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Foreign Material Management in Nuclear Power Plants and Projects

IAEA

International Atomic Energy Agency

FOREIGN MATERIAL MANAGEMENT IN NUCLEAR POWER PLANTS AND PROJECTS

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FOREWORD

Materials and substances entering and moving to parts of plant systems where they do not belong by design can potentially damage important equipment or components, or the entire system itself. Such substances and materials — commonly referred to as foreign materials — that enter, or that are already present, in a system or component can adversely affect their required or desired performance or functions during normal operation. Consequently, they can cause extended or unplanned outages, unplanned maintenance, or increased radiological exposure to plant personnel and equipment. More importantly, if not properly managed, foreign material in — or carried into — critical systems, structures and components, such as reactor core and fuel, normal or emergency core cooling systems, containment isolation or protection systems, instrumentation and control elements and other safety related systems (or non-safety related ones supporting them) may hinder safe operation by potentially degrading or eliminating the safety margins, or even result in partial or total unavailability of systems when they are needed during accident conditions.

As such, the control of foreign material and prevention of foreign material related events are an important aspect of nuclear, industrial, radiological and environmental safety. The management of foreign material needs to be considered at every stage of a plant's lifetime, as it aims at anticipating and eliminating or minimizing foreign material intrusion that directly and adversely affects nuclear power plant safety and performance. Thus, a carefully prepared, planned, controlled and implemented foreign material management programme and associated processes and procedures are essential for the safe, reliable, efficient and productive operation of nuclear power plants.

IAEA observations and reviews of industry experiences and practices have shown that, despite the extensive industry efforts to exclude foreign material from systems, components and equipment, foreign material related events continue to occur at nuclear power plants. Therefore, the IAEA initiated work on collecting and sharing information among Member States on overall foreign material management guidance, including its fundamentals, implementation and good practices in the conduct of foreign material management programmes, processes and procedures in nuclear power plants. This publication is intended to address relevant aspects of foreign material management for nuclear power plants, including the roles of all stakeholders in various stages of the lifetime of a nuclear power plant, and to share knowledge on challenges, solutions and good practices based on the current knowledge and operational experience.

The IAEA wishes to thank the participating Member States and the contributors listed at the end of the publication. The IAEA officers responsible for this publication were A.N. Kilic and H. Varjonen of the Division of Nuclear Power.

CONTENTS

1. INTRODUCTION

Foreign material management (FMM) is one of the core components of nuclear, industrial, radiological and environmental safety, as well as the effective and efficient generation of electricity, as foreign material related events adversely affect plant safety and performance. Foreign material (FM) entering plant equipment and systems may cause degradation or incapacitation of equipment and system reliability, availability and operability resulting in extended or unplanned outages, unplanned maintenance or increased radiological exposure to plant personnel and equipment — even if it is promptly noticed, recovered and removed. Particularly, foreign material entering (or pre-existing) in core/fuel, normal or emergency cooling systems, containment structures, instrumentation and control and other safety related systems, structures and components (SSC) (or non-safety related SSC supporting those) may negatively impact the safe operation by potentially degrading the safety margins or incapacitating safety functions.

Foreign material entering and moving to other parts of the systems could also go unnoticed for a long time and eventually may result in damage to the internals of important equipment, affecting the satisfactory performance of critical functions or, more importantly, leading to their partial or total unavailability in an emergency or accident condition when the equipment is needed to execute its design function.

Consequently, a comprehensive and common strategy has to be in place by the owner/operating organisation to minimise or eliminate foreign material intrusion (FMI) events by managing the foreign material by any or all parties involved in the NPP lifetime activities, from its design to decommissioning, particularly during construction, commissioning and operation phases.

1.1. BACKGROUND

The concept for an IAEA guidance on awareness, control and management of foreign material in nuclear power plants (NPPs) arose from a recognition of FMM as one of the areas for improvement during the IAEA Operational Safety Review Team (OSART) missions after 2007, as specified in the Director General Report of 2009 [1]:

> "These missions, in addition to recognising some areas of strong performance," the report noted, "identified a number of areas where improvements are needed such as: […]; maintenance practices, including foreign material exclusion activities; management systems; and […]" [1].

At that time, the IAEA Safety Standard for commissioning and operation [2] set the requirement for a programme for foreign object exclusion, in Paragraph 7.11 under the Requirement 28, Material conditions and housekeeping, as:

> "An exclusion programme for foreign objects shall be implemented and monitored, and suitable arrangements shall be made for locking, tagging or otherwise securing isolation points for systems or components to ensure safety" [2].

Also, other publications on design and maintenance, such as Refs [3, 4], had included some degree of foreign material exclusion (FME) programme guidelines, as applicable in specific areas during the design and operation phase of nuclear power plant lifecycle, particularly as applied during maintenance and inspections.

Following the highlighting of effective exclusion of foreign material from the systems and components of nuclear power plants by Ref. [1], a series of activities to revise the safety standards with more explicit FME requirements and guidelines were initiated. Consequently, including the establishment of a technical and implementation level guidance and the dissemination of good practices — specifically and solely on management of foreign material, namely 'foreign material management' — was included in IAEA's action plans in 2011.

The issue that had led to this initiative, actually was identified much earlier, in 1996, by an IAEA topical report on events involving FMI in plant systems. That publication was distributed in 1997 [5] with an update in 1998 [6]. It was then determined and reported in the IRS[1] report [7] that the awareness of foreign material, particularly as to its causes and effects, was sometimes not clearly understood or adequately addressed at some plants. Also, around the same time, nuclear industry's awareness of (and attention to) foreign material control (FMC) issues affecting economic operation prompted the issuance of an event report in the USA by the Institute of Nuclear Power Operations (INPO) [8]. Consequently, a series of industry-initiated standards, guidance and expectations in the 1990s and 2000s towards achieving best practices and excellence in foreign material exclusion (referred commonly as 'FME practices') [9–11], particularly focusing on protecting fuel integrity during operations.

However, observations and industry experience reviews, thereafter, have shown that despite the extensive industry efforts on the good and effective practices for the exclusion of foreign material from the systems, structures and components (SSCs), the foreign material related events continue to occur at some nuclear power plants and to reoccur in the same or other plants during various activities of plant operation [12, 13]. Reported or observed events showed that system cleanliness and 'FME principles' from plant SSCs, particularly during the management of maintenance and outage activities during operation phase, were not applied in a manner which would produce the most benefits to the plant operations with respect to maximising availability and efficiency with optimised safety, reliability and quality and minimising radiological dose to personnel and equipment in meeting 'as low as reasonably achievable' (ALARA).

These events were attributed to deficient (or lack of effective) establishment, implementation, execution and improvement of the programmes, processes and procedures resulting in acute issues in fuel reliability, maintenance effectiveness and timely outage implementation. The programmatic deficiencies included, for example, several layers of cleanliness work and supervisory checks being removed from procedures for 'no added value' in the quality plan without spotting the discrepancy, or complacency, in FME awareness, training and insufficient procedural controls. Therefore, it became incumbent upon the leadership of owner/operating organisations at all organisational levels to communicate to workers and managers how and why spending effort on FMM activities reduces costs and increases efficiency in the long term and minimises the consequences of failure/omission of principles and programmatic barriers.

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[1] The International Reporting System for Operating Experience (IRS) is an international system jointly operated by the IAEA and the Nuclear Energy Agency of the Organisation for Economic Cooperation and Development (OECD/NEA).

Furthermore, three main observations of the operating experience with FMI events, pointing to the potential incompleteness, insufficiency, or inadequacy of current FME (i.e. FMM) programmes:

— Safety impacts (or potential impacts) above and beyond the fuel integrity and radiological aspects;
— Performance and financial impacts that have not been declining;
— Impacts from FMs that:

  - Have been left in the SSCs during construction,
  - Were not discovered during commissioning or subsequent operational activities and tests;
  - Were not considered or anticipated during the design for protection against;
  - Are not tracked and recorded during operations and realised during the decommissioning (or during the transition from operations to decommissioning).

Regarding operating experience with safety impacts (or potential safety impacts), the events that have been reported to IAEA's IRS by the regulatory bodies in the Member States also emphasised the importance of FME (FMM) programmes for safe and reliable operation of nuclear power plants. Intrusions of foreign material into the primary system and safety related systems have been reported and have ranged from minor safety consequences to major damages resulting in prolonged plant outages to meet the safety requirements. Additionally, regulatory bodies became concerned about significant events involving FMI to lead to important nuclear safety consequences. For example, during the reporting period of 2005–2008, which were summarised in the IAEA report [12], the events that had or might have had serious nuclear safety consequences included the following:

> "At a plant, a FM was discovered while performing control rod test during the periodic outage and inspection. During testing it was found that one control rod was near the fully withdrawn position although the reactor was shut down and all control rods should have been fully inserted. "It was likely that during work on the operating floor near the reactor cavity a cut scrap (a mixture of iron material, concrete and paint) had flown apart and fallen between a control rod cluster guide tube and a control rod within the reactor, thus interfering with the movement of the control rod" [12].

> "In another plant, a FM related event involved discovery of a large and intact ventilation duct, that was covered with deposit, at the bottom of the emergency (auxiliary) feedwater tank. The condition of the duct, and the deposit on it, indicated that it had been in the water for a long time. "The origin of the incident dates back to the last internal inspection when ducts were installed to ventilate the tank while a weld was repaired. A section of the duct was forgotten, most likely after the weld repair, despite the tank being inspected for cleanliness by the plant operator at the end of the repair operations" [12].

> "Another event involved the discovery of a FM in the piping of the containment spray system during a refuelling and maintenance outage. The discovered FM was believed to be the material that was used during the preparation of a test to be performed earlier in the outage and somehow moved to the diaphragm where it was discovered. This event was also

significant from the use of operating experience (OPEX) aspect of FMM, since similar events concerning FM in containment spray system previously happened in other plants. As stated in Ref. [12]: “Another similar event occurred in another plant where some material from construction days was discovered in the containment spray ring piping system. Although containment spray system was tested before, such blockage was not discovered due to the nature of the design until another unrelated event triggered an inspection of systems and components in the containment” [12].

As such, IAEA review of these events [5−7, 12−13] concluded that the most important aspects of foreign material with threat to safety were the potential consequences with impacts on the fundamental safety functions of:

- Heat removal — such as the risk of primary system piping flow blockage resulting in the loss of heat removal from equipment, systems, or fuel assemblies;
- Reactivity control — such as the risk of degradation or loss of reactor protection and control capabilities by, for example, jamming control rods, rendering mechanical and pneumatic drive mechanisms, valves, rotating machines inoperable;
- Confinement — such as the risk of degraded or incapacitated containment depressurisation and cool down.

In most cases, the system or equipment was not demanded and actuated, and therefore, the foreign material existing in the system had no tangible consequence to plant operation nor did it threaten the safety of the public. Nevertheless, the presence of foreign material could have led to the partial or total unavailability of the safety functions under accident conditions if, and when, the systems had been needed and their operation were impaired owing to the foreign material.

Repeating issues have also become a quality assurance (QA) concern of regulatory bodies in the Member States, as the issues were found to be recurring (in the same or different nuclear power plants) that indicated programmatic inadequacies. The reports that attested to recurrence of similar FMI events in different plants had demonstrated a challenge for both operation organisations and regulatory bodies with respect to effectiveness of foreign material management programmes (FMMPs) and their continuous improvement through OPEX. For instance:

- Several events in various NPPs showed that foreign materials which originated internally in the system got stuck under the disk of check valves, preventing their functioning.
- A series of FM discoveries in containment spray systems between 2009 and 2017 in different plants and countries, although the OPEX from those events were made available.

Additionally, the reliability of nuclear fuel has become one particular issue — from both regulatory and operational perspectives — as FMs in the primary systems have continued to cause fuel degradation and damage over the years impacting safety and reliability. Fuel failure prevention policies that did not enforce a robust foreign material prevention programme contributed to the likelihood of fuel failures, thereby influencing the dose received by workers and further protecting the health and safety of the public. Additionally, fuel failures from foreign material adversely impacting plant performance, FMMP has become a central concern for fuel reliability and integrity initiatives, such as of those aiming at zero fuel failures [14].

Beyond these known effects on particular safety systems, industry experience demonstrates that the financial impacts of FMI events are often and sometimes significant owing to declined or interrupted plant performance, such as the lost generation from unplanned outages and/or machinery breakdowns. Various events as reported in the IAEA's Power Reactor Information System (PRIS) database [15], these events have affected the plant availability either by necessitating unplanned outages or extension of planned outages for maintenance or refuelling. For example:

> "At one plant in 2015, a reactor scram (automatic trip) was triggered from the closure of all main steam isolation valves caused by spurious indication of high steam flow in the main steam lines. The cause of this complete valve closure was a pressure transient caused by foreign material in a main steam flow instrumentation line, partially blocking the pressure sensing line. This plant event caused over 180 hours of extension in the outage resulting in loss of revenue for unproduced 120 GW(e)-hour".

Another renown industry event that demonstrated the financial impacts of inadequate foreign material management was the 'lead blanket' event of the 80s and 90s [16]:

> "The series of events at one plant started with the detection of several steam generator tube leaks that showed the signs of unusual trend resulting in multiple short unplanned outages to check and repair. In response, an extended outage for tube inspections and subsequent investigation was started, lasting over a year. The inspections and investigations in this outage determined that high lead levels in the system was the major contributor. During the root cause investigation, it was discovered that two shielding lead blankets (blankets that are made of vinyl cover filled with lead pellets) were inadvertently left in the steam generators following the work performed during an outage six years earlier, in 1986, that can be characterised as 'FMI event'. Furthermore, following the extended outage, and after the subject steam generator was closed up, it was reopened upon a requested reinspection, peculiarly, during which another new blanket was found left in there. This was not only another 'FMI event' but also a 'repeated FMI event' at the same plant, during the similar activity, in the same task area and with the same foreign material, resulting in another extended outage for 10 months. The unit was restarted at the end of 1992 with a condition requiring a tube reinspection after 10 months of operation to confirm justification for continued operation. This reinspection was performed during the 1994 planned outage and the results of reinspection was not sufficient to justify continued operation, and as such, the unit was indefinitely shut down at around the end of 1995. In the following years, the unit remained shut down for two decades and it restarted eventually after the completion of refurbishment. This extensive refurbishment which included the replacement of all steam generators was a large, complex and expensive project of such a kind. The unit returned to service in 2012 after nearly twenty years of not generating electricity".

Financially, the failures or lack of FMMPs can significantly contribute to plant's losses and affect the nuclear insurers' liability on financial risks. For example, in 2000, American Nuclear Insurers, an association comprised of some of the largest insurance companies in the USA which provides insurance to the nuclear industry, performed an assessment [17] in which FMI was identified as a ‘significant factor contributing to machinery breakdowns’ and losses caused by FM resulted in ‘major damage to equipment’. The assessment further identified that:

> “Plant recovery can be extremely complicated and expensive because of the extraordinary measures that may need to be employed. Insured losses have frequently resulted from maintenance activities during or at the end of planned outages” [17].

Reference 17 also provided a list of elements for a FMMP as a set of recommendations that included those for policy, procedures, directives, instructions and FMM provisions and FMCs, as well as leadership, training and work planning. More notably, revision to this assessment [18], which was performed 17 years later, still discussed the FMM/FME programme as the share of machinery breakdown in losses merely reduced from 45.9% to 45%. Events and associated consequences with significant financial risk contributions have highlighted the financial importance of a robust FMMP, especially during outages and the importance of learning from OPEX and incorporating in the programmes, processes and procedures.

To further the safety, performance and financial implication, the aforementioned third main observation from the operating experience with FMI events points to the potential incompleteness, insufficiency or inadequacy of current FMMPs long before operation phase and beyond. Although highlighting robust management of foreign material and establishing and improving the FMM and FMMPs have been highly emphasised during the plant operation phase, some of the events showed the importance of FMM long before operation phase.

In addition to acute problems occurring during operation phase, operating experience shows that legacy FMI events (e.g. events occurred during design and construction) have resulted in latent potential safety, reliability and performance problems, issues and concerns (such as the containment spray piping event exampled in Section 1.1.1) during operation phase in some nuclear power plants.

A report by the European Commission’s Joint Research Centre (EC/JRC) in 2011 [19] collected and reviewed events that were reported in various databases on the latent impacts of foreign material ‘mishaps’. The evaluations of those events lead to conclusions that:

> “Average detection time of mishaps during the construction and commissioning is about eight years after the start of operations. More significantly, three out of four deficiencies are discovered by chance or fortunate coincidence, particularly “for civil work, electrical components, I&C, pipes and valves” [19].

The report emphasised the need for minimising the number of deficiencies during construction, manufacturing and commissioning of a new reactor, as they can be major latent failures for a long time with actual or potential consequences related to the safety and performance during operations. Analysing the events, the EC/JRC report recommended that:

> “During construction, manufacturing and commissioning, “a full FME programme should be implemented as soon as construction starts” and “cleaning activities should be submitted to the same quality process as other safety-related activities, and commissioning tests should be performed after the cleaning activities” [19].

Even prior to the construction and commissioning, the plants have realised the benefits and detriments of the concepts and features used in the design phase. For example, some nuclear plants have realised the benefit of the engineered structures, such as feedwater strainers or centrifugal filter devices, and have been installing design changes to improve fuel reliability by reducing the debris induced fuel damage or failures [20]. These later in lifetime design modifications showed that anticipation of FM impact on plant SSC during the initial design would have been beneficial (and more economical). Therefore, an earlier consideration of foreign material cause and effect during the design phase carries importance against anticipated FM production, intrusion and transportation in SSC in order to provide built-in engineering barriers for prevention and protecting against FM and related issues. Such design concepts and considerations help later during the construction, commissioning and operation phases, and further, in decommissioning phase.

Although it is not a traditional part of nuclear power project/plant programmes, it is also essential to continue the management of foreign material in consideration of decommissioning, for the safe and effective process, as there also have been issues with the impact of foreign material. For example, Ref. [21] provided some examples of issues encountered during decommissioning of spent fuel pools, particularly legacy pools, some of which can be attributed to the inadequate FMCs. Also, the FME/FMM challenges were noted in decommissioning during moving the spent fuel to dry cask storage, for example dropped FM items, in the decommissioning of Zion plant in the USA [22].

As it was acknowledged that the existing 'FME programmes' mainly targeted operating NPP management and staff in establishing and maintaining competent and effective people, programmes, processes and procedures, paying particular attention to fuel reliability. However, two main observations prompted further elaboration and expansion of application on awareness, control and management of FM in NPPs:

- Aforementioned events and operational experience necessitated to review good practices and lessons learnt and to establish a programmatic implementation guidance for a comprehensive FMM guidance (which encompasses FME);
- The Member States which are initiating and implementing new nuclear power plants and projects requested from the IAEA to provide more good practices and practical examples applicable to the phases before (and after) operation phase.

Therefore, a carefully prepared, planned, controlled and implemented programme — not only for FME during operation but also comprehensively for a FMM that is applied throughout the nuclear power plant and project lifetime — is important to safe, reliable, efficient, cost effective and long-term operation and such programmes need to be started as early as possible.

Consequently, it was decided to develop an IAEA publication specific for FMM and establishment, implementation and improvement of an effective programme for FMM:

- To reemphasise the understanding of the FMM and disseminate essential elements and characteristics of a programme/process for FMM;
- To summarise needs, challenges and opportunities of relevant entities, e.g. owner/operating organisations, nuclear power project developers, in establishing and/or improving the programme;
- To provide lessons learned in order to strengthen the FM awareness and management in design, construction, commissioning, operation and decommissioning of nuclear power plants.

1.2. OBJECTIVE

This publication aims to address all relevant aspects and principles of an effective and continuously improving the programme for FMM (hereafter FMM Programme or FMMP) throughout the entire lifecycle of a nuclear power plant, specifically focusing on:

— Foreign material management system, culture and responsibilities;
— Foreign material control;
— Foreign material intrusion event prevention and protection;
— Foreign material intrusion event mitigation, including search, detection, retrieval, recovery, analysis, assessments and evaluation activities.

This publication, therefore, intends to provide a set of descriptive and practiced processes that integrate safety, performance and economical aspects for reliable and efficient operation of nuclear power plants with minimisation or elimination of FMI events.

As such, this publication is primarily to assist organisations and persons involved in the FMMP preparation and establishment or in its application and maintenance, including:

— Nuclear power project and future owner/operating organisations in the Member States, who are purchasing and building new nuclear units, i.e. those entities establishing new FMMPs;
— Nuclear power plant owner/operating organisations (utilities), i.e. who are currently operating and continuously improving their existing ‘FME’/FMM programmes, including those that are transitioning from operation to decommissioning.

The implementation and application of FMM and FMMP involves the entire plant staff and the contractor/vendor personnel who are supporting the design, supply, construction, commissioning, operation, maintenance and decommissioning of the NPP safely and efficiently, as well as the regulators who are performing oversight activities involving safety related SSCs. Therefore, the plant/project owner/operating organisations and their contractors are intended as the primary users, while plant responsible designers, equipment manufacturers, suppliers and vendors, as well as the regulatory bodies, may also benefit. As such, the following designations in the Member States, who are building new nuclear units, i.e. establishing new FMMPs, as well as who are expanding, i.e. improving their existing FME programmes, are foreseen as users:

— Owner/operating organisations, i.e. utilities;
— Responsible designers;
— Contractors/service and equipment suppliers;
— Architect-Engineers;
— Fuel vendors/suppliers;
— Regulatory bodies.

1.3. SCOPE

This publication introduces guidance and good practices for successful FMMPs based on current knowledge and experience as it intends to disseminate the observations gained, the lessons learned, and the conclusions drawn for defining and maintaining roles, responsibilities and interfacing requirements of FMM. As such, it describes key FMM principles and activities such as administrative, technical, infield and engineered techniques and controls throughout the nuclear power plant and project lifetime. Accordingly, the following focal points are reflected and discussed:

- Definitions and fundamentals of FMM;
- Key roles, characteristics and responsibilities for establishing, implementing and maintaining an effective FMMP;
- Administrative, technical and human behaviour aspects of minimisation or elimination of FMI events, e.g.:

  - Management strategy and policies of FMM;
  - Designed and engineered features for FMC;
  - Physical and administrative barriers;
  - Organisational FMM culture;
  - FMM training methods and scope;
  - Equipment inspection, logging and accounting tools and methods in FMM;
  - Cleanliness and housekeeping attitudes and habits;
  - Proactive work planning and implementation with FMM considerations;
  - Verifications and controls at the job site or offsite for ensuring FM free components and equipment;
  - Compilation of the OPEX and application for FMM programme improvement.

Based on this foundation, the FMMP guidance is to be provided in order to protect plant assets against acute (or latent) damage to or degradation due to FMI and providing safe, reliable, available and efficient operation of nuclear power plants by:

- Preventing FMI events during construction, commissioning and operation of NPPs;
- Establishing policy, procedure and organisational culture for FM and FMC awareness;
- Learning from FMI event OPEX and FMM good practices and applying these learnings to existing programmes, processes and procedures;
- Determining the effectiveness and efficiency of the programme, qualitatively and quantitatively in order to continuously improve.

The considerations and aspects provided in this publication are not comprehensive lists of all needs, challenges and solutions, but rather provide key concepts that need to be taken into account in the programmes and processes for FMM, based on the operational experience and technical and administrative fundamentals.

1.4. STRUCTURE

The main body of this publication is divided into eight Sections including the introduction in Section 1 and the conclusions in Section 8. Five Appendices provide examples of administrative controls (i.e. procedural requirements) of FMMP that are obtained from the owner/operating organisations and industry support groups.

A glossary of specific terms used, and a list of abbreviations are also provided for the reader's aid at the end of the publication.

Section 2 provides common terminology and the fundamental definitions and concepts, focusing on the order of process and people aspects, including the definitions of: anticipation, prevention and protection, elimination, exclusion and mitigation and evaluation of FM.

Section 3 presents the application and the key elements of and activities involving and concerning FMM and FMMP in each successive phase of the nuclear project and plant lifecycle, including project initiation, initial design, construction, commissioning and operation, towards 'foreign material free operation'.

Subsequently, Section 4 identifies and discusses the fundamental aspects that are essential to the successful and effective establishment, administration, implementation and continuous improvement of a FMMP, including the foundation of it, which is the FMM cultural and behavioural aspects that are applicable to all phases of project/plant lifecycle.

Section 5, based on the operational experience and good practices, provides a 'how to' guidance on the establishment, governance and implementation and improvement of an effective FMMP and anchoring good FMM practices and behaviours towards 'foreign material free operation' in achieving 'no adverse effect of foreign material' on safe, reliable, effective and efficient operation of the plant.

Based on the premise that although an effective FMMP proactively governs, and puts processes and people in order, to eliminate and minimise FMI events by anticipation, prevention and protection, elimination and exclusion, they, in some cases, fail to do accomplish this objective. Consequently, 'reactive' FMM processes are resorted (including those for the latent FM). Therefore, this publication intentionally separates the reactive FMM aspects, namely 'mitigation' and 'evaluation', and associated processes, from proactive processes.

The mitigation aspect of FMM and associated processes and procedures in FMMP are addressed in Section 6 as the last action towards the 'foreign material free operation'; while the evaluation aspect (which is the very last resort to achieve 'no adverse effect of foreign material' on safe, reliable, effective and efficient operation of the plant when there is no other possibility but incorporating the FM into the plant SSC and their design and operation) is lastly described in Section 7.

Supporting examples that supplement the main body regarding the discussion on tools, methods and practices are provided in the appendices. First two appendices provide a sample set of criteria for the foreign material risk level (FMRL) and foreign material control area (FMCA) determinations, respectively. Appendix III illustrates an example of metrics for FMMP review and assessment. Appendix IV describes a sample flowchart for the determination of legacy and latent foreign material and associated actions and, finally, an example of FM awareness communication for foreign object debris (FOD) prevention, taken from aviation industry practice, is presented in Appendix V.

Accordingly, a suggested use of this publication is as follows:

- For primary understanding of the reasons for such a publication, it would be prudent for users to review Section 1.1 to get a perspective of the history and the current situation of FMM in the nuclear industry, as well as the importance of FMM and an a structured FMMP.
- Users then are suggested to view Section 2, since it is beneficial to follow the terminology used and the concepts presented and discussed in this publication. The user needs to aim attention at the denotation or concept to which a term refers, rather than the term itself,

as there are various words used for the same concepts throughout the industry. Subsequently, Section 4 also needs to be referred to follow essential and fundamental aspects and traits for any organisation on which effective FMM and FMMP is (or will be) built.

— Section 3 primarily targets the newcomer users, i.e. those who are approaching the implementation of their first nuclear power plant project and getting close to making decisions on design, construction and commissioning of their new NPP. Therein, particular attention is to be paid to engineered/designed FMM and FMC features that are conceptualised towards 'design for operation and maintenance' and included in the design and the realisation of the plant. Subsequently, Section 3 is also beneficial to existing operating organisations who have planned to implement plant modifications, particularly those are major changes such as refurbishment.
— Section 5 through Section 7 provide the collected guidance on the elements to be used in establishing a new FMMP, governing/administrating it and improving the effectiveness an existing FMMP based on good practices. These Sections could be beneficial to create associated FMMP processes and procedures during each phase of a nuclear power plant lifecycle.

It needs to be emphasised in the usage of Section 5 through Section 7 that in some organisations, FMI events continue to occur when they lack behaviours of a good FMM culture even though they are following the best industry practices in procedure writing and maintain large number of procedures that cover, in detail, every aspect of FMC and FMI event prevention. Conversely, some organisations which demonstrate habitual (i.e. not necessarily instructed) behaviours of a good FMM culture in the awareness and management of foreign material (e.g. show behaviours of cleanliness, good housekeeping, informal active communications and peer cultivation, risk recognition) have a few or no FMI events and maintain a good FMM with a minimal but sufficient set of instructions/procedures.

As aforementioned, the considerations and aspects provided in this publication are not comprehensive lists of all elements, needs, challenges and solutions, but they rather provide key concepts that need to be taken into account in the programmes, processes and procedures for FMM, based on the OPEX and technical and administrative fundamentals.

This publication is not intended to endorse or to invalidate a particular approach and it is intended to lead to informed decisions — by a good understanding of how and why the owner/operating organisations need to manage FM in/for their nuclear power plant(s) and/or projects by a structured FMMP. Nor is this publication a detailed and prescriptive implementation procedure to achieve an ideal FMM or a 'one size fits all' method for it. Rather, it is a descriptive process guidance providing major technical and administrative elements and tasks, roles and responsibilities, that would be assigned to individuals and entities in accordance with the specific corporate strategy, structure and culture of particular plant/project organisation in the most effective manner.

The guidance is supplemented by specific examples of FM awareness and management, from operational experience as well as good practices and lessons learned; however, the responsibility for the completeness and applicability of those examples for specific cases require users' efforts to validate and verify, as well as to assess for adaptability to their own organisation and situation.

2. DEFINITIONS AND CONCEPTS OF FOREIGN MATERIAL MANAGEMENT

The concept of FM and FMM is not new or unique to nuclear industry, as it has been applied to wide range of industries and foreign material (or foreign object or foreign matter) awareness has been very essential to many fields beside the nuclear industry, including aviation (Refs [23–27]), medical (Refs [28–31]), pharmaceutical (Refs [32–34]), food (Refs [35–38]), and so forth.

Before the detailed discussion for such control and management of FM at and around plant SSC, here, it is beneficial to identify some common terminology used and the concepts presented and discussed in this publication. The user is suggested to aim attention at the denotation or concept to which a term refers, rather than the term itself as there are various words used for the same concepts.

2.1. FOREIGN MATERIAL

Generally, a foreign material is defined as any material that does not belong to a body of substance, system, component or environment by design and/or intent and may cause harm to structural integrity or functional capability of that body or system.

This general definition applies to wide range of industries and the terms ‘foreign material’, ‘foreign object’, ‘foreign body’ or ‘foreign matter’ are similarly used in nuclear, aviation, medical, pharmaceutical, food industries [23–38].

Specifically, in nuclear industry, a foreign material is any material that is not part of the SSC — per design or intent — which would cause degradation and/or damage to their fit, form and or function.

In a nuclear power plant, the foreign material might be external to SSCs, such as tools, dirt, dust, oil, and may get into the SSC through an intrusion path, or they may be internal, such as erosion/corrosion products, broken/lose SSC parts and material generated by the SSCs within. Hence, the elimination, extraction and exclusion of foreign materials from plant SSCs is necessary to support safe and reliable plant operation by preventing undesirable consequences owing to adverse impact from foreign materials.

2.2. FOREIGN MATERIAL TARGET

A foreign material target is a body of substance, system, component or environment functions and conditions of which would be adversely affected when it contains or is introduced to foreign material.

In a nuclear power plant, the foreign material target is typically a system, structure, component or equipment that would get affected such that it would not be able to perform its function as designed (or desired) owing to the foreign material that exists in (or enters to) it causing damage or degradation in its fit, form or function.

It is possible that one type of FM may affect multiple targets. For example, dust can affect electric/electronic components (such as those in electric cabinets) while it can also affect the instrumentation line or sensors. On the other hand, one target can be affected by multiple FMs, such as fuel which could be affected by lose parts and debris and erosion/corrosion products.

2.3. FOREIGN MATERIAL PATH

The foreign material path is the route, ambient, medium, etc. that will transport, carry or bring foreign material to the foreign material target. There may be several paths between the foreign material and the foreign material target and there may be several transportation mechanisms on a foreign material path.

In a nuclear power plant, the foreign material paths are typically systems and parts that connect various components, equipment or systems, by flow/stream of liquid or gas, for example, piping systems, ventilation systems. They can also be an environment or structure in which foreign material can be introduced to the systems, such as dropped objects from overhead work, ice formation from humidity, sea organisms in the cooling water body, dusty air.

Figure 1 illustrates a simple schematic of a hypothetical plant configuration where a valve is removed from a line to a pump. As the system is open, the activity would create two FM targets: the valve and the pump, which could be subject to four FMs in and around the work area through several FM paths (three FM paths to the disassembled valve and two FM paths to the pump).

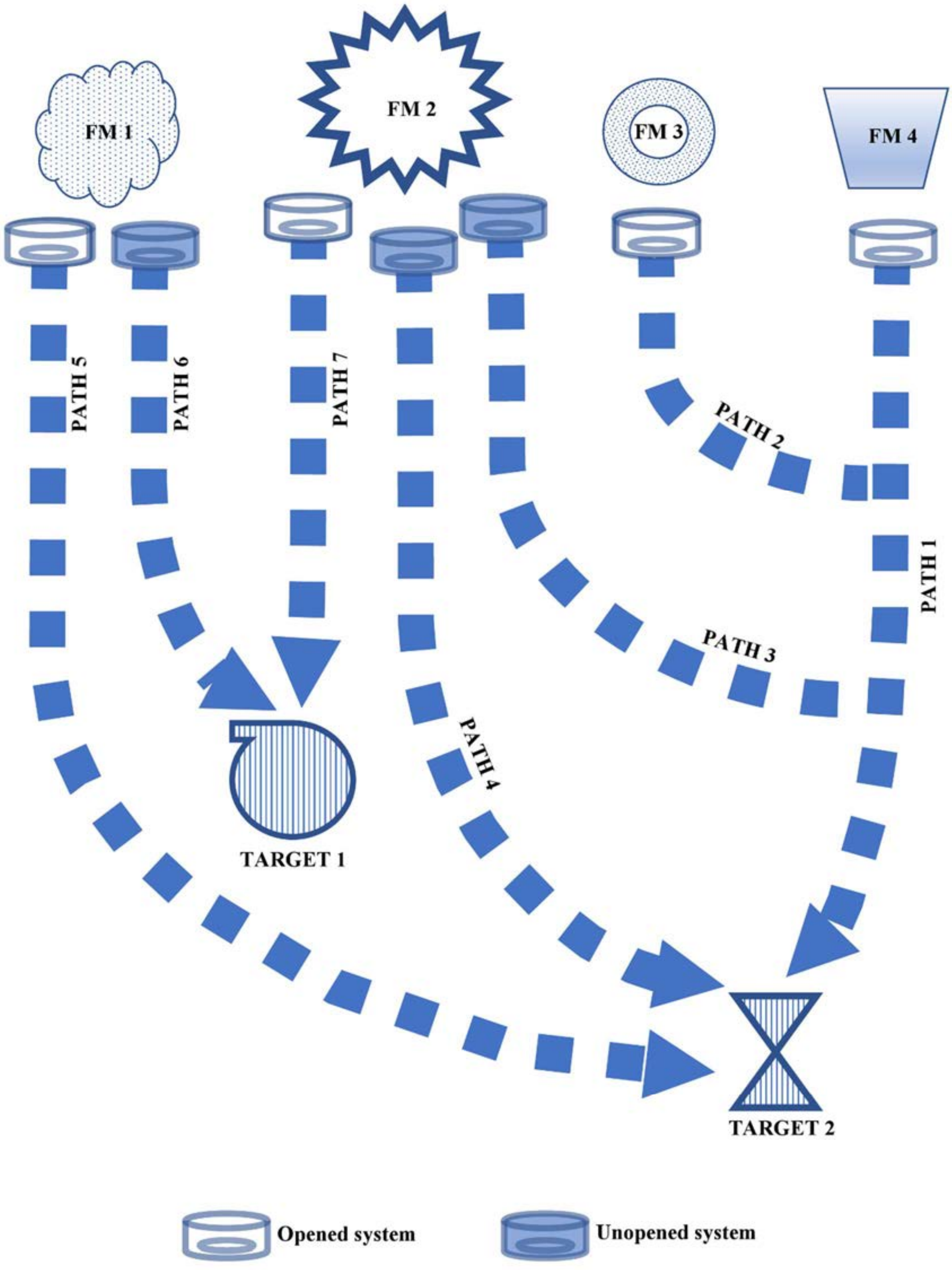

FIG. 1. Foreign material (FM), FM targets and FM paths in an activity area after a valve removed from a line to a pump.

2.4. FOREIGN MATERIAL MANAGEMENT

Foreign material management is the establishment and maintenance of necessary considerations, understanding, knowledge, controls and barriers for foreign material and between the foreign material and the foreign material target, such that the existence, introduction, intrusion, transportation or impact of foreign materials on the targets are eliminated or minimised.

The FMM in a nuclear power plant is a collection of people, processes, activities and their interfaces which together identify, control, avoid or minimise undesirable effects from FM on the SSCs with respect to adverse impacts on the plant's safety and performance. The FMM concept encompasses a set of thoughts, habits and performances, including:

— Commitments;
— Strategies;
— Behaviours;
— Concepts;
— Plans;
— Programmes;
— Processes;
— Procedures.

2.5. FOREIGN MATERIAL MANAGEMENT PROGRAMME

The FMMP is an official and formally structured arrangement, consisting of measures, activities, tools, methods, organisations, actions, opportunities, instructions and plans, that needs to be done or to be taken into account to help and support people in achieving to keep the plant SSCs 'free of foreign materials and/or foreign material impacts'.

In a nuclear power plant/project, the purpose of the FMMP is to maintain the design intent/integrity and nuclear safety and performance against FMI events of all kinds throughout the NPP lifecycle: from design through construction, operation and decommissioning; and to prevent acute or latent damage to or degradation of plant assets in operation and maintenance (O&M) of plants. The FMMP specifically aims at raising and maintaining awareness and control of FM such that the plant SSCs are free of FM and they are not susceptible to FMI during the plant lifetime. Although this is particularly important when open systems are susceptible to FMI while being built, transported, stored, installed, serviced, repaired or inspected, for example during plant modifications, refuelling outages, corrective/preventive maintenance or tests, the awareness and control of FM applies at all times.

Therefore, the FMMP activities discussed in this publication involves a variety of functional areas in a nuclear power plant design and O&M, including:

— Design and engineering;
— Manufacturing/fabrication;
— Procurement and storage (warehouse) and material and parts control;
— Operations;
— Chemistry;
— Quality assurance, control and oversight;
— Maintenance and inspections;

— Work planning and scheduling;
— Information technology;
— Training;
— Or any other activity needed to develop and implement a safe, successful, efficient and continuous operation of nuclear power plants, free of foreign material impacts.

An effective FMMP comprehensively governs and puts in order processes and people aspects towards long term aim of foreign material free operation, including the key parts of: anticipation, prevention and protection, elimination and exclusion, and, should these fail, mitigation and evaluation, to stop foreign material from adversely affecting the safety, quality, reliability and economic operation of the plant and functions of the plant SSCs (Fig. 2).

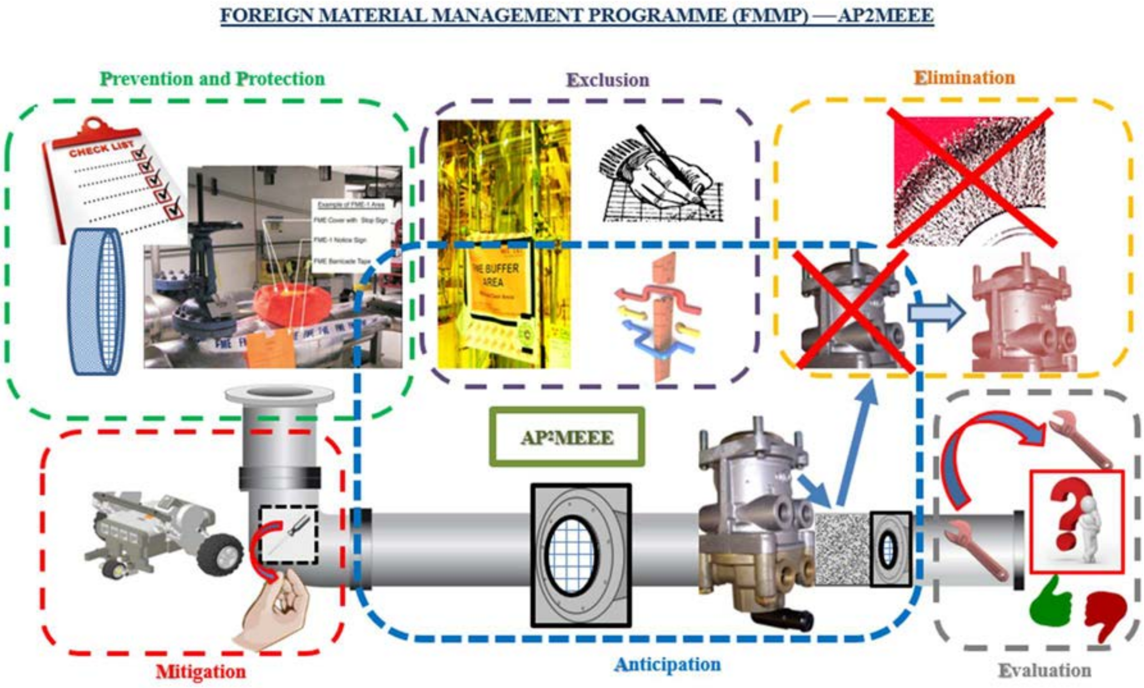

FIG. 2. Domain and key concepts of foreign material management programme.

Definitions and brief descriptions of each key concept of an integrated and comprehensive FMMP, that are depicted in Fig. 2, are provided in the following subsections and are further discussed in detail in later Sections in this publication.

2.5.1. Anticipation

Anticipation is the awareness and knowledge of FM, primarily identifying and understanding what a foreign material for a given SSC is and recognising and conceptualising its potential production mechanisms and/or potential paths for ingress/intrusion/transportation and possible impacts on the SSC.

Anticipation is continuous throughout the plant lifetime since awareness, recognition and knowledge of FM and its impact on the plant SSCs are likely to improve and expand with new findings and understandings as the plant configuration changes, scientific and technical information advances and more operating experience accumulates.

2.5.2. Elimination

Elimination is to recognise, identify and remove known FM, FM target and FM paths during a planned activity, operation or function. This also includes taking measures and actions to physically remove FMs in and around the activity area or, if they are necessary, to replace them with a substitute when possible. Replacing FM or FM generators for the performance of activity include various means, for example, replacing wire brushes with polymer brushes instead, using open ended wrenches instead of adjustable ones. Similarly, in the design of SSCs, selecting material less susceptible to erosion/corrosion, such as using Teflon or sheet gaskets instead of spiral wound gaskets, when applicable, may eliminate FM or its generation.

2.5.3. Prevention

Prevention is taking measures and controls to minimise or eliminate:

— Anticipated foreign material;
— Potential target SSCs;
— Anticipated paths to the target SSCs.

The preventive measures can range from engineered measures to administrative checks and controls to ensure that the FM and FM path to the target SSC is avoided or reduced to harmless levels. These measures and controls may include lowering the risk for the existence/creation of FM, FM path and FM target, establishing boundaries around the workplace, administratively controlling possibility of FM in activities and activity areas. For example, using lanyards is a prevention measure against the possibility of a tool becoming FM, as well as setting orientation of the components during assembly, disassembly and storage.

2.5.4. Exclusion

Exclusion[2] is a system of means, methods and tools to keep a known or identified FM (or potential FM) that cannot be eliminated and prevented or protected from, far away from the unavoidable and/or unprotectable FM targets and paths, so that the possibility of encounter of foreign material and the target is minimised. The exclusion measures vary widely from situational awareness to the pursuance and implementation of measures that would control, prohibit or separate FM (and potential FM) from target SSCs and the FM paths. These means and tools also include physical exclusion barriers and boundaries for equipment and people and administratively excluding/limiting (or ensuring the exclusion/limitation) known or potential FM in workplace, such as administrative checkpoints, buffer areas, tool reconciliation, and in other activity aspects.

2.5.5. Protection

If the known/anticipated FM or the potential interface of that FM with the target SSC and path cannot be avoided or reasonably minimised, the protection of FM targets and FM paths from the FM is needed. The protection of SSCs can be accomplished mainly by physical and/or

[2] It should be noted that, foreign material exclusion, or shortly FME, is a common terminology used to describe the programme in most industry practice and it typically covers protection and mitigation processes, procedures and activities. However, it is not to be used interchangeably with FMM or the 'exclusion' defined herein, as the management of foreign material applies in other processes than protection and mitigation.

engineered means. These could include, for example, special devices (commonly known as 'FME devices'), designing and installing filters/strainers in plant systems, monitoring and detection equipment and/or people.

2.5.6. Mitigation

In some cases, despite the anticipation, prevention, protection and exclusion measures, it is possible that FM can enter (be generated in the SSCs) and can reach/enter the target SSC. This FMI event may occur either due to an unknown, unrecognised or unanticipated FM, FM target or FM path) or owing to the failed (or inadequate) prevention and protection barriers, flawed controls or hidden precursors.

The mitigation is the recovery/removal of the foreign material if an FMI event occurs, as well as the elimination of its adverse (or potential adverse) consequences, such as the adverse effects on the fit, form and function of target SSC and any other SSCs that have just become targets or potential targets upon FMI. Therefore, it discussed exclusively in Section 6.

2.5.7. Evaluation

The last option and the least desirable and extremely rarely performed part of FMM deals with evaluating and accepting the intruding FM that cannot be recovered and removed, as part of SSC, i.e. redefining the material as 'non-foreign' and 'a new part'. In other words, it makes and declares that foreign material or substance a part of the design intent and facility configuration.

The evaluation to support the decision to make the foreign material 'non-foreign' for SSCs consists of comprehensive investigations and assessment of all aspects in integrated design and overall operation of the SSCs, utilising the original/existing design basis information and knowledge.

To accept a FM as a part of the design or a part of normal operational configuration requires solid scientific and engineering justification that would override the original design, thus, meaning a design modification. Accordingly, the design and configuration control programmes to be followed.

Therefore, to stress again, this concept of the FMM needs to be very rarely resorted, only after all concepts and efforts of the FMM is consumed (or in cases that removal/recovery/mitigation efforts of the material are proven to carry much larger safety risks). Therefore, it discussed exclusively in Section 7.

2.6. FOREIGN MATERIAL DEFENCE IN LAYERS

Anticipation, elimination, prevention, protection, exclusion, mitigation and evaluation parts of FMM, establish together a series of measures, actions and purpose to defend plant SSC against FM. Figure 3 provides examples of how these measures could be used for a simplified hypothetical activity of disassembling a valve and connected pump to work on an opened system — with four known/anticipated FM and two FM targets (the valve and the pump) and seven FM paths that lead to one or both of those targets — as each part is numbered in small circles:

— Circle 1 indicates the elimination of a foreign material (FM 3) from the environment in and around the activity by removal or substitute;
— Similarly, Circle 2 is the elimination of FM path (Path 5) to FM target (Target 2, valve) by not opening the inlet to the equipment, for example, by not removing (or immediately reinstalling) an orifice cover on the valve;
— Circle 3 is the prevention from foreign material (FM 4) by securing it to avoid potential intrusion or impact;
— Circles 4 show the protection of:

- Openings of Path 1 and Path 2, that lead to the FM target (Target 2, valve), by FMC devices,
- Opening of Path 6, that lead to the FM target (Target 1, pump), by FMC devices,
- Opening of Target 2 (valve) where a FM can reach to it through Path 4 (noting that Path 4 will be open and create a path for a potential FMI during the activity) by FM protection (i.e. a FMC) device;
- Target 1 (pump) by permanent FMC device (inbuilt strainer) by design, noting that Path 7 will be open and create a path for a potential FMI during the activity;

— Circle 5 shows the protection against FM (FM 1) by excluding FM 1 from the work area by FM barriers;
— Circle 6 shows the exclusion (isolation) of work area/zone where opening that leads to Target 1 through Path 7 and Target 2 by Path 4 to Path 7 and from all FMs (note that, although both FM targets have protection devices on them, Path 4 and Path 7 have susceptibility to FM that may enter to either path and have to be recovered and removed before the system is closed for preventing future damage);
— Circle 7 shows the prevention (Target 2, from any FM that could reach it by Path 3) by not opening multiple entry points in the work zone.

FIG. 3. Various uses of foreign material management and control elements. FM —foreign material, FMC —foreign material, FME —foreign material exclusion.

This approach provides a layered defence to prevent, eliminate or minimise the adverse impact of FM on the safety, quality, reliability and economic operation of the plant, as shown in Fig. 4.

In accordance with the key concepts that are defined in Section 2.5, Fig. 4 illustrates the application of layered defences to a hypothetical and simplified activity that will open a system consisting of a pump and valve. The activity will necessitate to detach the valve that is at the pump's discharge side, creating two FM targets (the pump and the valve) both of which to be protected against a FMI with a layered defence approach, as follows:

— At the anticipation layer, two FM paths to the pump and four FM paths to the valve are identified and potential FM production mechanisms are recognised, including tools with moving parts that may detach or fall apart (such as wrenches with worm screws, adjustable jaws, pins and nuts);

- At the elimination layer, some tools are removed (by substitution or elimination of extraneous task that would require their use) from the activity (crossed out in the Figure) in addition to one path to the valve by securing the opening of that path;
- At the prevention layer, the tools are secured by lanyards to reduce the possibility of them falling into the system, and also, the valve is oriented upside down such that FM entry to one of its FM paths is avoided, or reduced to harmless levels, for the known FMs during the planned activity;
- At the exclusion layer, boundaries and barriers are established and some tools are excluded from the area with a plan that ensures them to be taken in when needed and taken out after done with their use;
- At the protection layer, permanent and temporary FMC devices are installed, protecting the valve against FMI in all openings and paths by FMC/FME covers and protecting the inlet leg of the pump with a strainer;
- At the mitigation layer, as depicted in the Figure, despite all protections provided, while working on the pump, the cork screw of a wrench falls off and enters the path, which is later retrieved and the FMI is reverted.

In the last layer, if/when, after all options and attempts are exhausted and it is impossible to remove the cork screw from the path to the pump, finally, an evaluation is performed to accept the cork screw as a part of the design and configuration of the pump. This last, evaluation, layer, is the final defence for FM impact.

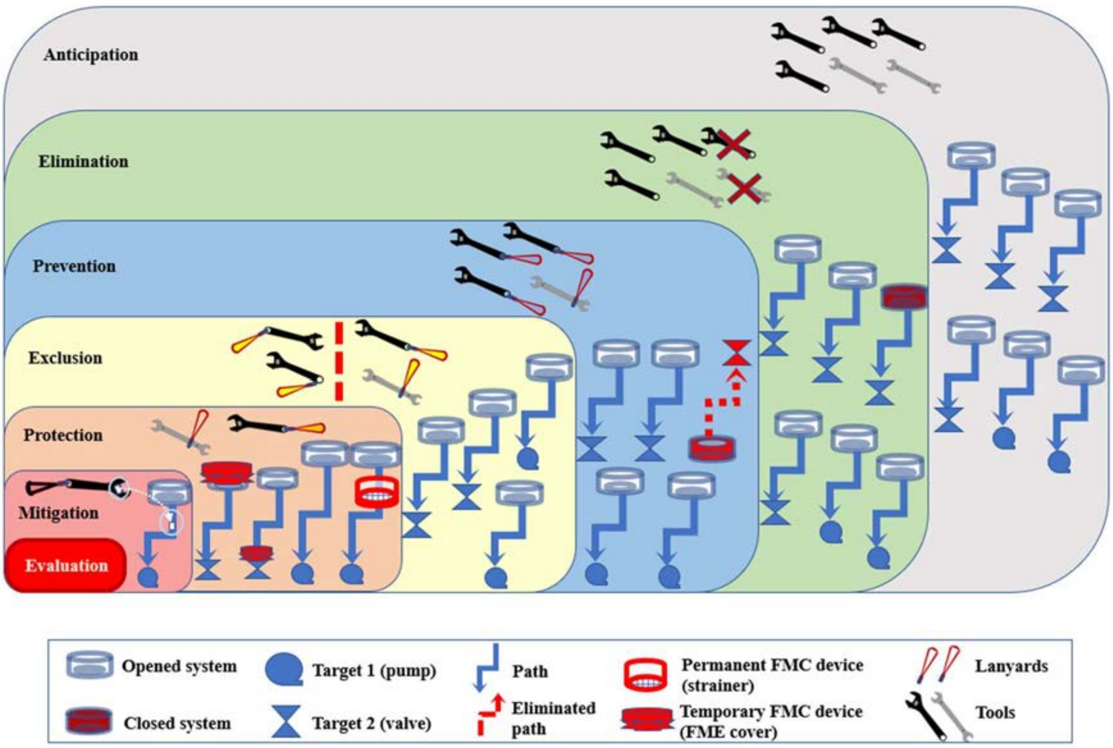

FIG. 4. Layered defence against foreign material intrusion (FMI) events. FMC —foreign material control, FME —foreign material exclusion.

3. FOREIGN MATERIAL MANAGEMENT THROUGHOUT NUCLEAR POWER PLANT LIFETIME

As aforementioned, FM that exists in plant SSCs is consequential in plant operations, regardless of the time when they entered, as some major latent FM related failures or defects discovered in SSCs during the operation, causing actual or potential events related to the safety and performance, can be traced to the FMIs during construction, manufacturing and commissioning. Such occurrences render the FMM essential and to be started and practiced long before the operation phase, necessitating the establishment of FMMPs well before the plant begins to operate. Accordingly, a structured and integrated FMMP need to cover all associated activities, such as engineering, procurement, fabrication, transportation and installation, testing, corrective/preventive maintenance, during the entire lifetime of the plant (design, construction, commissioning, operation and decommissioning).

As different organisations may be in charge of different phases and associated activities throughout the NPP lifetime, FM awareness, control and management will have variety in its extent, content, roles and responsibilities and interfaces/directions, etc., depending on the specific activities and working conditions at an applicable phase. All of these organisations, including the contracted work force, play an important role in controlling and managing foreign material; therefore, each of those entities needs to be aware of its role in the strategy for FMM. This becomes even more critical when multiple organisations are conducting simultaneous activities such as construction, commissioning, major plant modifications or refuelling outages.

However, the prime responsibility is assigned to the owner/operating organisation of the NPP and covers all the activities related to the operation directly and indirectly. It includes, as a minimum, the responsibility for: (1) setting the standards and expectations; and (2) oversight and supervision. As such, it is strongly recommended by the industry experts that a FMMP is established by the owner organisation as early as possible in the nuclear project, noting that:

— It is often the case that the owner organisation does not have (or is not required to have) a mature FMMP and a complete set of processes and procedures during the specification, bidding, bid evaluation and contract preparation stages. However, as a minimum, the FMM requirements and expectations ought to be established by the owner/operating organisation in the plant/site/station policy and continuously updated to ensure that plant designers, suppliers, vendors, constructors (and future operating organisations) are aware of those requirements and expectations for safety and performance of future operation;
— For each stage in the NPP lifecycle, FMM may take the form of a collection of processes and subprocesses, with interfaces among the processes which together prevent undesirable affects from FM on plant safety and performance. Supervising and overseeing the activities of all other related groups, such as designers, suppliers, manufacturers and constructors, employers and contractors, as well as the responsibility for operation of plant by the operating organisation itself ensures the meeting the standards and expectations;
— In some cases, the regulatory body may require a plan for FMMP or related/associated programmes and requirements, such as system cleanliness and housekeeping, as an explicit part or implicitly within quality assurance of the construction and/or operating licence application.

Therefore, a comprehensive and common FMM strategy is necessary to be in place by the owner/operating organisation to prevent FMI events by any or all parties involved in the plant's lifetime activities long before the operation phase, starting with design considerations and with decommissioning phase in mind.

This Section provides some guidance on, and examples of, how the different organisations can contribute to FMM throughout the successive stages and activities of a NPP's lifetime. It should be clear that the emphasis of the FMMP will focus on distinctive objectives at the different stages of the NPP lifecycle, as discussed in the following Sections.

3.1. PROJECT INITIATION PHASE

From the consideration, affirmation and planning of new (or additional) nuclear power generation until getting ready to invite and evaluate bids, followed by the contract, preparatory activities involving technical specifications and management system are carried out for the decisions on the implementation of a nuclear power project. They include collection and determination of the project technical input, such as regulatory requirements, industry codes and standards, technical specifications, quality requirements.

Generally, FMM and FMMP are not an explicit part of this phase; however, they need to be noted in preparation of contracts and approval/qualification of vendors is a critical part of the stages in this phase. As these contracts or vendor approvals are one of the most effective instruments available to the plant/project owner for articulating programme and process expectations and setting obligations/agreements of a plant supplier (and of their subcontractors), bid preparers/evaluators and contract writers may resort to indicate specific programmatic items at this stage.

This phase provides an opportunity for proactively thinking about the expectations and requirements for specifications and programmatic controls in future design, manufacturing and construction activities which may include those for FMM and FMC. For example, in many Member States, there are regulatory requirements that would be applicable, such as those given in Refs [39–42] on the product cleanliness, housekeeping or material compatibility. Such requirements and owner's expectations would necessitate a certain degree of awareness of FM and FMM and associated conditions may be included in the contractual clauses for designers and equipment manufacturers.

In the case of an existing and experienced owner/operating organisation who is planning a new (additional) power plant project, a mature FMMP already exists and the owner/operating organisation has established policies, commitments and values, in addition to the accumulated knowledge and OPEX of their own or the accessibility to others' (in nuclear and other industries). This knowledge and experience include not only the lessons learnt regarding 'latent foreign material' (see Glossary and Section 6 for definition) related events that happened due to the vendor/contractor performance during construction and commissioning (and later discovered during operations); but also, the specifications and performance of existing technologies and products, as well as some vendors' management systems, behaviours and values. Therefore, a good set of FMM requirements and expectations for bid invitations, bid evaluations and contracts can easily be prepared in the case of an existing and experienced owner/operating organisation implementing a new NPP project. Here, it should also be noted that, in some expanding programmes, time period between a new project and the last time a plant was built may be long enough to diminish [then gained] design and construction knowledge and experience. In such situations, it may be necessary to be renewed/refreshed by an effective search on the latest experience from other recent projects in terms of FMI events, existing FMMP applicability, potential gaps, pitfalls and lessons learnt.

On the other hand, for a newcomer project owner who is building the first nuclear power plant, it is very unlikely that a FMMP exists; however, absence of a programme is also acceptable, since an explicit FMMP is not essential (or required) at this stage. Saying that, it would be a good practice for the project owner/team to have FM and FMM concept and awareness, as well as some knowledge of FMI events related to the design and construction phases. This may involve requesting information and/or comparing (and if necessary, auditing) potential vendors' work standards, practices and technologies for design, manufacturing and construction, particularly those concerning their programmes for provision of clean, *'foreign material free'* product. This information exchange may include, for example:

— Vendor's management systems (e.g. design control processes, quality assurance programmes) which would describe the ways it ensures/contributes to FMM, such as cleanliness and housekeeping expectations, manufacturing/installation management controls and practices;
— Design alterations due to experience gained during construction and operation related to FM knowledge, particularly for critical SSCs;
— Historical information on FMI issues encountered and resolved during construction, cleanliness and housekeeping commitments, etc.

It would also be beneficial to include review of engineered FMC expectations based on the existing design and operation from existing nuclear power plants (or from other industries, such as aviation industry) in each stage (e.g. bidding, tendering and contract preparation).

All of this exchanged information needs to be reviewed, any related expectations are to be agreed and accepted by the project owner organisation (or their delegated entities) and, if deemed necessary, are written in contracts for engineering, procurement, manufacturing, construction and commissioning.

3.2. INITIAL DESIGN PHASE

After technology is selected and nuclear power plant is being designed, activities are shared among the vendors varying from the reactor supplier and the architect/engineer to the suppliers and designers of components and many others involved in design. FMM is a consideration in design of the SSCs and their interfaces; and starts before actual SSCs are built and physically interfaced, as a part of design criteria, concept and requirements.

The aspects of FMM at the design stage are primarily FM anticipation and considerations of engineered FM prevention, protection and mitigation means, particularly with construction and operation stages in mind. Such a proactive FMM needs to include the anticipation and prevention of FM during design, regarding:

— Potential generation and transportation mechanisms/manners;
— Potential impact on the functions, characteristics and specifications of SSCs;
— Prevention and protection features, that could be incorporated in the design;
— Mitigation features regarding accessibility, reachability or extractability.

Therefore, the design — in various design stages (i.e. conceptual design; system and component level design; customised (modified standard) design) — would consider, for example:

— Material compatibility for generation of FM within the SSCs;
— Natural or forced FM movement possibilities;
— FM ingress and transportation paths;
— FM monitoring/detection/removal features, such as appropriate protection devices, access points;
— Maintenance, surveillance or special test steps for accessibility and ingress vulnerabilities.

All these specific design considerations have an initial and long lasting effect on FMM during construction, manufacturing, operation and decommissioning of plant SSCs. If a FM hazard or risk were not anticipated at the design phase, it would become very difficult to deal with in the operation stage when encountered. Therefore, as depicted in Fig. 5, all aspects of FMM are considered design phase.

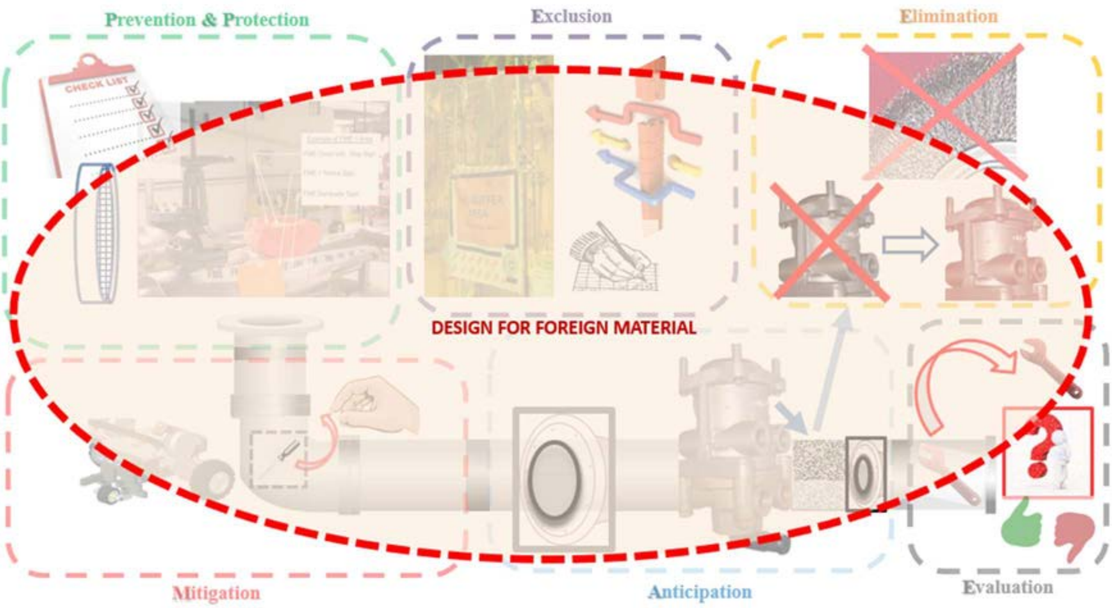

FIG. 5. Design process involvement in foreign material management.

The conceptual and system and component level design of a plant is typically the output of an existing planning and thinking process of the responsible designer and is available before the customisation of the design. Therefore, FMM consideration is part of responsible designers' roles and responsibilities as to ideas, thoughts and requirements concerning FMM based on designers' experience, awareness and knowledge. Later, it would be complemented by the expectations of the customer (i.e. the future plant owner/operator) for safe and efficient construction and operation).

3.2.1. Involvement of responsible design organisations in foreign material management during design

Plant supplier, who is assigned for designing the plant and its SSCs, will comply with the requirements set by the project owner organisation and the national regulatory body. For example, regulatory guides, industry codes and standards generally (and mostly generically) require that cleanliness and housekeeping, which is directly connected to FMM aspects, to be taken into account in the nuclear power plant design. The vendor will also meet the project owners' expectations, which were agreed to, for purchasing a 'foreign material free' design and plant.

Although the plant owner/operating organisation will eventually bear the prime responsibility for safe operation of the plant, technology/plant suppliers, i.e. responsible designers, are tasked and carry the accountability for the design activities, even in cases where design activities are subcontracted, for example, to engineering companies and component manufacturers.

Furthermore, plant supplier, design organisations and manufacturers (especially in a first built nuclear plant projects) have the best available information on design and technology, including the OPEX and they are the most knowledgeable about their products and services including knowledge and awareness of FM and its impact on SSC. They also have an established management system that would address programmes, processes and procedures related to 'design for operation', including FMMP for 'foreign material free operation'. Therefore, the primary FMMPs at this stage are those of design organisations and manufacturers.

Based on these criteria and requirements and the accumulated design knowledge of the responsible design organisation, the design considerations and activities relevant to FMM include the following focus areas:

- Design to prevent generation of FM in the system (e.g. flow induced vibration/corrosion, fatigue and stress corrosion cracking of the parts, welds, time dependent deterioration of material and components);
- Design to prevent ingress and transportation of FM (e.g. filters, strainers, fuel guards, vent orientation, drains, debris traps, ventilation, flashing and purification systems, adequate tolerances, use of organic material, chemicals);
- Design to resist adverse impacts of/from FM by fault tolerance/debris resistance features and materials (e.g. fuel cladding material, flow nozzle designs);
- Design to detect and remove FM from the system (e.g. access points, monitoring equipment features, vents, drains, flashing systems and their connections);
- Design to minimise human induced FM ingress considering the simple and sequential ease of accessibility, installation, testing, maintenance (assembly/disassembly) and removal.

In most cases, detailed methodologies may be provided for managing some of the FM from entering the SSC; for others, only broad recommendations may be instructed. In all cases, it would be useful to clearly identify analysis and design features addressing specific design aspect with respect to FMM. The plant owner and operator later can use this information to establish and incorporate into their comprehensive and conscientious FMMP during operation. Therefore, sharing of information (e.g. specifications, instructions, documents and records) between design organisations is essential for an effective FMM throughout the plant life. This information includes, but not limited to:

- Cleanliness requirements and compensating equipment specification and basis;
- Selection of appropriate and compatible materials (e.g. material that are compatible with potential service environment, such as high or low temperature lubricants, gaskets);
- Unique design features applied (e.g. type, form and orientation of seals to prevent contamination of oil during water flushing of the system);

— Selection of manufacturing/installation/refurbishment processes (e.g. welding, bolting, casting, forging, adhesive bonding);
— Chemistry control requirements including filtration, liquid/gas separation, purification systems and methods;
— Installation/removal/overhauling conditions and sequence considering potential effects on nearby structures and components (e.g. the space equal to the width and depth of the electrical equipment being kept clear of foreign systems or providing protection in design to avoid damages from condensation, leaks or breaks);
— Failure analysis (for example, air or other gases can solidify when directly exposed to extremely cold liquefied gases which in turn, may create plugs of ice as FM in cryogenic container vents and openings and cause the vessel to rupture);
— Monitoring requirements and methods to detect FM (e.g. lube oil or vibration analysis frequency and acceptance criteria, built-in bore scope stations);
— Requirements for planned/periodic maintenance requirements for cleaning, flushing, removal of debris or removal/replacement of aged material;
— Ease of access and good lighting for qualified workers and protection against unqualified persons, such as electrical equipment being metal-enclosed equipment or enclosed in a vault.

It is also a good 'design for O&M' practice to establish FM target and path diagrams (FMT&PD) based on the operability and maintainability considerations, that have been taken into account in the design of key SSCs — similar to the other design output drawings, e.g. piping and instrumentation diagrams (P&ID), process flow, maintenance and repair, pneumatic and hydraulic system diagrams and schematics. Figure 6 depicts such a schematic that could be prepared by the designer that highlights possible FM paths and considers O&M activities that are potentially subject to anticipated/known foreign materials for FM target, which, in this example, fuel and core.

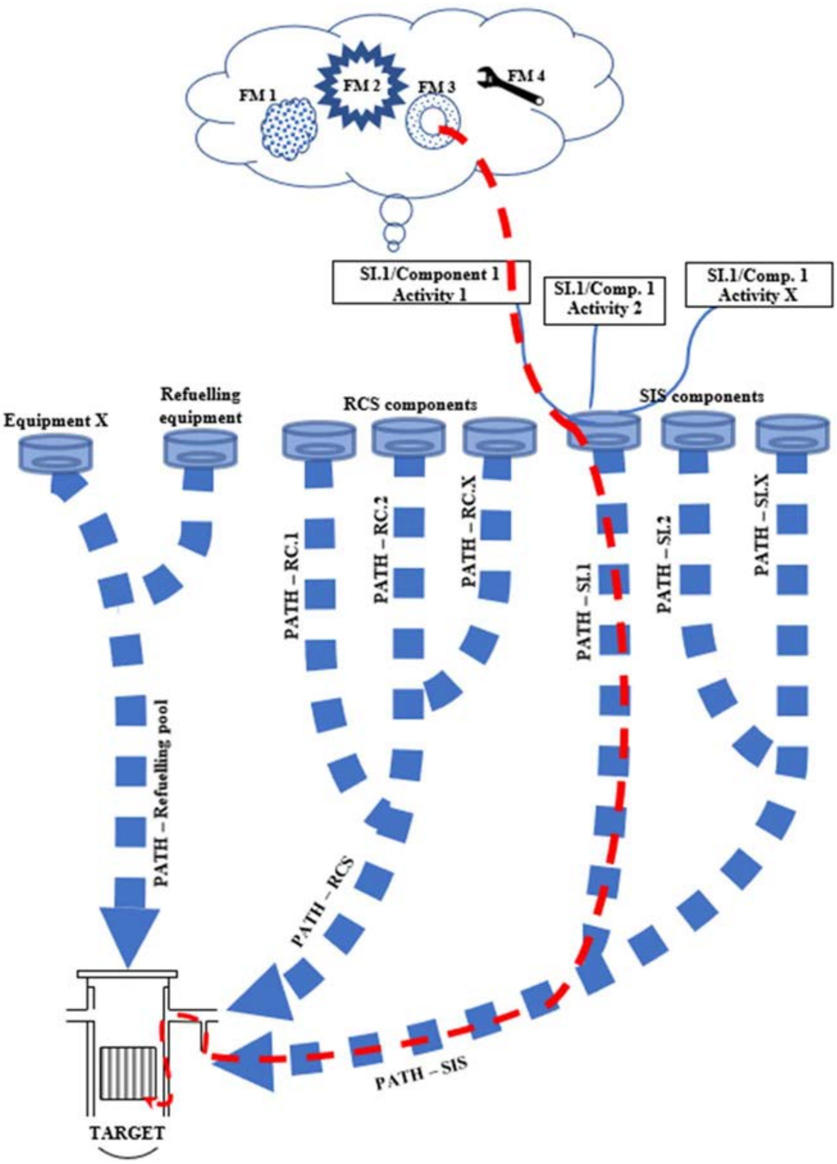

FIG. 6. A very simplified schematic for anticipated foreign material during predicted plant activities that could reach core and fuel from various paths by coded activities and paths. RCS — reactor coolant system, SIS — safety injection system, FM — foreign material.

3.2.2. Involvement of project owner organisations in foreign material management during design phase

In order to receive a product that complies with all criteria, requirements and expectations for safe and efficient performance during the operation, it is a good practice that the owner/operator establishes and clearly communicates its quality, cleanliness and material appropriateness criteria and expectations which may include FM aspects to the plant supplier, design organisations and manufacturers. It is technically and economically beneficial to include specific FMM requirements and expectations (based on lessons learnt from other nuclear projects and plants as well as other industries) in each bidding, tendering and contract document with a plant supplier, engineering company or manufacturer. In the management system documents, each entity involved could describe the ways it contributes to FMM, as applicable, and those are reviewed, agreed and accepted by the owner organisation (or their delegated entities) and, if necessary, can be audited.

Therefore, at the design stage, it is beneficial for the first nuclear power plant project owner organisation to start establishing a basic FMMP for requesting, receiving, understanding the 'FMM related' design information and to properly and adequately place these in plant records as a part of the requirements, criteria and bases of relevant SSCs.

Even in case when the project owner organisation defers the establishment of FMMP (and a modest set of associated processes and procedures) to the construction stage, a plant/site/station policy and commitment recognising the FMM requirements and expectations for safety and performance needs to be established by the owner organisation, as a minimum. Moreover, these policy and commitment may need to be continuously updated, in accordance with the project phase, to ensure that plant suppliers and future operating organisation are aware of those requirements and expectations. This basic policy and commitment will gradually expand towards a mature programme at the very early period of the construction and will be the plant's FMMP when the plant design is turned over to the operating organisation and plant starts operating.

3.2.3. Design modifications after initial design and organisations involved in foreign material management

After the approved design is issued, detailed system design and component level design may, in most cases, will continue after construction begins and physical design modifications will encompass the plant's service life, thereafter. Therefore, design for FMM will be a continuous consideration, as follows:

— During the construction, design modifications are initiated and implemented continuously either by the responsible designers or by the owner organisation, or both. The design change process at this period needs to require continuity in the design for FM and FMC, such as:

  - Design organisation's approval and clearance for installation and changes to FMM requirements and engineered controls, with appropriate evaluation and justification;
  - Maintaining the track records of FM and FMM issues and knowledge that is (or would be included) in the as-built design;
  - Maintaining list of foreign material that is justified as part of a system, e.g. redefining the intruding material as non-foreign and adopted design of the SSC (see Section 2.4.5);

— During the operation of the plant, the design and configuration of the facility is controlled and majority of design activities are initiated, performed and/or implemented, by the owner/operating organisation, although there will be cases with nearly equal share of labour with the responsible designers. These changes could also be well extensive such as refurbishment, major equipment replacement, major structural changes/additions, which may exceed the capabilities and competencies of the owner/operating organisation, requiring original responsible designers' and/or other external design organisations roles and responsibilities or may be deemed as nearly complex as the original design. Some of those changes during operation phase and the FMM considerations are further discussed in Section 3.5.2.

3.3. CONSTRUCTION PHASE

The construction (and reconstruction[3]) stage includes erection of the buildings and installation of SSCs, as well as both onsite and offsite manufacturing/fabrication, transportation, storage and assembly activities of systems.

Operating experience shows that the construction/reconstruction stage is very critical with respect to susceptibility of FMI events and makes the control and management of FM essential (and also challenging) primarily due to:

- Many systems and components being open and worked on;
- Multiple activities are being performed in the close proximity of each other;
- Wide variety and number of tasks and environmental conditions generating and moving potential FMs at the work zones and around the site;
- Large number of personnel from different companies, qualifications, backgrounds, even sometimes different languages, conducting activities simultaneously, independently or intermittently.

A trend analysis from the event reports from the IRS and the operating plant reports demonstrates that:

> "Large majority of the latent foreign material associated events during the operation can be traced back to a lacking or the deficiencies of FMM during construction, primarily involving items being left over in the systems. The items which are the most affected by construction, manufacturing or commissioning deviations are I&C (19%), electrical components (17%), welds (14%), valves (10%) and pipes (9%). More importantly, the average detection time of the initial defect is about eight years after the start of commercial operation and more than 75% of the events are discovered by luck or coincidence [19]. Among those, majority of foreign material discovered in the SSCs during the operations can be traced back to construction activities lacking adequate controls and barriers for foreign material, for example, construction or personal items were left in the work area or systems that would have been prevented by comprehensive FMMPs that are typically followed during operations".

This also emphasises the necessity of detecting the foreign material during the manufacturing and at the construction stage, as it may be difficult to identify them during operation.

During the consequent operation of the plant, reconstruction of the facility, such as refurbishment, major equipment replacement, site upgrades, major structural changes/ additions, may be initiated, performed and/or implemented by the operating organisation and/or other external construction organisations. Again, activities during these major changes can be as nearly complex as the original construction (i.e. 'reconstruction). Therefore, some of those major plant changes and associated activities conducted during operation phase will typically be subject to the same FMM and FMMP challenges as in the initial construction. Some of those

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[3] Herein, the term **'reconstruction'** of the facility indicates very extensive and complex changes to the operating facility, such as **refurbishment**, major equipment replacement, major structural changes/additions and site upgrades.

changes during operation phase and the FMM considerations are further discussed in Section 3.5.

Also, during the construction/reconstruction phase, design modifications may be initiated and implemented continuously (either by the responsible designers or by the owner organisation, or both). The design changes could also include the consideration of 'design for FMM/FMC', which may require designers' review and approval for installation and changes subject to FMM requirements and engineered FMCs and keeping records of FMM issues (including a list of, if any, FM that is justified as part of a system, as mentioned in see Section 2.4.5).

3.3.1. High importance areas for foreign material management during construction phase

During the construction phase, the emphasis of the FMMP is on the prevention, protection, exclusion and mitigation processes, particularly during planning and executing activities. Typical situations in FMM that are observed during construction phase, and particularly require attention, include:

- Loose parts falling into system opening of SSCs, such as, pipes, vessels, valves during installation;
- Objects left in the components during manufacturing in lack of cleanliness specifications or contractor's insufficient understanding of quality control (QC) requirements;
- Leftover construction and personal material in and around SSCs;
- Improper protection of equipment from foreign material ingress paths during packing, transportation and temporary storage;
- Improper removal of internal or external packaging materials, foreign material protection devices, protective lubricants or preservation chemicals and so forth from installed components;
- Contamination of systems by debris produced and carried from nearby activities;
- Need for effective system flushing and cleaning to remove debris from the SSCs where/when it could not be prevented.

3.3.2. Involvement in and tasks for foreign material management during construction phase

Early in the construction phase, the owner/operator organisation, i.e. utility, is formed and assumes a key (and gradually expanding) role in the development and implementation of the nuclear power plant project — as a responsible organisation for the plant. Within this owner/operating organisation, a core oversight group is also established (as an internal organisation/group of owner's coordinators, inhouse and contractor's experts) in order to assess the adequacy of plant construction with respect to verification of meeting or exceeding the owner's requirements and needs, including activities where FMM and FMCs are often needed and utilised.

Therefore, all organisations need to be aligned with the FMM requirements and expectations under a common FMM policy and commitment of the owner organisation. Leaders at all levels in the construction organisations are to promote and demonstrate an effective FMM culture and practices (see Section 4.3 and Section 5.3). As the foundation of such understanding and alignment, each entity, their departments, work groups and individuals involved in the construction activities need to be aware of the potential consequences of their activity with respect to acute and latent impacts of FM on the future plant and its SSCs, and more importantly, with the later safe and efficient operation of the NPP in mind.

As such, it is important that personnel of the owner/operating organisation overseeing and supervising the construction activities need to maintain a close contact with the vendors and other contractors. Maintaining a close contact will ensure that the specific opinions, expectations and requirements of the owner/operating organisation within the management system, are communicated, expressed and represented in order to be given due considerations in the construction activities towards successful operation. This is very essential since the owner organisation will become the operating organisation upon the issue of operating licence and will assume all responsibility for safe and reliable operation of a plant that is not to be adversely impacted by FM.

Accordingly, the FMM/FMC during manufacturing and construction requires clearly defined (and agreed by all parties) FMM requirements, expectations, roles and responsibilities for the performance, supervision and oversight of construction and other activities of all involved groups — including suppliers, manufacturers and constructors, employers and contractors.

In order to ensure that SSCs are manufactured, installed and left as *'free of foreign material'*, the manufacturing and construction activities need to be conducted in accordance with a management system and all aligned FMM programmes and policies of construction entities. Such a framework would require, regardless of the vendor company size or country, among others:

— A comprehensive and common FMM policy, commitment and strategy put in place by the owner/operating organisation to prevent FMI events by any/all parties involved in the construction and manufacturing activities;
— Collective awareness of the possible cross effects accomplished by common policy requirements, expectations and goals — anchored by the site management — and integrated activity planning by the project work control organisation(s);
— Verification of the programmes, processes and procedures, particularly those for associated quality assurance/quality control (QA/QC), of all involved entities by the owner/project organisation;
— A management system in place and includes FMM aspects in the inspections, validations, problem identification and, when events and/or programmatic and behavioural deficiencies are noted, the corrective action programme (CAP) and processes;
— Approval of the vendor's quality assurance programme (QAP), as well as the FMMP, which may require:

  - Performance of a shop floor and process survey of the manufacturers at their locations;
  - Confirmation of vendor's effective identification and analysis of FM hazards, risks and impact during entire manufacturing process, from raw material purchase and receipt to packing and shipping processing, such as utilisation of a hazard analysis and critical control points (HACCP) plan, that identifies critical points in manufacturing process that require FMM and FMC;

— Purchasing and vendor selection requirements of FM sensitive SSCs and parts (e.g. valves, pumps, electrical, electronic and I&C equipment and components, pipes/tubing, fittings/flanges/gaskets, expansion joints, pipe supports), including compliance with

specified standards and codes as in order to accept and approve QA/QC plans or programmes;
— Methods and tools to inspect in and around SSCs and equipment, such as direct visual, camera, borescope, x-ray or other applicable and assuring detection methods and, as applicable, to clean (e.g. flush, sweep, wipe, etc.), at the end of activities.

As discussed in Ref. [19], this validation and associated second party verification of *'foreign material free'* conditions of SSCs (and associated second party verifications by oversight, e.g. QA/QC, personnel who are either from the construction contractor organisations or owner/operating organisation, or both) need to be strictly performed and recorded by complete and formal documentation. Based on the lessons learned, it is strongly recommended by the industry experts to perform such activities, for example from cleaning, flushing, inspection activities, with same quality process (including independent verification, validation and documentation) to prevent existence of any leftover foreign material in all of the SSCs, not only in the required (e.g. safety related) SSCs. This is an important practice for successful plant performance during operation, in addition to the safe operation.

It is also very important that the future plant operating organisation is provided with sufficient data and records needed for subsequent improvement of the FMM programme, processes and procedures. As such, the personnel from the plant operating organisation needs be involved and/or informed (and in control, when possible) of the methods, tools, findings, learnings, issues, measures and countermeasures, as well as the events, near-misses, close calls and associated preventive and corrective actions. This will ensure that all FMM elements can be taken into account when SSC or task specific FMMP processes and procedures, including the operation, maintenance, surveillance and test procedures, are prepared for use in operation phase.

3.4. COMMISSIONING PHASE

Commissioning phase is the time to verify the functional capability of SSCs and to collect baseline data for operation. During the commissioning phase, the activity outcome and focus is on the design validation and verification and SSC turnover/handover from construction to operating phase. As such, a commissioning activity is the first point at which it is possible to check SSCs status and performance in operating conditions and to follow design organisations test and acceptance criteria of monitoring and detecting system anomalies that would indicate deficiencies, *including existence of FM in the as-built SSCs*.

The commissioning stage is also the last point at which it is possible to undertake these activities without any radiation dose to personnel before the plant enters the operating stage. Comprehensively performing activities prior to nuclear power generation (i.e. non-radioactive environment) ensures that the SSCs are 'free of foreign material' — including search and, if detected, removal in case of discovery. Moreover, taking and recording corrective measures to prevent reoccurrence or eliminate the impact — will help to minimise occurrence of FM related problems during subsequent operation, which then would necessitate the performance (or reperformance) of such activities under radioactive environment resulting in personnel and equipment dose.

During the commissioning, measurements of parameters (temperature, flow, pressure, vibration, etc.) and observations, results and analysis of sensory indications (e.g. colour, odour, noise, smoke) from direct visual and special confirmatory methods, tools and analysis, such as ferrography, x-ray, will ensure that there are no fault affecting the function and performance of SSCs — including those are due to existence and impact of foreign materials.

As such, commissioning stage is the right time to verify that environmental and cleanliness conditions, as well as the identification and resolution of deficiencies caused in the design and construction phases and the last opportunity to ensure SSCs are ‘foreign material free’ before they are turned over for operation, while transferring responsibilities for, and authority over, the FMMP from the construction organisation to the commissioning organisation to the operating organisation.

Overall, there are specific activities needs to be directly concerning FMM and the establishment and expansion of FMMP:

— Final inspection to verify and document cleanliness of SSCs for handover to the operation phase;
— Completion of system flushing and installation of permanent design features for foreign material prevention and protection, such as filters, strainers;
— Removal of temporary test features during commissioning, e.g. filters, strainers installed during the initial run and testing of SSCs to remove/collect/block any potential FM, before the system is cleared to put in service;
— Establishment of corrosion controls and water chemistry controls for operational systems;
— Confirmation/validation of effectiveness (or lack) of FMMP in prevention and mitigation of FMI events;
— Demonstration of human machine interface and recognition of the ways that the facility layout ensures ease of accessibility to the SSCs in order to enable their inspection, surveillance, maintenance and cleaning.

It is generally expected that, in some cases, construction and commissioning stages may overlap, putting the plant and the associated SSCs in a complex situation from the FMM and FMMP perspectives, as final adjustments are made during the construction of some systems while other systems are being tested. Under such circumstances, particularly activities performed in adjacent or nearby SSCs, there is a probability of incidents of FMI or foreign material impact. Each group and each individual involved in the construction and commissioning activities need to be aware of the potential consequences of their activities with respect to FMM as well as collectively awareness of the possible cross effects.

It should also be highlighted herein that the tests and activities that are performed during the commissioning may themselves be contributor to an FMI event. As an example, from operating experience, as reported industry experts:

> “During the commission test of a plant, resins were wrongly introduced into an auxiliary system as a part of a test. The impact of the incident was recognised and the piping was cleaned. However, a very small amount of aggressive chemicals remained in the circuit. Although the circuit was flushed with water for months during subsequent operation, the resin contamination was sufficient to induce corrosion cracking in an elbow of this auxiliary system”.

The operating organisation which is taking over the complete responsibilities and accountabilities for the FMMP from the construction and commissioning organisations needs to maintain adequate and competent staff who would be able to be aware and to intervene in case of inappropriate or inadequate FMM measures and issues.

It is also essential that, making equipment suppliers and installers responsible for the work and having commissioning and operation staff as members of their team ensures that the right expertise is made available in a timely way, experience is gained and knowledge transferred and defects are identified and resolved.

Again, it is learned from the OPEX that a formal, structured and effective facilitation of the transfer of responsibility and information (including knowledge gained by experience, observations and lessons learned) from the construction teams to the commissioning teams and, then on, to operation staff needs to exist. Including in this facilitation, the recorded verification and confirmation of system cleanliness during commissioning of systems is beneficial for effective and successful SSC performance during operation based on good baseline and historical knowledge and experience. Recording and preservation of all the findings and corrective actions related to the foreign material related events, near misses, close calls and identified hazards are vital for an effective FMMP during the operation stage.

Therefore, it is utmost important that, all information needed to incorporate and improve the FMMP for subsequent operation stage are noted, recorded and mitigation of existing deficiencies be carried out at this time. The records of 'as-found' foreign material, particularly the list of foreign material that is justified as part of a system, i.e. justified and accepted as 'non-foreign' (see Section 2.5.7), ought to be updated and maintained. Consequently, the SSCs that are handed over to the owner/operating organisation with such material presence need to be accepted as a part of 'as built' design and their design documents are updated accordingly.

3.5. OPERATION PHASE

During the consequent operation of nuclear power plant to achieve its purpose of safe, reliable, economic and regular production of electricity, FMM that is governed by a mature FMMP is essential to operate and maintain the plant with *no-adverse effects from foreign material* by providing foreign material awareness and control during operational activities in two folds:

— Ensure that the FMs do not affect the fit, form and functions of SSCs such that meeting or exceeding the design and operational requirements, limits and margins for ensuring safety, reliability and quality are not compromised;
— Protect assets against FM that may impact their availability and operability with longevity for an effective plant performance and efficient electricity generation.

Upon the grant of authorisation to operate (i.e. operating license) by the regulatory body, the owner/operating organisation is fully responsible for safety of the nuclear power plant [43] and for safe, reliable and sound operational decision making and operational activities. Therefore, for safe operation and asset management, the organisation owns an established, mature and structured FMMP with processes and procedures for control and management of FM and its impacts, including the management of organisational interfaces.

There may be variations in the focus of FMM during the operation phase depending on the plant activity, as well as the corporate strategy, style and tradition of owner/operating organisation; however, the key elements (defined in Section 2 and later described in Section 4) apply at all times. For example:

- For the FMM needs for daily or frequent operational activities, the owner/operating organisation may focus on exclusion (e.g. collective awareness and vigilance, detection, monitoring and observation);
- For routine maintenance tasks and periodic refuelling or maintenance tasks protection and exclusion, prevention and protection (and potentially search and detect aspects of mitigation) are the focus;
- For one-time, first of a kind and special cases, such as cases involving major facility modifications (e.g. major equipment replacement, plant refurbishment), FMMP could have wider focus that include all FMM aspects from anticipation to evaluation.

The FMMP during the operation stage also entails continuous learning and improvement, which will collect lessons learnt from the FMI events, near misses and close calls that point out areas for improvement in the programme and associated processes and procedures, as well as new knowledge on foreign material and associated impacts. It is useful for an owner/operating organisation to regularly consider lessons learned from its own experience, as well as those learned from the OPEX of other nuclear power plants (or even other industries), in order to avoid recurrence of problems and to improve the programme. Consequently, it is also important to maintain and update of OPEX database in a timely manner.

Many activities during the operation stage can expand the knowledge and awareness, can introduce FM into SSCs or may create opportunities, hazards and events for FMIs, for example, among others:

- Plant asset and performance optimisation and improvement measures, particularly those involving major equipment replacements and/or refurbishments;
- Preventive and corrective maintenance activities, particularly I&C, electrical, mechanical maintenance areas;
- Refuelling and maintenance outage activities;
- Plant design and physical modifications, including operating procedure modifications (see Section 3.5.2);
- Operator walkdowns;
- Surveillance testing;
- Chemistry and lube oil controls.

Although certain activities — especially those involve working on or around open systems, such as maintenance — create more opportunities for FMI events, an effective FMMP during operations requires application of the systematic management process to all activities at the plant/site, e.g. operation, engineering, work planning, oversight, surveillance, testing, chemistry control, radiological control.

Such systematic management process (and associated programme) provides a framework for coordinating all programmes and activities concerning the understanding, control, monitoring and mitigation of FM. More importantly, it ensures that the FM awareness is a normal part of daily behaviours and thoughts, i.e. not only during the times when the plant SSCs are open and susceptible to FMI.

Additionally, open and effective communication and coordination between organisations and between individuals is applied at all times of plant operations so that departments and people are collectively and continuously aware and vigilant of possible latent and/or cross effects of foreign material issues. In this manner, organisational understanding, awareness and vigilance is not specific to the special periodic activities as maintenance or refuelling outages, or one-time plant evolutions such as major SSC replacement and plant refurbishment, but rather it is common to all activities during the operation stage.

Here, two particular work evolutions that are shown by the OPEX to be very critical with respect to occurrences of FMI events and/or FMC capabilities, need to be highlighted: periodic maintenance/refuelling and design modifications. These two topics are, therefore, specifically discussed in the following Sections.

3.5.1. Maintenance and outage activities and foreign material management

Routine and special plant maintenance (both online or offline) and periodic outage[4] periods of operation phase are particularly concern FMM and FMC since these are the periods when: normally closed plant SSCs are open (and thus becoming FM paths and targets); there are substantial presence and movement of equipment, parts, tools (creating and bringing in FM) within and around activities; and the activities take place in large, multiple or adjacent areas and systems (establishing foreign material paths). Such periodic or urgent activities also may include both onsite and offsite fabrication, transportation, storage and disassembly/assembly activities of systems and components.

Operating experience shows that the maintenance and outage periods during plant operation phase are very critical with respect to occurrences of FMI events and makes the control and management of FM essential also (similar those in construction phase) due to:

— Wide variety and number of tasks together with changing environmental conditions generating and moving potential foreign materials at the work zones and around the site;
— Large number of personnel from different companies, qualifications, backgrounds, even sometimes different languages, conducting activities simultaneously, independently or intermittently.

Therefore, in most Member States, the FMMP is typically owned and maintained by the maintenance organisation of the owner/operator, as discussed in Section 5.6.2.

3.5.2. Design changes and foreign material management interfaces and roles during operation

Although nuclear power plants and their SSCs are designed for a target lifetime, many factors and drivers (e.g. obsolescence, component upgrades, long term operation measures, performance improvements) may make some earlier changes to the plant design and configuration desirable or, sometimes — as in case of equipment obsolescence —, inevitable. The activities involved with such modifications directly or indirectly may challenge/modify the existing FMMP elements and involves special focus on the FMM.

Particularly major plant modification, such as refurbishment, major component/component replacement or main structure improvement/additions can involve FMM as extensively as in the initial design and construction stages that were described in Section 3.2 and Section 3.3, respectively. However, unlike in those initial design and construction, the owner/operating

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[4] In some Member State NPPs, there may be three levels of periodic outages: refuelling outages with minor maintenance at the end of each fuel cycle; refuelling and maintenance outages at the end of every other cycle; and an outage that consists of refuelling, major plant system maintenance and renovation activities, typically every 10 years.

organisation is now primarily and solely responsible for the control of the facility. Therefore, it is the owner/operating organisation that initiates and implements the activities involved with the design change activities (although, as aforementioned) there will be cases with share of labour in the performance of these activities.

Maintaining the very high level of safety and performance expected of a plant requires that modifications arising during the operation, no matter they are major or minor, are made with a full understanding of design criteria and bases of the 'as built' plant, as well as the operational specifications for each system, equipment and component. It also requires an integrated assessment of their fit, form and function and their design interfaces and interactions with other SSCs. This full understanding includes the design basis and specifications of the systems and components that were considered, established and specified for FMM and FMC in the design.

When the owner/operating organisation carries out design modifications that includes change, replacement or refurbishment of SSCs, all activities are to be thoroughly assessed regarding the FMM requirements and expectations in design basis and O&M specifications. The results of these assessments need to be communicated with the responsible designers; since if the operating organisation may not be fully aware of changes to the installed design or in the materials or components selected or engineered FMC measures/means, some changes to the original design may have a detrimental effect on SSCs. Such communication with the responsible designers prevents those situations where some design and construction options that were chosen by the designer to prevent FM concern are not explicitly documented (or the records were not obtained or retained by the owner/operating organisation), and thus, the plant owner/operating organisation is not aware of those.

Failure to ensure adequate knowledge of FMM considerations in plant design will result in decisions on modifications, changes in operating procedures, and new or revised specifications for replacement and spare parts, etc., without a full understanding of the FM effects. Consequently, changes in design may have impact on the safety and performance of the plant and its SSCs, including the adverse conditions from changes to the built-in FMM features in the original design. Some examples for lack of proper FMM considerations in design changes, from OPEX, include:

— *Erroneous design change of SSC fit and form:* A certain strainer in the feedwater line to prevent foreign material of certain sizes or larger from entering the system was a built-in feature in the design to protect the target, e.g. fuel assemblies. Thus, the size selection of the strainer was based on the result of an evaluation/analysis of the impact from foreign material, larger than a certain size, entering the system and target component, fuel. Additionally, another design sizing analysis was performed to ensure that the strainer would not create flow restriction to affect the system hydraulic or thermal performance. For the design change proposing to replace the strainers to increase thermal and hydraulic performance, the design organisation's approval necessitated a complete assessment of all requirements for all other design functions, including the function for foreign material prevention and protection. Since the design records did not explicitly state such specific design criterion, requirement and assessment for foreign material impact, the operating organisation's decision makers reached a wrong conclusion that there is no design restriction to increase the size of the strainer to make the hydraulic performance better. This resulted in inappropriately changing the design (i.e. strainers) to improve thermal and hydraulic performance but created a potential foreign material induced fuel failures in the future.

— *Design change involving wrong choice of materials:* The design information concerning the originally selected material, e.g. consumable specification, was unknown (or omitted in design documents), resulting in the replacement of a chemical additive with a new ‘alternative’ material that was not compatible. The new material, as a foreign material (in this example, a foreign liquid material in a liquid system), created an adverse impact for system chemistry posing a potential risk for the plant operator for the maintaining integrity of the system.

— *Operating procedure change unknowingly modifying design intent:* Design requirements and measures are translated into operational specifications and procedures to ensure the SSC configuration remains consistent with the design intent and evaluations. These also include, cleaning methods and requirements, system as-left configuration, etc. In several cases, such operating procedures (instructions of which were directly tied to design requirements and assumptions) were intentionally revised to have SSCs with ‘foreign material’, with assumptions of those being ‘minor instructional change’. These particularly included procedures for draining, venting, filling or flashing of systems and components. For example, draining emergency core cooling system (ECCS) piping to prevent water from flowing to the containment sump after a periodic test (although the design requires that piping to be normally filled with water) leaving air in the piping as a foreign material (i.e. air in liquid). In another case, while design is requiring complete draining of water from outdoor piping system, flashing procedure was omitted to note to ensure that the system is completely water-free without considering water becoming foreign material. Importance of such omission can be expanded to, for example, air and moisture left in systems that will be filled with sodium that may have severe consequences.

— *Wrong assessment of ‘like for like’ basis in the replacement of parts:* It was decided to use available spare parts in stock which fit and function would indicate ‘like for like’ replacement; although new parts were made of slightly different materials than those originally used. The original material had a design basis for its selection for minimisation of erosion/corrosion and associated foreign material generation, without a proper assessment of the potential material compatibility, the replacement resulted in generation of foreign material in the system and consequences due to its impact.

Therefore, the design change process needs to require continuity in the design for FMC, such as design organisation’s approval and clearance for installation and changes to FMM requirements and engineered controls, with appropriate evaluation and justification during the operation phase.

3.6. DECOMMISSIONING PHASE

The FMM for decommissioning can typically be considered in two phases: (1) During the transition from operation to decommissioning; and (2) During the implementation of decommissioning activities.

Until the start of decommissioning activities, there is a transition period from operations to the decommissioning that will have actions mainly performed by the owner/operating organisation. The first and main decision on ceasing operation and on permanently shutting down the plant marks the start of this transition period. Between the decision to shut down and the actual end of operations, the owner/operating organisation will have activities and decision on several aspects of decommissioning, particularly the plans and paths for management of large volumes of waste generated by decommissioning. The existing FMMP and FM records, knowledge and history may become a part of preparation for decommissioning strategies, programmes and plans.

However, nuclear power plants which are entering a decommissioning stage may wish to re-evaluate FMM requirements and may consider potentially reducing the scope of the FMMP. Basis and rational for this rescoping is due to the importance of protecting only required SSCs, such as active safety systems or stored spent fuel, versus systems to be disassembled, removed and disposed of as scrap or waste early in the implementation of decommissioning. Particular attention of FMM during transition to decommission is given to disassembly and disposal to protect those SSCs as multiple and simultaneous activities could be conducted around those.

Also, due to a potentially long time period of decommissioning, special attention ought to be made to the types of FMC and protection devices used for the SSCs and scrap material storage means, which may be different from during normal O&M, as wear and tear may become a factor (for example, some materials, such as plastic covers, may degrade over time). In such cases, selection of appropriate FM control and protection devices and performance of periodic inspections could become a part of the FMMP scope to ensure the integrity of FMC devices is maintained.

4. FUNDAMENTAL ASPECTS OF FOREIGN MATERIAL MANAGEMENT

Regardless of the phase at a nuclear power plant lifetime, there are fundamental elements of FMM and these important elements apply whether the FMMP is at its establishment, maturation, implementation or improvement stage. Therefore, controlling and managing FM and understanding associated impacts and potential hazards and consequences of FMI events, as defined in Section 2, is a collection of processes and subprocesses — including the interfaces among those — which together prevent undesirable effects. These processes and relevant interfaces built upon a set of key elements, that focus on the plants' safety, reliability and performance. The effectiveness of FMM and FMMP is built by these elements which can be summarised as '3 Ps' (policy, people and performance) and '13 Cs' (commitment, conviction, culture, cognisance, cultivation, communication, competence, contribution, collaboration, cooperation, coordination, control and conduct) of FMMP, as illustrated in Figure 7.

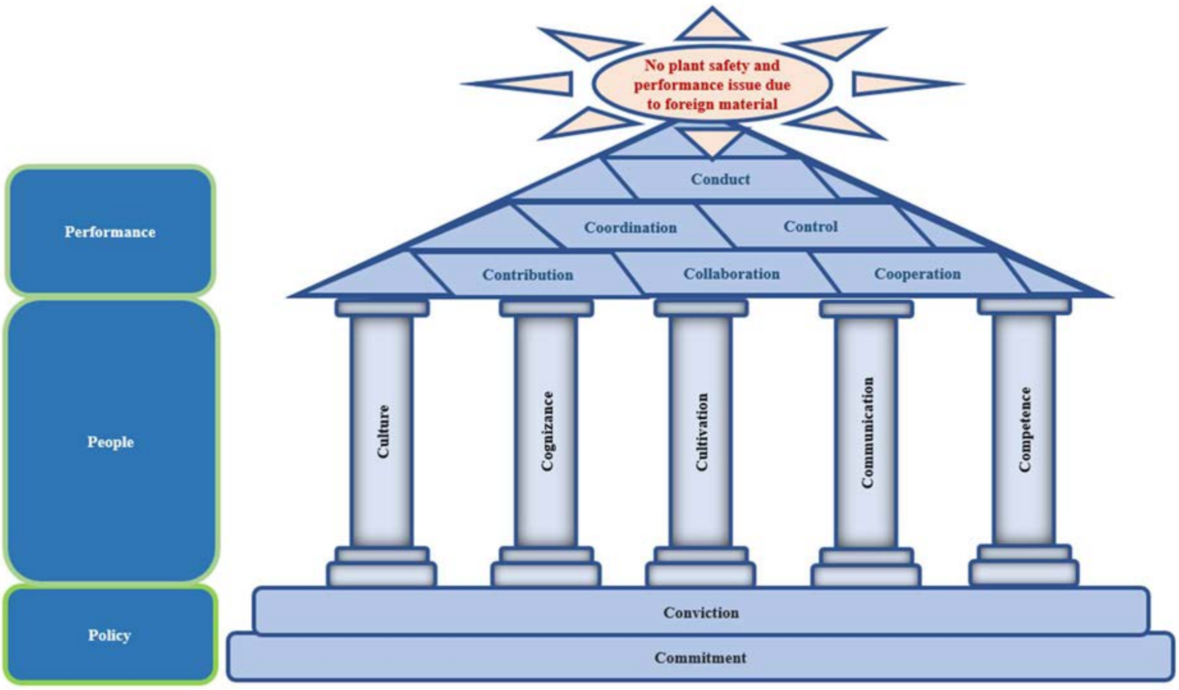

FIG. 7. Building blocks of FMMP towards no plant safety or performance issues due to foreign material.

Specifically, the key elements consist of the following:

- Corporate level commitment and a resolute policy defining philosophy, strategy, values and allocation of resources with adequate and clear FMM expectations and goals in supporting safe and sound decision making on the management of FM in all activities;
- Culture of understanding, promoting and demonstrating values and conscience in practices, as well as behaviours, in/for FMM;
- Organisation with collective awareness and ownership where roles, responsibilities and interfaces are clearly identified and defined, such that everybody pays attention to FM, FM target, FM paths, FM hazards and risks and understands consequences of their actions on plant safety and performance;

— Systematic implementation of a governing programme for FMM in establishing, developing, coordinating, integrating, assessing, modifying and improving associated processes, procedures and activities proactively that administers:

  - Site/plant procedures that are written, controlled and implemented with the premises that the task performance start at work management planning (or design) stage specifying the FMM requirements, risks and control measures and making them part of the process until final application in the field and subsequent closure and task critiques;
  - Training for the awareness, knowledge, skills and attitudes for FMM which anchors effective work practices and ensures competency for recognising FM and associated risks and undesirable effects and consequences in personal and organisational decision making during activities;
  - Effective work practices towards identifying FM issues and requesting or providing information to identify and resolve those correctly, effectively and in a timely manner, which are understood and performed at all levels of the organisation;
  - Provision of adequate time and resources for 'critical thinking' on FMM aspects of the tasks with sufficiency for core activities and with allowance for discretionary and urgent activities such that opportunities for incorrect/inadequate task performance due to unrecognised, miscommunicated, misunderstood, omitted, rushed actions;
  - Implementation and practice of a systematic approach for continuous improvement with effective and prompt problem (or potential problem) identification, corrective action and trending programmes to document and track FM related events, near misses, close calls, potential hazards and observed weaknesses and gaps;
  - Application of conclusive and conducive metrics with objectives to assess the overall health of FMMP and to discover areas of improvement;
  - Oversight, both continuous and periodic, of the FMMP and associated programmes, processes and procedures through focused observations and feedback of work practices and programme itself;
  - Periodic assessments of the FMMP by internal and external organisations, including benchmarking, to identify areas of improvement and implement industry practices (or the practices of other industries in which FMM is strictly practiced), to identify and to develop and implement plans for FMMP optimisation;
  - Use of OPEX in an effective and timely manner, including complete review and extraction of applicable lessons learned with timely incorporation in the FMMP elements, processes and procedures to prevent or minimise similar events, deficiencies and/or vulnerabilities.

This Section expands upon these elements that, as experience shows, lead to effective establishment, implementation and continuous improvement of FMMP and its use in decision making for the routine and emergent nuclear power plant and project activities. Implementation of these elements are discussed further and in detail in the Sections that follow Section 4.

4.1. COMMITMENT

In order to efficiently implement and effectively follow any programme of a nuclear power plant and/or project, every person in the organisation needs to understand and own his/her role, priorities and responsibilities for the application of a programme within the context of corporate vision — towards safe, reliable and efficient generation of electricity with quality and longevity.

As such, effective application and execution of programmes and processes start with a sincere corporate commitment since the corporate strategy, style and tradition will drive every task performance, allocated resources, plans and schedules, determination of type, scope and quality of work practices, as well as safe and sound personal and organisational decision making. Furthermore, such an allegiance will also guide personal attitudes and behaviours towards an excellent performance in all activities, which are very important for the safety and performance of the NPP and for the health and well-being of individuals (i.e. commitment to each plant personnel, as well as to the internal and external communities).

In the commitment, the board of directors and plant executive officers have a defined responsibility to ensure nuclear safety is the priority for/in decision making, as this commitment by the corporate level management is the essence of understanding, agreement and alignment throughout the organisation. Therefore, the commitment needs to be initiated at the corporate level with a purpose to achieve safe, reliable and efficient electricity generation and professed and demonstrated by the most senior level to flow down and to involve the entire organisation. To ensure this achievement, subsequently, clearly defined expectations and values at all levels — starting with the nuclear power plant project (and later, owner/operating) organisation's board of directors and chief officers — are established, documented and communicated.

Specific to the FMMP, the corporate leaders and senior managers adopt, agree and reflect the vision, desire and commitment for FMM with the key attributes of *foreign material free operation* to be understood and followed by them and the rest of the organisation.

4.2. POLICY

As it is discussed in the publication by the International Nuclear Safety Advisory Group (INSAG), INSAG-4 [44], behavioural policies promoted at a high level create the working environment, condition and individual behaviour throughout the organisational levels, since it is where the attitudes, decisions and methods of operation demonstrate real priorities. It is necessary to declare and disseminate the aspects and expectations of the corporate commitment, on safe, reliable and efficient operation, by a policy. The policy:

- Sets, adopts and promotes behaviours and values throughout the entire organisation;
- Proclaims, edicts and communicates the commitment and all expectations and provisions for its application.

Thus, for an effective FMMP implementation and execution, it is essential to establish and demonstrate the corporate commitment to excellent safety and performance by a clear and concise corporate level FMM policy to adopt behaviours and values of/for/in *foreign material free operation*.

By making key attributes of the commitment plain and simple, the FMM policy guides and aligns all parts of the organisation to the FM awareness and consideration of behaviours and values in every task which has relevant FMM aspects. More importantly, it states that such behaviours, values and attributes are valued and applied consistently by the management and everybody in the organisation.

With this policy as the foundation, governing programme and associated processes and procedures will be built for the implementation and conduct of FMM appropriately and hastily in the personal and organisational decisions on plant safety and performance.

4.3. CULTURE

While establishment and adherence to the policy and procedures are necessary and essential for a successful FMM, they are insufficient if applied and executed impersonally. Having an individual and plant/site culture of personal and organisational commitment, awareness, alertness and advancement of knowledge and using sound judgement with proper responsibility, accountability and ownership in 'their' activities is the key foundation for success of a mechanically and administratively utilised programmes.

Operating experience show that, in some organisations, FMI events continue to occur when they lack behaviours of a good FMM culture even though they are following the best industry practices in procedure writing and maintain large number of procedures that cover, in detail, every aspect of FMC and FMI event prevention. Conversely, some organisations which demonstrate habitual (i.e. not necessarily instructed) behaviours of a good FMM culture in the awareness and management of foreign material (e.g. show behaviours of cleanliness, good housekeeping, informal active communications and peer cultivation, risk recognition) have a few or no FMI events and maintain a good FMM with a minimal but sufficient set of instructions/procedures.

Successful FMMP implementation typically shows two common characteristics of the behaviour and attitude of the organisation, i.e. its FMM culture:

— Everyone in the relevant organisations is aware and act to assist the control and management of foreign material and make decisions accordingly (i.e. with consideration of key FMM attributes and with safety and reliability being the top priorities);
— They support and contribute to the improvement of the FMMP, not because 'they are told to do so', but 'they want to do so'.

Therefore, main cultural elements of an organisation in developing and maintaining a sound and effective FMMP commonly include the following aspects that exist and are fostered in/by the organisation:

— Foreign material *awareness* and *vigilance* (e.g. what is FM for a specific FM target and its potential risks and consequences);
— Cultivated personal *engagement*, *responsibility*, *ownership* and *accountability*;
— *'Clean as you go'* and housekeeping philosophy and habits;
— Self-driven *observation and reporting to learn*, understand, share and improve;
— *'No blame policy'* which sees a learning opportunity (for people, processes, organisation, plant and industry) in every mistake;
— Learning, *informing and coaching* in an open, respectful and collaborative environment.

4.4. PROACTIVE PROGRAMME

The FMMP, whether at its initiation, maintenance or progression, needs to be proactive rather than reactive, e.g. anticipating issues rather than encountering them or correcting problems, instead of investigating them, after they occur. Accordingly, the programme's aspects, requirements, expectations, as well as shortfalls and defects, are well and carefully considered by taking into consideration the core knowledge and previous experiences and learnings (by own staff or by others), *before* a FMI event occurs or weaknesses in the programme is identified by others than the own personnel. Unfortunately, in many cases:

- The initiation or improvement of FMMP is driven by an FMI event that had already adversely affected plant performance or safety. In other words, the programme is often initiated or revised by a 'force' to improve an inadequate (or declining) FMM. This force is due to an event, or potential, event which is, typically: identified by the emergence of undesirable consequences, recommended by industry peer groups, such as IAEA, INPO, World Association of Nuclear Operators (WANO), or enforced by the regulator body. In such cases, efforts on the programme improvement are conducted by a management 'directive/dictate';
- The initiation or review and fix of FMMP are performed by bringing in professional staff external to the groups and/or organisations to 'create' a new programme or 'fix' the existing one with a new (their external) perspective.

Naturally, in the first case, the employees tended to perceive these efforts as compliance with management directives imposed on them by outsiders and responsibility is on the plant/corporate management. In the latter, the employees incline to believe that the responsibility for FMMP is on those professional staff who are brought in and is delivering the programme improvements. In either case, the belief adversely impacts the ownership and commitment. These situations more extensively and absolutely require management's sincere commitment to the programme (and its improvements) *for the future not for the past* and *for the employees and company as a whole* and not for the outsiders, making the repair of the programme more challenging than it should be when that commitment is not there.

Programmatically, an effective FMMP throughout the service life of an NPP requires the use of a systematic and proactive approach that provides a framework for coordinating all programmes and activities relating to the understanding, controlling, monitoring and mitigation of foreign material that has a potential to enter SSCs. One recognised approach to systematic establishment, implementation and continuous improvement of any management programme is Deming's 'Plan–Do–Check–Act' (PDCA) cycle which is illustrated in Fig. 8 and is provided as an example of a programme management method, for the purpose of this publication.

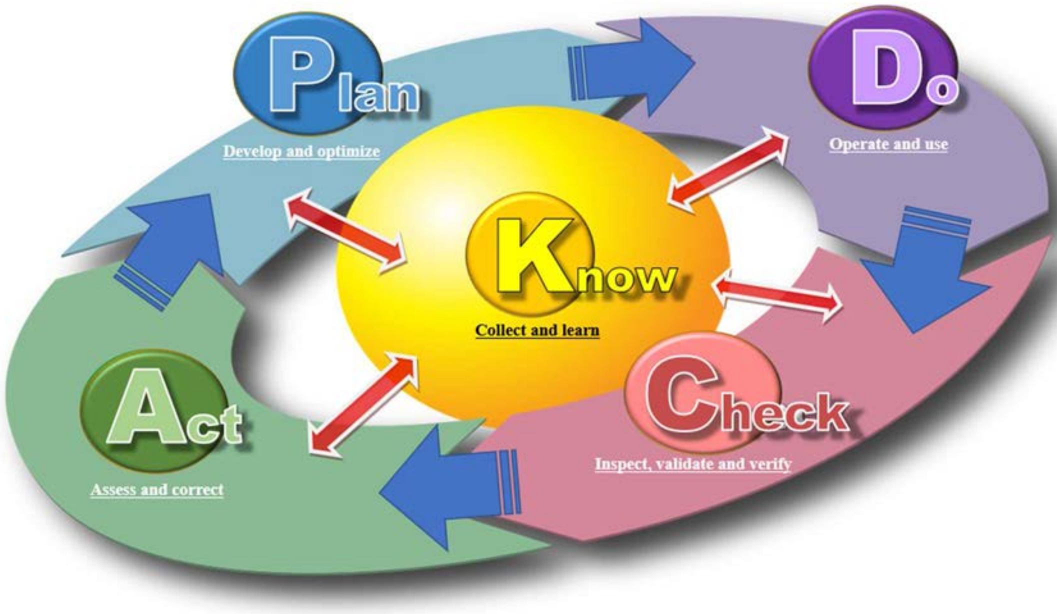

FIG. 8. An illustration of the Deming`s Plan–Do–Check–Act (PDCA) cycle.

The '**Know**' activity (or the **'Core')** of the improvement cycle, is FM awareness and knowledge, i.e. knowing and understanding the FM, its paths and potentials for intrusion to the SSCs and potential impacts on SSCs. The FM knowledge and awareness are the core to an effective FMMP implementation and improvement and is the key to all FMM activities and instructions. The closed and cycling loop of activities around this core is the continuous improvement of the FMMP and it feeds to, and is fed back to, a better understanding and knowledge of FM and its control, exclusion and status, i.e. to its core (shown as double arrows in Fig. 8), to be used back in the activities around this core:

— The '**Plan**' activity involves continuous activity of establishing, developing, coordinating, integrating and modifying existing programme, processes, procedures, instructions and actions that relate to managing and improving the programme to meet the FMM policy and commitment;

— The '**Do**' activity aims at preventing foreign material ingress into a system or component and eliminating conditions/settings for potential FMI events. This is accomplished by through carefully controlling expected FM and FM related issues in relevant activities, areas and operation/use of equipment and tools, in accordance with procedures, instructions, work planning and with competency;

— The '**Check**' activity involves the timely detection and characterisation of FM through inspection and monitoring of an activity, structure or component, human performance, procedures, environment, as well as the identification, recording and reporting of deficiencies. It also serves as the monitoring of the programme itself as a checkpoint for identification of programme's strengths and weaknesses, particularly those in the 'Plan', 'Do' and 'Act' activities;

— The '**Act**' activity aims at the timely assessment and correction of FM prevention, detection and mitigation elements through appropriate programme modifications, including procedural and cultural aspects, to determine the type and timing of any corrective actions required. It is mainly the corrective actions to those identified in 'Check' activity in addition to the knowledge and awareness that have been added (e.g. from plant's own or other's OPEX).

At the beginning stage of this cycle, which is the programme development, the 'Plan' activity primarily relies on existing knowledge of internal and external organisations and existing OPEX. At this stage, the core of the cycle and initial structure of activities mostly consist of:

— Engineered features for FMC are embedded in the plant and its documentation based on the existing component and system design, manufacturing, installation, maintenance processes and/or contractual agreements;
— Procedures and processes, together with organisational structure heavily utilises the lesson learned (unstructured, tribal and/or organisational knowledge, experience from internal/external organisations, peer practices, etc.) and the adaptation of good practices and guidelines from nuclear peers (e.g. benchmarked programmes), or from other industries which are practicing FMM due to high risk of FM in their systems, processes and products (such as, aeronautical, pharmaceutical, medical, semiconductor industries);
— Basic system instructions and operational specifications by manufacturers to improve control FM hazards and minimise FMI.

As mentioned earlier, this initial programme is developed with as much as possible cooperation and participation from everybody in the organisation including external suppliers of equipment and services. As the improvement cycle revolves, the participation may take different approaches:

— In the earlier cycles of improvement, there exist visible/noticeable opportunities for improvement with adequate consideration of FM issues and hazards, particularly those for better planning, and execution of the work, better defining of responsibilities and for more appropriately allocating resources. Capitalising on these opportunities demonstrates to the management and the employees that a better programme is possible and is achievable.
  Opportunities and evidence of considering and valuing the lessons learned from employees' own experience, and implementing associated corrective actions resulting from personal observations and reporting, cycle the organisation into a stronger FMMP ownership by each individual with clearer values, responsibilities, processes and procedures.
  It should be noted, however, in these earlier stages, not establishing larger involvement of individuals owing to the perception/presumption of weakness due to limited experience and knowledge (and relying more on professional programme improvers instead) may result in 'imposed improvement' perception which slows down an efficient and effective continuous improvement of the programme.
  More importantly, the high level management ought to continuously and rigorously demonstrate their commitment, especially by personally participating and providing observations in the improvement efforts together with the employees, more so during earlier stages of FMMP. Such demonstration will help raising consciousness and collective awareness about the need for FMMP update and desire for improvement, as well as building mutual trust;

— In the later stages, the cycle of improvement is more mature with common participation, collective awareness and shared goals that create a self-propelling continuous process to achieve a better FMMP.

> Although it certainly still requires active management presence and participation in the activities, perception of 'imposing' diminishes to a very small portion of the staff. A large portion of the staff is sufficiently committed with well understood personal responsibility and accountability in, and for, the programme. Majority of employees actively considers, explores and communicates what they, personally or as a team, can add to the improvement of the FMMP in every activity they perform.

Regardless of the perception and initial response, systematic approach ought to be insistently and consistently used. The earlier the values and goals of the FMMP are clear to the entire organisation with the 'end in mind' approach, the more consistent and the more often the application improvement is, and the timelier and the more effective the implementation of the Deming's PDCA cycle.

It is also important in every improvement cycle, as applicable and appropriate for their roles, that contractors and suppliers work together with the internal organisations as their influence and responsibilities affect everybody at the plant/site/station, vice versa.

4.4.1. Foreign material knowledge and awareness ('Know')

The degree of awareness and understanding of FM determines the degree of success and excellence in establishment, coordination and optimisation of processes and procedures, as well as activity planning, implementation, execution and correction of all relevant activities, by proactively predicting, controlling and preventing FMI events. Knowing and understanding FM types, characteristics and the causes and effects of their ingress/existence in plants systems and components are the core of a systematic and proactive FMMP and the foundation for a successful FMM (Figure 9).

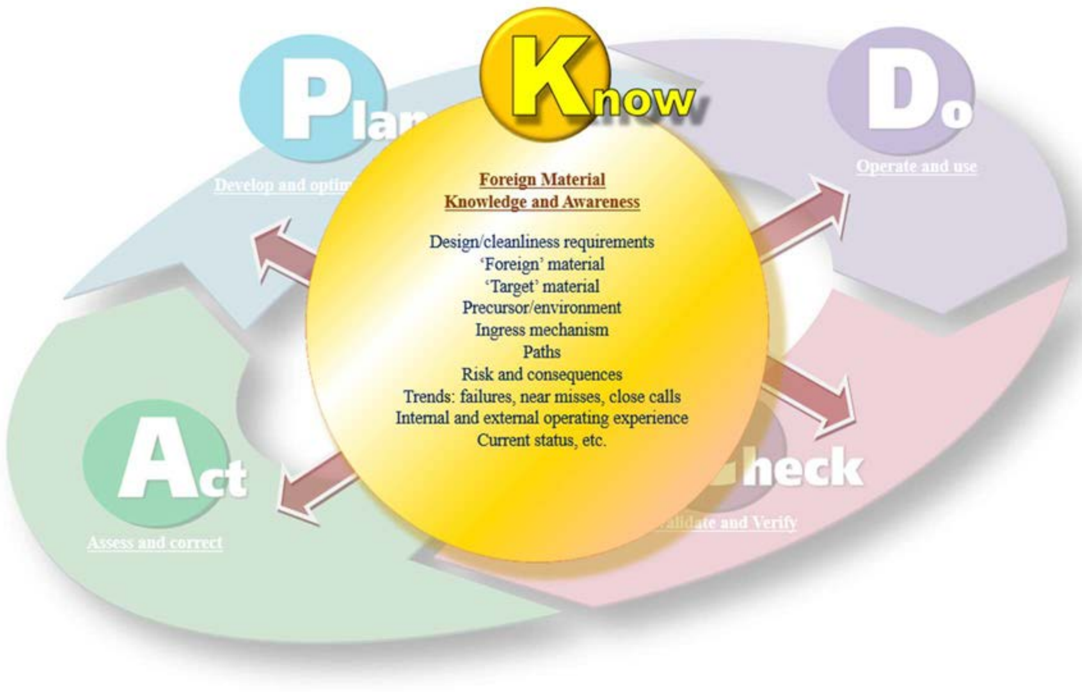

FIG. 9. Information and knowledge about foreign material, 'Know', as the core.

This understanding is mainly derived from design information and knowledge of the SSCs to identify what is not expected/desired to be in a component or system by its design or its operation, i.e. what is 'foreign' to the system or component which maybe a solid (for example, generated crud, dropped tools, dust), liquid (such as leaked chemicals, left oil residue) or gas (e.g. unvented air, steam) substance.

As explained in Section 3.2, the design of SSCs considers FM generation and intrusion and provides engineered features for prevention and protection from these FMs, as well as the monitoring, detection and elimination of FM based on required/desired functions, compatible material properties, etc. Design and operational and technical specification, such as cleanliness criteria, access requirements, operating conditions, are also considered in the design and provided in the facility records. Having information and knowing design functions is necessary to identify risks and to mitigate consequences of ingress/existence of specific and certain FM on the SSCs.

Knowledge and information of component, system and plant layout, as well as other processes such as the assembly/disassembly instructions, also provide information to identify ingress paths and transportation mechanism of FM in and around the SSCs during their operation and maintenance. This information supports prevention and protection of SSCs from FM by removing and/or controlling the precursor, stressors and the environment.

In addition to the baseline knowledge of FM regarding their type, generation mechanisms and potential ingress/egress/transport path that are considered during the design and installation, the 'Core' subsequently gets larger by the addition of:

- Specific O&M experience, history and records (including those of/from construction and commissioning activities);
- Inspection and benchmark results, and generic (nuclear and non-nuclear industry) OPEX;
- Research and development;
- Lessons learned from failures, events, near misses and close calls.

These accumulating information and knowledge are also significant contributor to the understanding and awareness of FM, methods for prevention of generation and exclusion and, in case of an FMI event, known/learnt methods of its mitigation.

However, accumulation of information and knowledge need to be continuous and the collection and dissemination of new learning need to be part of the FMMP in raising awareness and vigilance. This can be accomplished by embedding processes and mechanisms in FMMP and other programmes, such as training (agreed for different roles), OPEX, performance improvement, corrective action, as well as dissemination mechanisms, for example, in information and communication mechanisms and campaigns.

4.4.2. Development and optimisation of foreign material management ('Plan')

Managing and improving the FMMP is a continuous activity of establishing, developing, coordinating, integrating and modifying existing programme and its processes, procedures and activities. It encompasses preparation, coordination, maintenance and correction of programme requirements, instructions and expectations for the governance of the plant/project activities related to the FMM and FMC and for the prevention, detection and mitigation FMI events based on the latest information and knowledge in the 'Core'.

The FMI events often can be traced back to a lack of knowledge or communication of requirements, task conditions and criteria, as well as to unclear roles and responsibilities. These, in turn, point to insufficient documentation and coordination of task planning among the plant's internal and external organisations, which necessitate a systematic 'Plan' for the programme. The objectives of systematic coordinated FMMP planning[5] include, among others, to:

- Fulfil an overview role;
- Integrate existing relevant programmes in order to identify areas for additional effort;
- Eliminate any overlaps in responsibility and unnecessary activities;
- Provide a mechanism for programme coordination, incorporation of lessons learned and implementation of effective corrective actions for continuous improvement.

Although this coordination generally requires a modest financial and time investment, the positive cultural and organisational implications may be considerable.

At the end, the 'Plan' activity ensures all programme factors, requirements, expectations and the key aspects for the programme, processes and procedures are documented and associated instruction are made available to the staff who will be performing activities that involve FMM (Figure 10).

[5] A 'programme planning' described herein is not to be confused with the 'activity planning', which is discussed in Section 4.8.

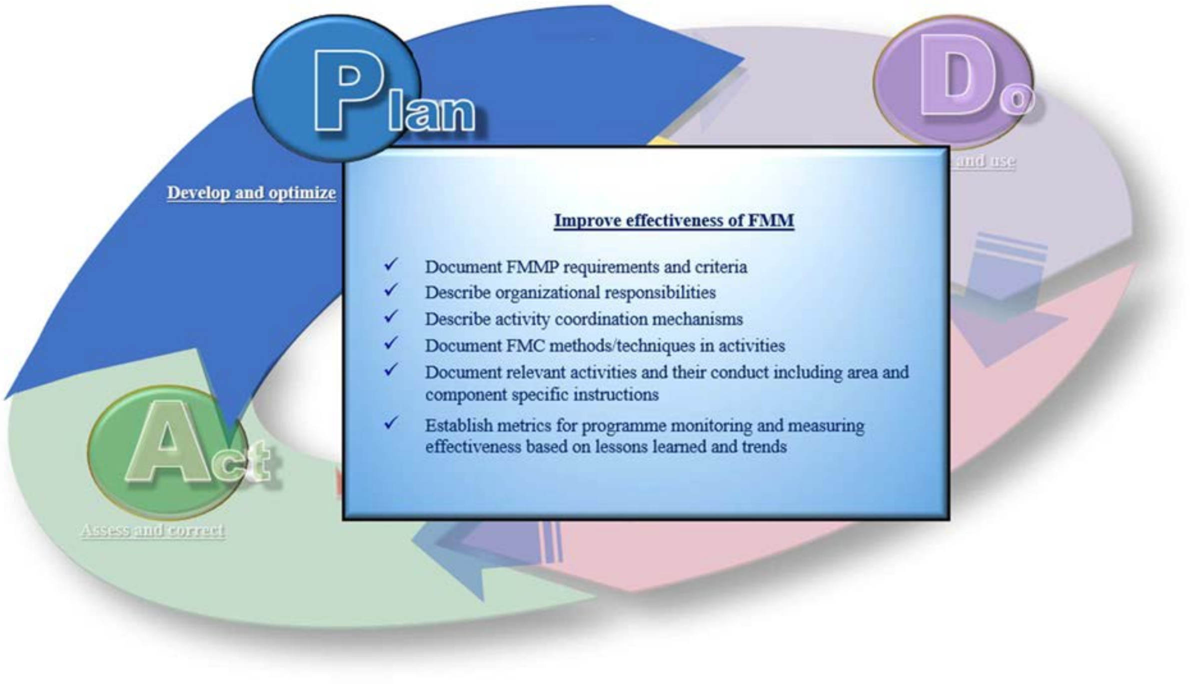

FIG. 10. Establishment and revision of the programme, processes and procedures: 'Plan'. FMM — foreign material management, FMC —foreign material control, FMMP —foreign material management programme.

As such, the 'Plan' activity is where the site's (or plant's or fleet's or project's) FMMP is developed, documented, controlled and, at later cycles, optimised.

Initially, at the 'Plan' activity, FFMP description documents typically contain the following elements, which are based on the corporate policy:

— FMM requirements and expectations;
— Programme ownership;
— Roles and responsibilities;
— Prevention, protection, exclusion, mitigation, evaluation requirements;
— Work planning requirements;
— Training requirements;
— Performance indicators (metrics) and process to monitor and modify programme.

Subsequently, these elements will be detailed in a governing (administrative) FMM procedure to describe an overall framework for administration, as discussed later in Section 5.

The effectiveness of FMM and FMMP can be significantly improved through the planning and coordination of all relevant programmes, processes and activities, taking into account the human and environmental conditions and limitations, such as foreseen (and/or experienced) task conditions and appropriate personnel qualification.

The systematic FMMP planning bidirectionally facilitates the common communication among all contributors in the organisation towards the improvement of FMMP. In this process, each contributor, whether organisation or individual, can clearly see their role in the programme improvement process, as well as a collectively informed team approach that stimulates creativity and amplifies the benefits of individual or organisational contributions.

4.4.3. Application of foreign material management ('Do')

Conduct of, and conditions around, activities during the entire lifetime of the NPP directly affects the generation, and even more so, the industrial, nuclear and radiological safety, as they are primary opportunities for allowing/disallowing presence and ingress of FM in plant SSCs as they may result in degradation of plant safety and availability. Since practices in operation, construction or maintenance influence the conditions of SSCs and their surroundings, NPP staff has an important role in minimising FM and/or its ingress to SSCs when performing those practices.

Thus, the 'Do' phase covers 'doing' what FMMP has set up for preventing FMI and eliminating conditions/settings for a potential FMI through carefully controlling and managing FM while performing plant activities in work areas and operating/using plant SSCs. This can be accomplished by the use and control of proper environment, equipment and tools and by performing tasks in accordance with procedures, instructions and as planned by work control with awareness and competency (Figure 11).

FIG. 11. Application, implementation and performance of foreign material management: 'Do'. FMI —foreign material intrusion, FM —foreign material.

Again, a good understanding of FM and ingress paths and mechanisms provides for the optimisation of conduct of activities, operation of SSCs and the environment where activities are conducted, as well as the implementation of procedures and work orders that provide instructions for the conduct of activities.

Overall, 'Do' is the implementation of FMMP and some of specific 'Do' activities, therefore, include:

— Performing activities in accordance with the prescribed and designed procedures, specifications and instructions;
— Recognising the omitted and deficient instructions to conduct activities with FMM and report for later correction and optimisation of procedures;
— Avoiding contamination and potential contamination of systems and components with solid, liquid and gas contaminants, as applicable;
— Effective monitoring of FM for specific, relevant and/or potential FM target systems and components;
— Maintaining good record of completed activities with FM issues and lessons learned;
— Controlling environmental interfaces such as:

- Tool, equipment, and personnel;
- Heating, ventilation and air conditioning (HVAC) system that keeps plant environments within prescribed conditions to prevent FM transportation;
- The environment of inaccessible or limited-access SSCs where mitigation of FMI event can be difficult and can result in costly unavailability;
- Performing activities by competent personnel;
- Maintaining the tool and equipment in good order.

4.4.4. Inspection, observation and verification of foreign material management ('Check')

Inspection and monitoring activities performed before, during and after the performance of tasks are to detect, monitor and eliminate FM and the implementation of FMMP before safety and performance of systems and components are jeopardised. The procedures and tasks for pre and post task inspection, testing and monitoring could address the adequacy of anticipation and detection of FM and the appropriateness of prevention, protection and exclusion tools and methods before, during and after tasks (Fig. 12). It also ensures the discovery of a FM in SSCs, should an FMI event to occur.

FIG. 12. Verification and validation of the programme status and its implementation: 'Check'. FMM —foreign material management, FM —foreign material.

Furthermore, the 'Check' involves timely detection and characterisation of deficiencies, pitfalls, lessons learned and good practices in the FMMP, and other relevant programmes, processes and procedures, as well as in operation and maintenance of SSCs, human performance and competency and work environment.

'Check' is mainly accomplished through observations, inspections, oversight, reporting and monitoring of an activity (it is very important to note that this includes *self and peer checks observations*). Additional data to improve the programme can be obtained from pre- and post-job briefs and can be trended for programme health status and improvement areas.

Also, many of the FM presence/ingress to the SSCs are discovered not only by non-destructive examination (NDE) techniques (e.g. visual inspection, loose parts/tools monitoring, vibration monitoring, sound, robotics) performed on the SSCs themselves, but also by more global monitoring of people, policy and performance in relevant process and places, such as packing, transporting, unpacking and storing facilities, activities and systems, towards identifying flaws in handling SSCs.

Identifications and determinations (and recording and reporting both positive and negative ones) of effectiveness/ineffectiveness of activities, including the instructions, work environment or staff, feeds back to the FMMP and associated processes and procedures, such as operational procedures, maintenance instructions and/or related programmes and processes. It requires the assessment and understanding of findings regarding the changes and modifications to be made towards better FMM and related non-conformances and their observed effects.

Together with a thorough understanding of FM, FMM, FM related activities and procedures (as well as a FM event, near miss or close call) and their objectives or consequences, the results of 'Check' and the subsequent trending provide an important input to decisions regarding the type and timing of preventive and corrective actions for FMMP and other relevant programmes, processes and procedures.

Furthermore, findings and lessons learned, often derived from trending FMI events, near misses or close calls at the 'Check' stage, provide valuable information to improve and proactively manage the FMMP itself. Such findings, observations and lesson learned can later be incorporated as programme correction in 'Act' stage and improvement actions in the next round of 'Plan' and 'Do' stages.

It should be noted that a risk informed and graded method of observations, checks and inspections could provide better targeted. More focused and effective inspection and monitoring towards the programme improvement. For example, a proactive monitoring and inspection programme can be used for detecting a potential FMI or for identifying a condition or environment for a potential FMI.

It is also important that inspection and monitoring may require to be directed not only to specific SSCs, particular task and task area, but also to surrounding task areas and the facilities of general plant and of manufacturers/suppliers.

4.4.5. Assessment and improvement of foreign material management ('Act')

The 'Act' activity aims at the timely mitigation and correction of deficiencies and weaknesses identified in the FMMP by a thorough and appropriate assessment, audit (including self-assessments) and implementation of the requirements and areas for improvement identified by oversight during the ‘Do’ and ‘Check’ activities (Fig. 13).

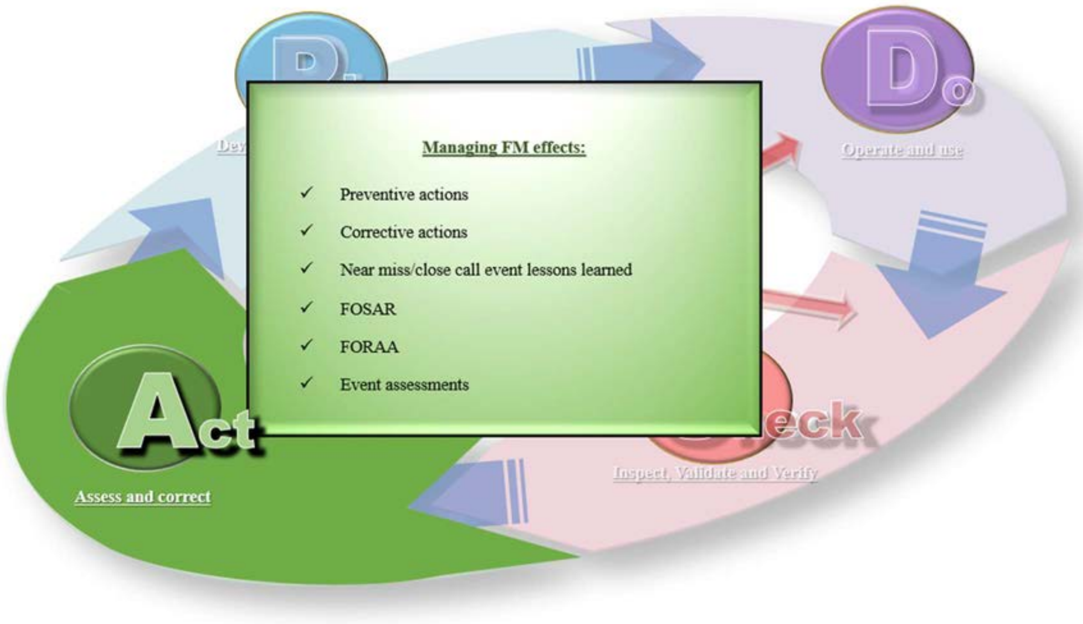

FIG. 13. Assessing and correcting/adjusting the programme: ‘Act’, FM —foreign material, FOSAR —foreign object search and retrieval, FORAA —foreign object review and assessment.

A variety of preventive and corrective actions are available to mitigate issues by the assessment and evaluation of detected issues, challenges and pitfalls during the inspection and monitoring of foreign material and associated processes and tasks by, for example, self-checks (during ‘Do’) and oversight (during ‘Check’). Decisions on the type and timing of the corrective and improvement actions are based on assessments of the observed events, near misses and close calls, understanding of the applicable FM prevention, protection and control, predictability of future potential for FMI events, available decision criteria and the effectiveness of available technologies and training.

Additionally, benchmarking of other nuclear or non-nuclear FMMPs can be beneficial in identifying opportunities to improve. A set of performance indicators (metrics) are to be developed to assess the effectiveness and health of the implementation of the FMM programme.

4.5. GRADED APPROACH TO IMPLEMENTATION

In an effective and efficient FMMP, *all* activities around the SSCs are reviewed for potential threat for an FMI and further planning and guidance are established to control or manage FM or to eliminate or minimise the risk of FMI during performance of these activities, using a graded approach. This graded approach will determine the necessity, type and extent of the application of FMM administrative controls, checks and requirements (e.g. for methods, tools, people[6]) that are to be applied to arrangements and activities in their planning, development, implementation and execution. In turn, the use of the graded approach, which is also discussed in the IAEA publication TECDOC-1740 [46], will help to optimise resources (human, equipment and financial) and costs of preventive, protective and mitigative controls.

In establishing graded control of the activities, there are some common characteristics, based on the existing IAEA industry practices and lessons learned, including:

— Regardless of the organisational and corporate driving factors, selected graded process and its *graded approach cannot, in any manner, compromise safety* and has to be consistent and compliant with the applicable regulations, codes and standards;
— There is no 'one size fits all' grading process as it would vary depending on an organisation's strengths and weaknesses and corporate philosophy driving the corporate policy, strategy, goals, finances and character and culture of the organization;
— Scaling of graded approach, similarly, will be driven by the same corporate and organisational characteristics that will assign and apply a value, importance and significance to a particular arrangement and activity. However, it is prudent and sensible to apply tighter controls to more significant activities based on their cause and effect aspects. Such aspects that need to be considered and weighed include:

  - Nuclear, industrial and radiological safety impacts and importance;
  - Quality and reliability designations, requirements, expectations and effects;
  - Plant performance goals and expectations;
  - Degree of probability of FMI event based on the existing/generated FMs, created FM paths and FM targets during the entire activity;
  - Severity of consequences of FMI regarding safety, health, economic and financial aspects;
  - Rarity/frequency/specialty of the activity;
  - Complexity of the activity;
  - Level of interaction with parallel activities of the same or different scale;

— Administrative framework and associated documents (i.e. administrative procedure) need to provide *clear definitions for grading method, criteria, metrics*, such that all activities are graded consistently, without complexity, ambiguity or subjectivity;
— Considering the large volume of activities in a plant/project, *grading process will demand time and resources*. However, based on OPEX:

  - Challenge with the demand for time and resources can be eased by pre-grading standard, frequent and routine activities that are performed under same conditions (people, environment, work area, task sequence, nearby SSCs and parallel activities, etc.) without a need for grading every time activity is performed unless there is a change from the standard implementation.
    It should be noted that, for such pre-grading processes, the conditions considered in the grading process need to be clearly defined and recorded in tasks instructions, as any deviation from those conditions would necessitate review and control, and if necessary, regrading. The extent of review and control would be dependent on the amount and magnitude of changes to standard task performance and area;

[6] As noted in Ref. [45]: "Controls and checks that could be graded include, for example, aspects such as qualification and training for individuals, type and format of procedures, and requirements on verification, inspection, testing, material, records and the performance of suppliers" [45].

- Graded application of the FMMP requirements and controls, on the other hand, minimises the costs while improving the safety and quality of the performance of tasks by enabling the management to allocate and prioritise resources and attention focusing on activities of greater significance and utilise them to a lesser degree in less critical activities. This prioritisation and focus would achieve minimising FMI events that would have more adverse consequences for nuclear safety, personnel and equipment health, plant performance and economics (since a significant FMI event could result in the allocation of much more resources and more costs and more loss of revenues;
- Graded approach will — in a one-time effort —also identify products and activities of lesser (or no) importance and significance among all activities which, then, will enable to determine the minimum amount and extent of controls to be applied going forward;

— It is possible to assign different grading for different stages of the activity evolution. However, in such cases, entry and exit conditions from one grade to next need to be well defined, documented, validated and verified. Additionally, the changes to the administrative and physical FMCs, from one grade to the next, need to be identified and clear instructions need to be provided for the change management.

4.6. ORGANISATION

The nuclear power plant (or project) owner/operating organisation — as it carries prime responsibility for nuclear safety — holds direct and/or indirect responsibilities at every stage of the lifecycle of a plant, to ensure safe and reliable operation, as well as efficient, effective and economic performance. The direct responsibilities also include the establishment, implementation and maintenance of programmes, processes and procedures. To accomplish this, the plant/project organisation is structured with clearly defined roles and responsibilities for a specific programme (and associated processes and procedures) and the programme ownership is assigned to an individual or department in accordance with company strategy and philosophy and with the application of *'organising for the task'* principle (see Section 5.6 for the description and details of this principle).

Thus, as one of the plant/project programmes, FMMP would also have defined organisational roles and responsibilities and a programme owner. It should be noted that *'organising for the task'* principle will necessitate changes in the assignments and responsibilities as the activities and foci of the programme changes at each phase of lifecycle. Therefore, the organisation needs to be flexible to adjust the structure, tasks and assignments accordingly. For example, the FMMP organisation could be an oversight organisation to the vendor/supplier's FMM programme/organisation at the design stage, while it could be a construction FMM programme/organisation at the construction and commissioning phases. On the other hand, the FMMP organisation may be structured as an independent, permeated or within a specific discipline, and so forth, during the operation phase.

Regardless of how the organisation is structured, there will be key responsibilities and roles. Figure 14 illustrates an example of organisational structure during operation phase depicting key roles in the owner/operating organisation as parts of the establishment, administration and maintenance of FMMP. Establishing a specific structure of organisations and assignment of particular roles and responsibilities will be further discussed, in detail, in Section 5.6.

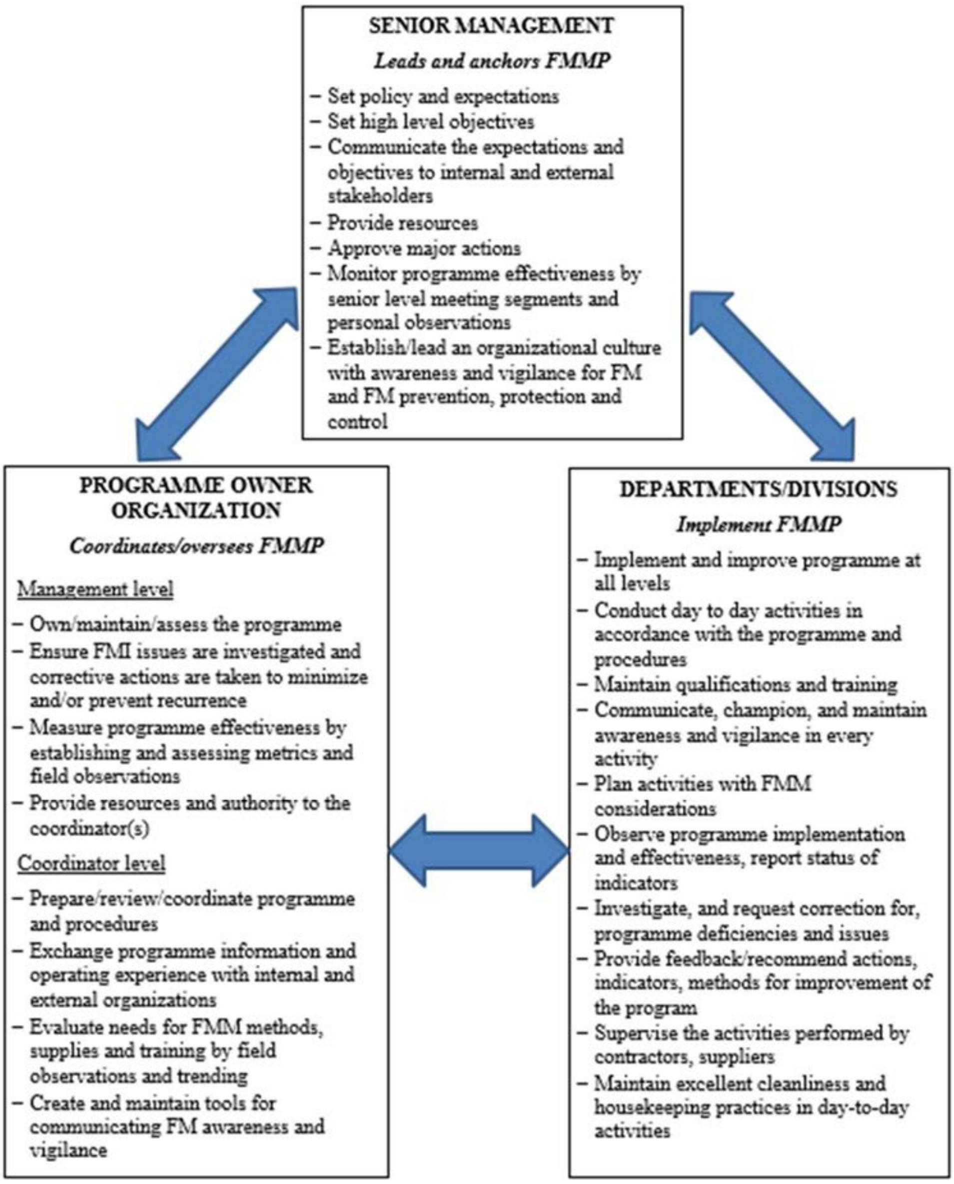

FIG. 14. An example of organisation for the foreign material management (FMM) tasks during operation phase. FMMP —foreign material management programme, FMI —foreign material intrusion, FM —foreign material.

While the FMMP ownership may be assigned to one individual or department, the entire organisation — from the highest-ranking officer at the site down to the worker in the field — understands and shares an equal goal in promoting and demonstrating good FMM practices and behaviours at all times in a NPP’s lifetime. Collectively, they share a common, but not diluted, ownership and accountability. It is equally important in effective implementation and practice of a FMMP that every person in the organisation understands and owns his/her role, priorities and responsibilities in achieving *no-adverse effect of foreign material* on safe, reliable and efficient operation of the plant. Therefore, to ensure these attributes are achieved, clearly defined roles, particularly the roles and responsibilities for all levels of the organisation, as well as potential impacts on safety and performance in cases of not understanding of key attributes and/or omission of responsibilities, are documented and communicated. Accordingly, regardless of the title or position of ‘official’ programme owner in the organisation (in a specific phase in plant lifetime), entire plant/project/site staff needs to know what their task is in the FMMP and how their skills and knowledge are to be (can be) used in achieving and maintaining programme’s expectations and goals that are stated in the FMM policy.

All team members also need to know and respect the input and feedback expected of the other members in the plant (which is particularly important in periods of rapid organisational change), including of those that are external, such as contractors, who are working alongside them. The owner/operating organisation also has the responsibility for supervising the activities of all other external (onsite or offsite) organisations, such as suppliers, manufacturers and constructors, employers and contractors. Therefore, a comprehensive and common strategy to promote FM awareness and to communicate FM and FMM requirements and expectations have to be in place and maintained by the plant (or project) owner/operating organisation to minimise and prevent FMI events by any or all parties involved in structured manner.

As a characteristic of successful organisations, any programme is initially developed with total cooperation and participation from everyone in the organisation, including external suppliers of services, and it is started as early as the birth of nuclear power project with a corporate level commitment and policy. Therefore, to bring in everyone’s participation and collective ownership, programme expectations and goals need to be continuously and clearly communicated to everyone in the organisation (both internal and external).

4.7. TRAINING AND QUALIFICATION

Training is an essential part of the FMMP applying to all stages of a proactive and continually improving programme that is outlined in the Section 4.4. A structured training system is required to ensure the awareness, understanding and interpretation of FM and FMM in the planning and performance of tasks, as well as the preparation and implementation of procedures for those tasks, including the communication of principles and culture. Based on the graded approach used in FMMP, the level and extent of skills, competencies and knowledge will depend on the factors that need to be considered in scaling of the tasks and activities, as discussed in Section 4.5.

The training programme will ensure that the plant/project personnel and the contractors who are preparing, performing and monitoring tasks, including those who are administering and maintaining the FMMP, have the necessary skill, knowledge and competency to carry out their tasks according to required level and extent in FMM.

Reference [47] provide a guidance on the qualification and training of personnel for nuclear power plants and the conduct and evaluation of training that would also include FMM training, qualification and certification (noting here that qualification/certification is a management system process that grants permission to individuals to assume certain roles and responsibilities and perform certain roles or tasks based on the skill, competency and knowledge level that is necessary for correct performance). The FMM training and qualification programmes and processes eventually result in only skilled, competent and qualified people being assigned to particular roles or tasks associated with FMM.

The training programme and qualification/certification processes associated with FMMP, therefore, need to be designed to enable individuals to gain, understand and interpret, as a minimum:

— A thorough understanding of FMM, including why particular FMM measures are required or expected;
— Consequences FM on nuclear, industrial and radiological safety and plant health and performance and how their work practices, performance, behaviours and attitudes in FMM ultimately supports the safe and efficient operation phase of the plant lifetime;
— Roles and responsibilities for specific task performers, particularly how their functions and roles are tied to the FMM;
— Recognition of interfaces with other organisations in FMM prevention and the protection against, and mitigation of, FMI events;
— Evaluation of the person's competencies and abilities (which is normally accomplished by a test or objective assessment of knowledge and skills) so that management has a basis for granting authorisation to individuals to fulfil the role or perform certain activities.

It is very beneficial to support these training and qualification objectives with audio-visual examples from OPEX and lesson learned (both own OPEX and OPEX's of others). For example, as mentioned by the experts on FMM training, based on their observations:

> "Particularly the visually documented events, such as pictures of tank failure by clogged vent valve and documentary video of a self-discussion by the person who experienced the impact of forgotten FMC plugs in his activity, are good OPEX material that have been very useful for the audience to see and understand (and feel) the importance of effective FMM and consequences and if FMMP is not established and/or implemented properly.
>
> Always interesting for the audience and capture their attention are also the audio-visual examples from non-nuclear fields (food, medicine, aviation, pharmacy), such as pictures of Concorde accident (plane in flames and the FM on the tarmac that caused it), foreign body in food and pills, forgotten tools inside the body after surgery, etc. Also, photo captures of real personal life situations that the audience can connect to in their daily lives, such as the picture of a jewellery box set up on a shelf right above water closet opening in someone's house, help FM, FM path or FM target understanding and awareness".

Overall, the training ought to enable the individuals and organisations to have necessary mental and physical capability for their area responsibilities for FMM as implemented by a graded approach. As such, in addition to a minimum general FMM training for all relevant plant personnel, the specific aspects of FMM needs to be embedded and integrated in the training for specific disciplines, such as maintenance, security, engineering, at a level of required skills, competencies and knowledge.

The development of the training to support the FMMP need to be in line with systematic approach to training (SAT) methodology, but to simplify, the basics of the training can be covered by looking at the *five 'W's* (why, who, what, where and when) which are discussed in detail in Section 5.5.8. For example, the minimum general FMM training needs to provide staff, and where necessary the contractors, with an appropriate understanding of the site policy and expectations, procedures and corporate policies for FMM. In addition, individuals and organisations need to gain appropriate understanding of the associated arrangements for the management of foreign material, for example, processes and procedures for the area awareness, controls, housekeeping, cleanliness, observations, identifying and reporting issues, events, close calls and near misses, and more importantly, improvement of FMMP and FMM practices.

Accordingly, the FMM training programme may vary in wide range of methods, e.g. classroom lectures, computer-based training (CBT), mock-ups, self-reading, tacit knowledge transfer by mentor and protégé approaches.

It is important that individuals (and groups) gain a wider understanding of the tasks they undertake, in order to understand the implications of their activities for others and to acknowledge the value of among the appreciation of the higher importance of issues, such as efficient and safe operation of the plant. These essential needs are addressed by broader training, sufficient to ensure that individuals at every level and organisation understand the significance of managing FM, as applicable to their and other's duties. The training also provides mutual awareness of the consequences of mistakes arising from misconceptions or lack of diligence on their or others' part.

Thus, the training programme first is to be able to identify training needs and qualification requirements for individuals and organisations according to their roles and responsibilities within/for FMMP. In addition, the training needs are periodically, or within the cycle and restructure of proactive FMMP improvement, reviewed and revised. This review is to take account of learning, experience, including organisational changes and changes in plant and processes, as the roles and responsibilities may change. Traditional techniques, such as training needs analysis (TNA), that are built upon defined requirements for technical and personal (e.g. communication and team working) skills for FMM, including oversight and management skills can be used to evaluate potential training needs, to approve training solutions and, where it is possible, to suggest other management initiatives to improve facility performance.

Finally, the competency of information gained by the training, is ensured by both the conduct and the evaluation parts of knowledge acquisition and transfer. Hence:

- FMM training needs to be provided to an agreed programme and be recorded;
- As part of the training programme, an assessment of knowledge, awareness and skills gained on FMM is necessary. For particular tasks and personnel, this may require undergoing formal qualification (certification) and authorisation for task performance and responsibilities, including those for FMM (for example, for maintenance staff);
- An evaluation of FMM training effectiveness, that is governed by the evaluation process within the training programme, needs to be performed. The evaluation is done against the approved FMM training needs and FMM training programme and process descriptions, as well as the formal QA requirements of SAT based training procedures.

It should be noted that, managers and supervisors are especially required to take appropriate FMM training. The training for leaders, firstly, includes a thorough understanding, demonstrating and communicating corporate policies, expectations and goals. This training also needs to include both the acquisition of sufficient technical understanding of tasks and the necessary managerial skills to supervise the activities that their organisations perform. This provides them with awareness and goal of FMM in their organisations, such that they know the crux of FMM and discuss in pre and post job evaluations. It also enables them to interface with other organisations and their leaders in a mutual understanding and support.

4.8. PLANNING

One of the key elements of an effective FMMP is complete, comprehensive and timely planning and preparation of the activity. Planning is a forethought, visualisation and organisation of the activity, in terms of the associated human, environmental, material and financial conditions and resources, utilising all information and knowledge available, in preparation of the task performance.

Planning of an activity regarding FMM firstly involves the identification of potential FM and FM hazards, FM paths and FM targets associated with that task, FMI risk and risk levels. Once the hazards and risks are identified, there is a process of determination of FMM methods, tools, skills and job sequence to eliminate, minimise and manage these risks during the actual performance of the activity. This may involve understanding of the tasks, people, environment and course of actions in performance by seeing how they are now and visualising what will it look like during the activity performance. Hence, it will consist of identification of critical FMM and FMC elements and understanding of what will be needed (task review), where it will be needed (area and support review) and when it will be needed (schedule and arrangement) related to the performance of the activity with no or minimised risk for an FMI.

Task, area and support review and schedule and arrangement illuminates determination and understanding of need; purpose and timing of FMM and FMC during the activity performance; and prerequisites for, and challenges of, executing associated tasks. It also reveals necessary competencies, skills, methods, tools, as well as information exchange, hold, review and check points, inspections and verifications, etc. It is necessary that all these have to be considered, understood and planned for prior to the performance of the task, for a later successful implementation and completion of the activity.

Understanding the task and its conditions at planning stage can be established by many methods including work area walkdowns by planners, and performers to identify job conditions and potential hazards and risks, simulation of the activity in the workshop or in a mock-up setting, reviewing previous experience of performers and activities.

In addition, proposed, planned and anticipated changes to plant conditions, area restrictions, or process limitations also need to be included in the planning considerations. In particular, the planning will ensure that the significance of any known and anticipated change or abnormal situation is communicated and assessed with respect to FMM and FMC in advance. This impact and change assessment will also help planning and establishing interfaces and communication methods and timing among the relevant individuals and groups before, during and after the activity.

It needs to be understood that the planning cannot include all situations, as there might be unexpected/unknown/unanticipated situation during the activity performance or changes; however, it is a good practice to anticipate and consider contingency and allowance for recovery of activity schedule and coordination of resources as a ‘contingency plan’.

4.9. COMMUNICATION

Success of FMM is strongly dependent on the correct and timely communication and exchange of activity information (e.g. plans, schedules, requirements, challenges, needs, means, points of importance, work area status, changes and updates) that needs to be shared prior to, during and after the performance of activities. The lack of such communication can impact the activity, its schedule and resources (human and financial). For example, in an outage, if/when there is a lack of communication between the maintenance and warehouse organisations to provide/receive the information on when a task is to start, appropriate component/equipment/

material/part support cannot be provided when it is needed, delaying the activity and occupying the resources that may further trickle into overall outage schedule.

Furthermore, the FMI events, close calls or near misses, including the FMI incidents and nonconformances, are often caused (or amplified) by a lack or deficiency in communicating requirements, task conditions and criteria, as well as roles and responsibilities and the documentation and coordination of task planning and performance among the plant's/project's individuals and organisations. Such occurrences of 'lack of communication' include, for example:

— Inadequate or incomplete written and verbal communication;
— Failure or non-existence of formal or informal communication mechanisms;
— Undefined or weakly established interfaces between organisations relevant to the activity;
— Omitted, contradictory or misleading information, directions and instructions;
— Insufficient coordination between individuals and groups at every level of the organisation.

The communication needs to be in all directions. Therefore, programmatic and organisational arrangements, mechanisms and methods need to be in place to also promote receipt and provision of feedback from individuals on their own experience and programmatic observations, concerns, challenges and successes. This feedback receipt and delivery, such as feedback arrangements, mechanisms and methods from/to individuals, include not only on FMM requirements for specific task, but also the overall FMMP framework, structure and implementation. It is also important that the groups and individuals at all levels in the organisation are open, honest and responsive to feedback received to avoid inhibiting effective communication. Communication in every direction (both vertical and horizontal, as depicted in Fig. 15) is a key aspect of an effective FMM and associated programme, process and procedure implementations.

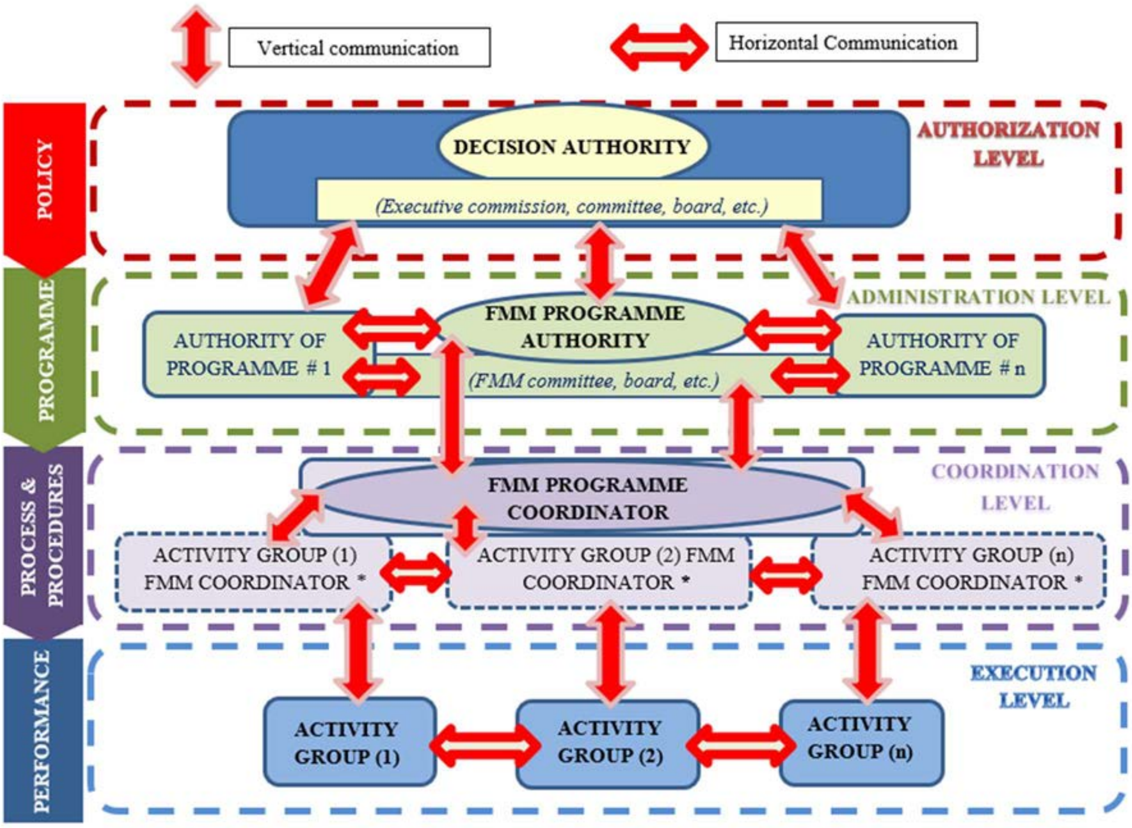

FIG. 15. Typical interfaces and communication between and among levels for foreign material management (FMM) activities. (Only to illustrate communication types. The specific roles, responsibilities and activities shown in Fig. 15 will be further discussed in Section 5.4.1 and Section 5.6).

Vertical communication is generally essential in the communication of corporate commitment, FMM policy and FMMP expectations and needs in order to permeate through the organisation and for the organisational alignment on the FMM principles. As such, timely, clear and consistent communication by the senior management is necessary in order to have everyone in the organisation to understand and to consistently and collectively adhere to the commitment, FMM policy and programme expectations.

Horizontal communication, whether between the organisations or between the individuals, builds up and fortifies individual or team role, responsibilities, situational awareness, ownership and learning/informing elements of FMM and FMMP. The horizontal information exchange also maintains and enhances the organisational and individual interfaces prior to, or during, the conduct the activities and ensures that all involved parties exchange the needed and correct information about the activity, work area and the status and progress, in a timely and orderly manner such that miscommunication, misunderstanding, omission and delay of information are avoided.

In either direction, both formal and informal communication methods and tools could be utilised for vertical and horizontal communication of FMM and FMMP aspects. Typically:

— Formal mechanisms include interface documents, procedural review and check requirements, scheduled and required meetings, periodic programme and task review

sessions (including required pre and post job briefings), checklists, flowcharts that are part of the work orders and instructions;
— Informal mechanisms may include prompt verbal feedback to line colleagues and leaders, discussions between internal and external points of contact, occasional discussions within groups and senior management, activity knowledge or observation notes (these notes may be a formal mechanism, if they are required by the programme, in some organizations).

In all organisations, both formal and informal communication are utilised for vertical or horizontal communication — both in verbal or written forms — depending on the purpose, significance, timeliness and extent of the information and the interface between the delivering and receiving individuals and/or groups (for example, vertical communication of FMM commitment, policy and expectations could include informal methods, such as senior managers communicating face-to-face with presence and visibility at the activity areas, as well as in training classroom, group/staff meetings, shop floors. Similarly, horizontal communication could be in form of formal FMM plan review and commenting or informal group discussions between organisations). In effective organisations, however, it is ensured that these dependencies are clearly defined and described as to their applicability and boundaries and conditions.

Regardless of what method is used vertically or horizontally, the purpose and content of message need to be clear such that the receiving party ought to know why the information was provided and understand and use it correctly. On the other side, the providing party needs to make sure why the information is to be used and confirm that the message is correctly and appropriately received and understood (for example, by practicing three-way communication technique). In order accomplish these, the interfaces need to be defined such that the nature and characteristics of information exchange (e.g. counterparts, place, type and direction) is clear and integrated.

Moreover, ownership and management responsibilities and accountabilities of the FMMP are assumed by the individuals based on the levels of effort, i.e. administration, coordination and execution levels, similar to that is shown in Fig. 15. Considering these combined/corresponding efforts of FMM and FMMP and associated information exchange, it is also beneficial to establish interfaces at and between all levels to ensure all involved parties are informed on the background, requirements, expectations and instructions on the matters related to activities in an integrated manner. The types of interfaces may be:

— *Required communication interfaces:* These are the interfaces that are used to convey the information required, by laws, regulations, owner requirements such as the interface between the owner/operating organisation and regulatory authorities on compliance, assessment, approval and oversight;
— *Informative communication interfaces:* These are the interfaces that are open to exchange of FMM and FMMP related information between the organisations, associated with activities which have impact or involvement of individuals or groups in these organisations. For example, a particular maintenance activity needs to comply with the FMMP requirements and expectation as well as the radiation protection programme requirements. The activity also needs components and their timely availability for installation. As such, activity organisation would be closely associated with, and would have an impact on, other organisations, such as radiation protection and warehouse which also need to comply with their applicable FMM and FMMP requirements. These organisations need to involve each other in the activity. Additionally, it could be necessary to interface with other proxy organisations, for example, FMMP administration

staff. As such, informative communication interfaces are established and used to convey and exchange information and knowledge so that all parties can make balanced and informed decisions and efforts in their tasks.

It is critical that these interfaces need to be carefully controlled by administrative procedures to prevent omission of required and expected communication and the omission of necessary information.

4.10. PERFORMANCE IMPROVEMENT PROCESS

A learning organisation not only learns from errors, but they embrace opportunities to improve by proactively identifying possible gaps. The non-conformance and event reports and metrics relevant to FMM should be reviewed periodically to identify any recurring issues or adverse trends. Corrective actions should be established to address both the direct and root causes of FMI events. Effectiveness of the corrective actions should be monitored and reviewed to ensure they eliminated the cause. Recovery action plans should be developed for those actions proven ineffective. Additional information on process improvement can be found in Reference [48].

5. ESTABLISHMENT AND ADMINISTRATION OF FOREIGN MATERIAL MANAGEMENT PROGRAMMES

A programme and its associated processes for FMM need to be defined, established, described, documented, implemented, assessed and continually improved in accordance with industry requirements and standards, as well application of industry (and non-industry) good practices and of learned lessons. Requirements for a management system, such as provided by IAEA Safety Standard for safety leadership and management [49] and associated IAEA Safety Guide for management systems [50] (and its application methods [45]) can be utilised, with a graded approach [46]. Existing industry guidance provided by nuclear industry [9−11] and non-nuclear industry [23−38] entities can also be utilised to develop the FMMP and its processes and procedures. Available nuclear industry OPEX collected and reported by IAEA's IRS report and other organisations [5−13] would be very beneficial and could be considered when the processes are established, improved and/or optimised.

Regardless of methods or tools used for its development and optimisation, firstly, the FMMP ought to be aligned with the strategy, character and goals of the organisation and be designed to meet or exceed the requirements and expectations of corporate FMM commitment and policy. The FMMP and associated processes and procedure, of course, need to take into account the organisation's culture and build the programme accordingly.

Secondly, the main goal of the FMMP has to be to achieve and enhance safety and performance by:

— Bringing together in an integrated and coherent manner, all the requirements and expectations for managing the FM towards *foreign material free operation* and *no-adverse effect of foreign material* on safe, reliable and efficient operation of the plant;
— Describing, clearly and precisely, the planned and systematic actions necessary to provide adequate confidence that all these requirements and expectations are satisfied.

Finally, the effective implementation of a proactive FMMP relies on applying the programme elements and continuously reviewing and improving those. The implementation is a perpetual process that counters common and observed weaknesses and that builds on recognised strengths and new learnings. It requires that:

— A clear and integrated strategy be adopted by plant owners and senior management;
— Programme commitment, policy and expectations, and any changes to those, are continuously and timely communicated;
— Appropriate organisations and technical and administrative processes be in place;
— Proper tools and resources be available.

It is evident in the nuclear industry that the utilities (or project owners) who are demonstrating high levels of safety and performance (high capacity factor, O&M costs effectiveness) and long service life have common characteristics, as follows:

— They introduced and implemented proactive management systems and programmes for their processes, including FMMP, early in the lifetime of the plant, prior to operation;
— They anchored culture for ownership and dedication for improvement of programmes, processes and procedures;

— They include their contractors and vendors agree and follow adherence to the same standards and principles, including those for FMM, as those implemented by the project/plant/site staff more effectively and effortlessly.

The FMMP can be anchored in FMM related project/plant processes, procedures, work instructions, human performance tools in an integrated and precise manner, including the following rules:

— Related procedures and instructions provide guidance for FM controls and prevention of, and protection against, FMI events through all phases of the work process and activities;
— Procedures/instructions clearly describe the elements and fundamentals of FMM during the activities, including their administrative and technical basis;
— Interfaces and associations between the FMM process and other processes (such as housekeeping, testing, maintenance, work control, work planning, training, corrective action process, chemical and lubrication control programs, radiological controls, policies and principles) are clearly defined in the procedures/instructions;
— Procedures/instructions define how the activity can be carried out in a controlled manner and, where appropriate, identify the steps to be taken in the event of a loss of FMM; and more importantly;
— Instructions in the process documents include, describe and explain the utilisation manner and conditions of specific human performance practices and tools for FMM. It is observed that the organisations that have strong human performance practices and regularly and habitually utilise 'event-free performance tools' have fewer FM related incidents.

This Section provides a collection of common methods for specifically implementing and improving FMMP observed in good practicing organisations, including non-nuclear industry entities where foreign material/object/matter/body is critical for design, construction/manufacturing, validation/commissioning and O&M. As such, it can be used as template guidance for owner/operator organisations who are establishing and implementing a new FMMP, as well as a guide for successful continuous improvement of existing FMMP in order to identify the weak elements of their programmes to be strengthened and to recognise strong aspects of their programme to build upon and share with industry (nuclear and non-nuclear) peers.

5.1. MAKING COMMITMENT

As discussed in Section 4.1, the first and most important step of effective application and execution of FMMP is to start by making an executive corporate level commitment to *foreign material free operation* as a part of ensuring nuclear and radiological safety and efficient and economic performance. This commitment by the executive corporate level management is the genesis, foundation and the backbone of understanding, agreement and alignment throughout the organisation and it needs to be:

— Sincere;
— Initiated at the corporate level with a purpose to achieve success in effort for *foreign material free operation*;
— Professed and demonstrated by the most senior level to flow down and involve the entire organisation;
— Towards an excellent performance in achieving *no-adverse effect of foreign material* in all relevant activities as it is important for the safety and performance of the NPP and for

the health and well-being of individuals (i.e. commitment to each plant personnel, as well as to the internal and external communities).

As the corporate strategy, character and tradition are the drivers for safe, sound and aligned personal and organisational decision making throughout the entire organisation, this commitment sets the ‘meaning’ of FMM for every task performance. Furthermore, it sets a value for FMM for the allocation of resources (financial and human), setting plans, schedules and quality of work practices, as well as attitudes and behaviours.

In the commitment to *foreign material free operation* for safety and performance, the corporate executives and senior managers adopt, agree and reflect the vision and desire for FMM to be understood and followed by the rest of the organisation associated with the following key attributes:

- Priority of nuclear, industrial, radiological and environmental safety;
- Excellence in maintenance and operation, as they directly relate to industrial and radiological protection of staff;
- Vigilance in efficiency, effectiveness and economics in electricity generation;
- Agility and timeliness with consideration of plans and schedules;
- Longevity, reliability, availability of equipment and other assets during the entire plant lifecycle.

The commitment that is established, documented and communicated to the entire organisation serves to make every person in the organisation understand, own and value his/her role, priorities and responsibilities for the application of FMM in everyday job within the context of corporate vision — towards safe, reliable and efficient generation of electricity with quality and longevity, in an aligned manner.

Therefore, the corporate commitment to excellence in operations typically includes expectations and values for controlling and managing FM and minimising and eliminating FMI hazards and events within, and consistent with, the corporate vision for prevention of FMI events. Such commitment is to agree that no FM affecting safety and performance enters or exists in the plant SSCs in all phases of the plant’s lifetime.

Per this commitment, the organisation’s management adopts and demonstrates an obligation to achieve *foreign material free operation* by prevention, protection and mitigation of FMI events and to continuously improve the FMMP, during the entire NPP lifecycle. The commitment emphasises the importance of FMM during the plant activities and of potential impacts from an ineffective FMM resulting in adversity in safety, reliability and plant performance.

5.2. SETTING AND PERMEATING POLICY

For an effective FMMP implementation and execution, it is essential to establish, document, permeate and demonstrate the corporate commitment to excellent safety and performance by a clear and concise corporate level FMM policy to state and adopt behaviours and values of/for/in *foreign material free operation,* as discussed in Section 4.2.

The FMM policy is the guidance and the alignment of the organisation to the importance and value of being aware of FM and of its impact on the plant safety and performance. More importantly, it asserts and exhibits in writing that such behaviours, values, attributes and actions and their consistent and customary consideration and application to every task by the everybody in the organisation are also sincerely valued and appreciated by the management.

The FMM policy statements declare a sincere statement and adherence to an excellent FMM performance in all activities, as it is important for the safety and performance of the NPP, as well as the health and wellbeing of plant personnel and external communities. The policy has to make it plain and simple that nuclear plant safety has the utmost priority, overriding, when necessary, the demands of production or project schedules and that no FM impact on safety is an important part of it.

As such, the policy needs to be *clear and concise* with credible and realistic implementation and it needs to include main terms and elements of the programme, such as:

- Expression of corporate and senior management commitment to ‘foreign material free operation’;
- Statement of rational for, and objectives of, ‘foreign material free operation’;
- Core values and principles of FMM as to safety, reliability and performance;
- Framework for management system and the place of overall programme in the management system;
- Management structure with assignments and responsibilities within the organisation for FMM;
- Clear definition and criteria for application of priority and graded approach to identify, acquire and use of FMCs (e.g. application of stringent controls to safety and performance critical equipment, proportional controls when the consequences of FMI events are relatively tolerable);
- Assurance of allocation of resources based on priority and graded approach accompanied by the associated (and well defined) threshold and criteria FMMP implementation and application;
- Specific requirements and guidance for implementation of FMMP internally and externally (to the owner’s organisation, such as vendors, suppliers, contractors, etc.).

It has to be kept in mind that the policy needs to contain the definitions of the strategy, requirements and expectations clearly, as they will be the framework and the basis for establishing processes and writing the governing administrative procedure for the FMMP and associated implementing procedures, as well as the values and behaviours. Clarity has utmost importance in a policy since it will provide an understanding and alignment which will define the FMMP and the associated processes and result in comprehension and progression at all levels of organisation. Conversely, an unclear policy, and its unclear requirements and expectations, will lead to confusion and disarray which, in turn, result in the regression or implosion of the programme.

Furthermore, the policy needs to include descriptive (not prescriptive) overall guidance and the alignment for the control and implementation such that the FMM requirements, risks and control measures are defined at the beginning of the plans/activities/tasks and they are made part of the process until the final state.

More importantly, managers at every level genuinely show their commitment to terms of this policy and understand their self and direct interest and roles in those terms. They assume the championship of the policy and show active support of FMMP, since they carry a vital role in demonstrating and disseminating the corporate vision and commitment to the control and management of foreign material with the understanding of its essentiality for safe, reliable and efficient operation. They sincerely pay attention, be visible and regularly review/listen and involve in the improvement of FMMP and associated processes by 'demonstrating and communicating by action' their continuous commitment and support to their staff and the policy. For example, it is a good practice for managers to communicate face to face with presence and visibility at the activities and areas such as training classroom, group staff meetings, shop floor, has the strongest effect on gaining trust and sharing values and vision, noting that these need to be their sincere and wanted interactions.

5.3. ASSESSING AND ENHANCING CULTURE

As mentioned in Section 4.3, while adherence to the FMM procedures is necessary and essential for a successful implementation and execution of a FMMP, they are insufficient if implemented and applied impersonally. Furthermore, without an individual and organisational culture and associated behaviours of collective awareness, responsibility, accountability and ownership, a mechanically and administratively implemented FMMP will not go too far. Successful FMMPs have one significant common characteristic: everyone in the organisation, individually and collectively, think and act to contribute to the management of foreign material and to the improvement of the FMMP towards *foreign material free operation*, and they do so, "not because they are told to do so, but they want to do so" [51]. The importance of this characteristic can be seen by the contrast observed between two actual plants, in the following examples:

> "One NPP requested assistance from industry groups to establish a new and effective FMMP and the associated governing administrative procedure. When this NPP representative presented and explained what attitudes/habits their employees have been demonstrating for years, it became evident for everyone in the meeting that all personnel at that plant have already had the key personal habits, such as:
>
> — Clean as you go;
> — Housekeeping and cleanliness;
> — Questioning attitude;
> — Awareness and alertness;
> — Observation and interpretation;
> — Issue reporting with suggesting solutions;
> — Following and seeing the results of their observation for areas for improvement.
>
> It was clear that all plant personnel have been thinking and behaving so without an established FMMP, and associated processes and procedures, and more importantly, without any formal requirements to do so".

For such organisation, establishment of a FMMP would only consist of writing all these already being demonstrated behaviours and actions (which have been self-compelled and peer-supported) into documents only to formalise the processes and procedures by detailing the application of methods and activities of organisations around those already existing and practiced values.

On the other hand, another NPP organisation presented a contrasting case:

> "One plant had all their procedures and processes comprehensively established in accordance with the industry guidance and best practices;

> however, despite the enforcements, bonuses and penalties, unintended violations of procedures and lack of key attitudes and transparency continued to exist and grow. The plant staff became concealing, not reporting near misses, or even events, and self-deficiencies for fear of blame and discipline, or for 'not to lose bonus at the end of the year'. Furthermore, they became discouraged to provide suggestions because 'nothing would be done about it' or 'nobody would listen'. FMI events continued to occur in this organisation although it was following the good industry practices in procedure writing and maintaining a large number of procedures".

The difference between these two organisations is the behaviour and attitude of an organisation, not only in FMM but in all aspects, activities of a daily life in NPP, i.e. its culture, that was (or was not) built or was built naturally (or unnaturally).

Building culture in an organisation is not a mechanistic or rule-based process [44, 52]. It involves beliefs, values, habits and attitudes, and therefore necessitates to learn, teach and demonstrate what a 'good' behaviour looks like and how it is worthwhile to have them not only at work but also at home.

There are key processes and attitudes, based on certain 'good' practices for observation, enhancement and anchoring certain traits and habits associated with a good FMM culture. The following Sections address building some of those aspects and traits that are applicable not only to FMM culture, but basic elements of NPP organisational behaviours and habits. These are keys characteristics of an effective FMMP ensuring everyone in the organisation (including the plant vendors, suppliers and contractors) knows, understands and agrees that, in every task they perform, they can actively and personally contribute to the effectiveness (or failure) of the FMMP.

5.3.1. Awareness

Awareness is the ability to know, observe, recognise, understand and interpret [one's] state and relation regarding a subject matter and surrounding, [his/her] actions related to that subject matter/surrounding and the reasons, results and consequences of his/her actions (or inactions). Awareness in FMM goes beyond having information and knowledge and it is in three folds:

- Observing and interpreting FMs, FM paths and FM targets as to causes and effects on own, team's, company's state, as well as the public and the environment, at large;
- Understanding and recognising the reasons for, and goals of, FMM and FMMPs in big picture and observing and exploring opportunities in their effective application and further improvement in every relevant activity;
- Understanding, recognising and demonstrating own merits, skills, competencies, experience, knowledge areas of contribution and influence that is useful and supportive for FMM and FMMP.

In organisations with effective FMMP and FMM, everybody (leaders and workers) knows, recognises, acknowledges and understands that the anticipation, observation and interpretation of FMs, FM paths and FM targets are the cornerstones for achieving safe and efficient performance of their place of occupation — and more importantly, for protecting themselves and their colleagues. They also understand and recognise the place, merit and importance of their role, responsibility, skill, contribution and influence in safe (and reliable and efficient) generation of electricity.

The first building block for achieving such understanding and recognition in a plant/project is to clearly specify '*who* (individually or as part of a team) *does what, why, how and when*' in support of managing FM and prevention of FMI events. It is equally important also to value and recognise everybody's roles in the programme as an influencer as well as a contributing ambassador. As such, everybody could understand and agree that they are collectively both a donor and beneficiary in the success of the programme.

Some of the good practices in increasing foreign material awareness include:

- Promotion of FM awareness such that the extent of consequences in case of 'failure' affecting not only plant safety and production bottom line, but also safety of working environment for individuals and their colleagues, including the potential impact on their community. Providing examples of nuclear (and non-nuclear, e.g. aviation, food, medical) industry FMI events and resulting impact on those organisations, industry and surrounding community can be used to increase awareness of failure;
- Effective communication mechanisms and defined interfaces are in place which ensure the alignment of everyone in the operating organisation regarding FMM principles. Effective communication mechanisms are discussed in Section 5.5.10 also include the use of communication devices such as posters, signs, videos, websites, newsletters, etc. Consideration also should be given to communicating good practises and actions that have given good results.

5.3.2. Ownership

Ownership is mainly the feeling of being strongly associated, familiar and identified with a task, activity, group or place because one has knowledge, connection, belonging, interest and expertise, such that those tasks are something that one can personally and customarily invest in with his/her time, skill, idea, energy and other personal contributions.

Ownership is not associated with assignment or possession[7], i.e. but rather *assumed position of responsibility and accountability* for a task, area, team, idea or issue, when a person can feel comfortable and confident:

- To have a control/charge of it;
- To be able to conduct and make decisions about it;
- To have an influence on it; and, at the same time,
- To be able to do so *autonomously* with self-judgement of how well he/she carries out the tasks and how he/she stakes own activity.

This assumption of responsibility is taking initiative to accomplish things with pride and trust, self-reward, self-challenge and self-accountability, i.e. it is the reply: *'I can do it, you can count on me'* to *'we need someone to take ownership of the issue'* request (either from management or from colleagues, or more importantly from self), instead of a reply like 'it is someone else's problem/job'.

[7] This *feeling* of 'owning' is different than 'possessing' something physically or financially. Although both of these uses 'my' or 'mine' to describe, the ownership is more emotional, such as 'my town", 'my neighbourhood', 'my family', ''my team', 'my job', 'my wheelhouse', i.e. things, people, places that one can identify and feel a part of if owing to his/her knowledge, connection, interest and expertise.

In ownership; however, autonomous does not mean that the person works alone and does not let others be involved, as there may be other contributors or resources for the task although it is under one's ownership, for example, when working with innovative ideas, since the person who assumes the ownership may not have time or some of the scope may require expertise and efforts of others to bring it to practice. Autonomy, rather, means someone (a manager, teammates, colleagues, etc.) has confidence and trust in one's capability, capacity, judgement and decision making, as well as his/her being responsible and accountable for himself/herself.

Here it should be noted that, this 'confidence' and 'trust' need to be established in both directions. The autonomy is provided by the management by trusting the person's own responsibility and self-drive towards producing good results in accordance with the organisational strategy, i.e. he/she will '*do the right thing at the right time*'. On the other hand, the employee earns the trust by demonstrating and affirming that he/she works to bring positive results, and takes appropriate actions towards those results, as an obligation to the organisation's goals and strategies, with responsibility and accountability. He/she shows that he/she works to bring results for organisation's/team's goals, in addition to his/her own goals. He/she also needs to have trust in management and colleagues that the work, in which he/she is investing time, skills and effort, will be valued and he/she will be provided necessary resources accordingly with the importance of that task that he/she sees.

Overall, mutual trust, responsibility and accountability when applied sincerely by both sides, create a feeling of being connected to, associated with, and important for all sides, i.e. ownership.

Some of the good practices in increasing FM and FMM ownership, responsibility and accountability include:

— Management expectations are clearly defined, communicated and genuinely demonstrated throughout the organisation by appropriate policy, personal commitment and practice and are followed up and recognised through observations — by the management and the frontline — and reinforced by peer coaching and continuously improving behaviours;
— Clear, reasonable and achievable FMM standards, principles, definitions, procedures, requirements and guidance/training for all activities. These provide the staff with an assurance and knowledge of what they and the others are responsible, qualified, vulnerable and/or accountable for preventing and controlling the FM and protecting against the consequences of FMI event;
— Clear criteria, objectives and targets to measure success (and failure) with prompt feedback mechanisms. These should be not tied to a reward or punishment goal, rather they should allow every individual and group contribute to the timely and constructively learning and improvement in prevention and control of the foreign material hazards and events in the plant/project activities;
— Practicing effective observations for improvement in the area of ownership, responsibility and accountability, including: Staff are comfortable with being observed; observers understand and knowledgeable of what they are observing; in peer and management observations, everyone is comfortable with coaching and correcting (or being coached and corrected).

5.3.3. Cleaning and housekeeping

Not only for a successful FMM and FMMP, but also for every activity that is performed in a plant/project, everyone has the same awareness, ownership, responsibility and accountability for minimising hazards by keeping their equipment and workspace clean and orderly during their tasks. By just observing general action of employees in cleaning up their environment in and around the plant (walkways, hallways, staircases, coffee break rooms, shop floors, etc.), such personal trait is one of the easiest to recognise and can easily be confirmed as the reflection of organisational culture for the cleanliness of equipment and workspaces.

'Clean as you go' is the key work ethic and habit of housekeeping and cleanliness demonstrated by continuous behaviour of removing debris during an activity to prevent creation, accumulation or transportation of FM. This, in turn for FMMP, ensures that the potential for FM entry into the system is controlled and minimised/eliminated prior to, during and at the end of the activity. 'Clean as you go' can be specifically stressed and enforced during a specific task, for example, by work-order/procedure steps for initial, periodical and final debris removal; however, it has to be a habit of everyone in the organisation during routine daily work and environment.

Housekeeping is also a habit of having and maintaining the equipment and the area orderly in order to maintain an organised, uncluttered, non-impeding fashion.

For a successful FMMP, it is necessary that personnel are habitually aware and responsible for cleanliness of work area, SSCs, equipment and tools and for their utilisation and maintenance in a clean and orderly manner. As such, these habits are essential to minimise the creation and hazard of FM. Everyone in the organisation has the same responsibility of minimising hazards by keeping their equipment and space clean and orderly during their tasks, and furthermore, in their general behaviour and environment at the plant/site. Hence, housekeeping and 'clean-as-you-go' are the foundations for successful FMM.

As aforementioned, *clean as you go* and *good housekeeping* behaviour, in general, is very easily observable habit in a workplace and organisation. For example, in some NPPs, any debris is noticed, and it is acted upon immediately by personnel such as picking up and disposing of the items, notifications, coaching, reporting and/or preliminary assessment, when necessary. People in the organisations with strong 'clean as you go' and good housekeeping culture not only pick up items that they have dropped or left behind, but also items inadvertently dropped or left behind by others. It is also an evidence for good culture to observe whether a jobsite is left after the completion of the activity as clean as (or cleaner than) when work is started. Some other observations of good housekeeping practices include:

- Personnel carry only needed items in the area;
- Items are pre-staged and used in an orderly manner;
- Unused items stored securely, or removed from the area;
- Personnel at jobsite as well as the personnel in the nearby activity areas are aware of impact of their uncleanliness or disorder on others, and thus, act on restricting interference;
- Not only the personnel storing, maintaining and providing tools but also the performers ensure cleanliness of tools and equipment, e.g. free of grease or loose paint, used for task.

Also, some good practices for reminding and anchoring habits and behaviours of housekeeping and 'clean as you go' behaviour include:

— Pre-requisites to perform area cleaning to meet or exceed the defined cleanliness standards and requirements before the opening of systems and components;
— Instructions to perform removal of foreign material or other debris generated from the activity at predefined hold-points and/or intervals;
— Expectations to remove any possible foreign material with an immediate potential to ingress to the system as work progresses regardless of predefined intervals or hold points are reached;
— Instructions to perform area cleaning at the end of the activity to meet or exceed the defined cleanliness standards and requirements before the closing of systems and components, or before the start of the next activity on the same system or component;
— Instructions to clean the area of any debris and ingress paths when work discontinues for a period of time such as those at end of shift, a long activity breaks due to waiting for the sequence of simultaneous activities, inspection hold point, unclear/conflicting procedure, etc.;
— Requirements, standards and expectations for housekeeping, cleanliness and material condition are clearly and explicitly established in plant/project documents including the basis for those requirements (noting that the initial and continual training scopes and covers those for owner/operating organisation's staff and contractors);
— The leaders routinely and genuinely, bolster the standards and expectations as part of their supervision, oversight and observations in the field during the activity, as well as prior to the performance of activities.

It must be noted that in some Member States, housekeeping, cleanliness and material condition programmes are required by regulations and those are interrelated with the FMMP. All of these programmes consist of the procedures and processes put in place to ensure that facilities, equipment, work areas and access routes are kept in good condition, in accordance with the design intent and operational and regulatory requirements of the facility. However, it must also be noted again that a mechanically and administratively implemented programme will not excel unless everyone in the organisation habitually acts to contribute.

5.3.4. Observing and reporting for improvement

Reporting in another main cultural behaviour/trait which is primarily driven by the personal and organisational understanding and recognition of its value and importance for learning, informing and improving. Therefore, it needs to be embraced by everyone with an intention to increase personal and organisational awareness (see Section 5.3.1).

Unfortunately, in most cases, reporting is associated with adversity, i.e. something bad happened, it meets a given threshold for reporting 'requirement' and it is a mistake that needs to be 'corrected'. Even more unfortunate, it is tied to some kind of reward and/or penalty system for performance, for example, number of event reports is being (or being tied to) a performance indicator that measures success/failure of a person, team, organisation or overall plant (such as its position in the industry) in a certain area, such as FMM. Considering that the first person, team, organisation or plant that witnesses the event is actually the person, team, organisation or plant who made the mistake or caused an adverse incident, the use of reporting as their performance, particularly to penalise them (or to have them go unrewarded), may have them hesitant to report or incite them to fix it at the spot and move on, such that 'it did not happen because no harm was done'.

However, an organisation with a good culture sees reporting as a learning opportunity from *any* experience, not only from bad ones but also from good ones, just like one does in everyday life as the best learning tool. Such organisations understand that first step towards learning from experience is reporting in order to share both good and bad experience with others for betterment of the same/similar tasks in the same organisation and/or same industry (or other industries). In that context:

— Report of a good experience with FMM encapsulates something that *went well* (and why it went well) and doing the same next time or making it a standard thing to do in the same (or other similar) process will make the FMMP better;
— Report of a bad experience with FMMP captures something that *went bad* in order to open an inquiry to analyse and understand 'what went wrong' and 'why it went wrong' such that the gaps and appropriate improvements to close those gaps are known to make the same (or other similar) processes and the FMMP better.

As it can be noted, in both types of reporting, 'betterment' is the common objective, i.e. reporting aims to learn, inform and improve. Such collection of good and bad experiences provides not only lessons learned and betterment, but also means for measuring the health of FMM programme, processes, procedures and practices, as well as, the organisational culture. Moreover, reporting does not always have to be formal as it can be accomplished by scribbling in personal notes, and later in knowledge sheets, what is learned from that day or activity. It is a great practice to note down the ideas that can improve the activity performance or personal skills of own or others for the next time.

It should be, very importantly, noted that the learning from good or bad experience apply to everyone, particularly the leaders (from first line supervisors to senior managers), since the most effective leaders learn from the good and bad experiences of their own, of groups, organisations and industry to improve their, and their workforce's, skills, attitudes and competencies.

Furthermore, their higher level view of reports improves communication within and with outside organisations enables leaders to obtain more information by asking other leaders for their perspectives, opinions and judgements, and subsequently, to utilise collected and analysed data to determine future organisational actions, strategies and tactics for better performing FMMP, processes and people.

5.3.5. Attending by trending

It can be seen in the previous Section that there is a difference between reporting a good experience and a bad experience such that the latter one involves more in-depth review and analysis of something that went bad. Something going bad, i.e. the 'incident', initiates the question 'why it went bad' and inherently means that there were adverse underlying reasons to make it go bad.

No matter how successful a programme is, or has been, due to the human nature and physical unknowns, there is always a potential for an act or condition that may result in incidents and majority of these acts and conditions do not happen randomly. The underlying reasons to create that act or condition (i.e. errors/mistakes) can be traced to long standing issues that have gone unnoticed — primarily owing to a process failure that needs to be identified and corrected/improved.

This fact that errors will occur needs to be accepted by the management and personnel, but it is essential to acknowledge that remediation and reaction to the errors are more important than the errors themselves. As rightly stated by James Reason:

> "The most detrimental error is failing to learn from an error" [53].

In that manner, it needs to be understood by everyone at site (or plant/project) organisation that it is more important that the errors/mistake/failures are not repeated and, if repetition inevitably happens, the reactions to the next occurrence is improved and consequences are minimised and/or mitigated. Committed errors ought to be acknowledged less as a matter of concern than as a source of learning and experience from which the owner/operating organisation and the industry can benefit. This acknowledgment is essential due to the facts about failures that:

— They are lessons learned that indicate that some elements of the programme are not working well and in need of improvement in order to prevent recurrence of an FMI event in case of a failure, or escalation into an FMI event in case of a near-miss/close-call;
— When let go unreported and/or unevaluated, a potential sequence will be the recurrence of errors and, very likely, with more serious consequences to the plant/site/station equipment and personnel;
— They are the proof of vigilance, anticipation and questioning attitude which are the positive traits of staff.

Therefore, collection, trending and analyses of bad experiences, i.e. 'incidents', as well as collected expert and leader perceptions, opinions and judgments on an incident, lead to the identifications of specific areas where the gaps lay and to those areas for improvement. In addition to reporting, incidents need to be analysed and trended for continuous improvement of FMMP and associated processes, procedures and practices. The extent of analysis depends on the complexity and severity of an incident, and hence recording and trending need to identify the type of incident. Regardless, any classification and trending need to encompass all the incidents that could be a learning opportunity.

Generally, all acts or conditions (failures) result in actual, potential or avoided consequences. Accordingly, FMI incidents may be defined and classified in the following manner:

— *Event* (failure with harm): FM related incidents that occur due to an act or condition and cause harm to safety or performance,

— *Near miss* (failure with 'dodged' harm): FM related incidents that occur (or would occur) due to an act or condition, but do not cause harm to safety and performance under the time or situation (e.g. owing to unintended or coincidental defences, prompt recovery/mitigation measures or luck); however, they could have occurred, caused harm, in different circumstances,

— *Close call* (failure with an 'averted' harm): FM related incidents that could have occurred or led to a harm; but their occurrence or consequence was avoided by timely observation, interpretation or intervention.

It should be noted that, there is no 'one size fits all' classification and there are various definitions for incidents. For example, near misses and close calls are sometimes used interchangeably (or they are treated as the same) since they both 'dodged a bullet' in a situation or circumstance, while in some literature, such as Ref. [54], close call has a distinctive definition, as:

> "Any unsafe act (formerly termed irregular working) or unsafe condition that in different circumstances could have led to an accident or personal injury or could have resulted in damage to property or equipment. These are occasions where no one was hurt or nothing was damaged, but this is more by chance than by the application of systemic controls" [54].

Also, a widely used method to trend the events by FMMPs in the industry, have two classifications for 'event', based on the severity of consequences: major (or high level) event and minor (or low level) event. In such classification, a 'major event' is defined as a consequential incident that brings the tasks to a halt, reported and evaluated, while a 'minor event' is a non-consequential incident where the adverse condition is a 'correct as you go' condition. A minor event is reported and disseminated only to increase information and knowledge for FMM and to provide additional data for measuring the health of the FMMP, the organisational culture and plant practices.

For the purpose of this publication, definitions based on acts and conditions that have actual, potential and avoided consequences, and accordingly classifying the FMI incidents as events, near misses and close calls, is particularly useful for two reasons:

— Separately classifying near misses and close calls distinguishes the way one learns from them: reactively or proactively, i.e. realising the hazard and harm after or before the incident, respectively (or, in simple terms, the difference between 'being lucky' and 'being vigilant');
— From OPEX, it can be seen that most FMI events could be predicted from previous near misses and close calls in the same or other organisations with similar programmes.

Again, there is no perfect classification system; however, whatever the classification is, the underlying objective is always *to learn from incidents* and the learning starts with reporting, classifying, analysing and trending them. Accordingly, there is no difference between incidents, whether they are events, near misses and close calls, in terms of reporting them and learning from them to improve the programme, processes and procedures in the next round of Deming's PDCA cycle.

Overall, a successful FMMP and its continuous improvement heavily relies on all employees and industry peers to be encouraged to record, report and communicate all FM events, near misses and close calls, inclusive of observation of minor conditions. Furthermore, it is essential for the improvement of a FMMP to ensure that all FMI events, near-misses and close calls (internal or external to the organisation) are reported and tracked. Accordingly, some good practices for reporting and trending culture are:

— Near-misses and close calls are treated just like events and all failures are reported regardless of their significance;
— Clear requirements and criteria for reporting of issues on FM generation, transport, potential for intrusion are in place and those are communicated to workers as part of the training programme and/or by other management system tools, such as job briefings, observation programme, condition reporting procedures;
— Events, near misses and close calls are documented in the CAP and their causes are evaluated in a graded approach;

- Remedial actions in response to the findings from an incident are timely fed back and incorporated into the programme;
- Vigilance, anticipation and questioning attitude for potential hazards and events are never relaxed, guards are never let down and that complacency is not acceptable;
- Reporting of occurrence and acknowledgment of errors and precursors perceived as positive attitude and trait;
- Personnel reports, evaluates and takes corrective action with honest self-assessment and avoid the attitude that corrective actions (and the FMMP as whole) are 'good enough';
- Observation of challenges, potential hazards, error precursors are fixed, their discovery is recorded and tracked as a potential near-miss;
- Keeping a record of deviations, i.e. 'tagging deviations', in FMMP, processes, procedures, practices and cultural traits that makes following and understanding trends easier and also makes it easier to seek out and find trends of interest (here, it is essential to have the deviation screening groups to have good knowledge about deviations related to FM such that they would be able to address corrective actions to the right organisational departments).

5.3.6. No blaming

As noted in previous Sections discussing cultural traits of awareness, ownership, cleaning and housekeeping, reporting and trending, every individual from the most senior management to frontline needs to observe, identify, report errors and resulting events, near misses or close calls. These actions directly contribute to correct imperfections or improve elements in the FMMP in order to help others, as well as themselves, to avert future problems. Therefore, the value and importance of finding, reporting and fixing imperfection, including the errors and mistakes of their own, are clearly declared to everybody. The declaration has to assure everyone, unless intentional, making errors is in the human nature and that is not something to be embarrassed of or to be blamed for.

The corporate policy, therefore, states and adopts behaviours and values for *'no blame'* principle for people admitting errors/mistakes and reporting events, near misses and close calls caused by themselves and their colleagues.

It is proven by the OPEX that a *'no-blame'* principle works for bringing up deficiencies in the activities and conditions, thus in turn, improves learning from experience to better the programme, process and people. For example, it was observed at one NPP that:

> "The transition to 'no blame' policy resulted in an abrupt and substantial increase in reporting of events, near-misses, close calls, and even minor mishaps, etc., which resulted in the calibration of key performance indicators and criteria to better represent the actual status of performance and safety".

However, also from the OPEX (that was discussed in Section 5.3.4) there are still resistance to declare, agree and demonstrate such a culture trait by a policy owing to big hurdles and resistance to achieve to such level of culture are:

- The concern or even fear of the individuals of blame, penalty or disciplinary actions towards them or their colleagues;
- The concern of leaders that the large number of reports for committed errors, i.e. events or close-calls) indicates (or can be perceived as) 'failure in leadership' and necessitates

blame, penalty, or adverse actions by the management hierarchy or even by the regulatory body;
- The concern of employees that the number of incidents would adversely affect their monetary and merit incentives through their income or bonuses.

Because of such environment, employees tend not to admit errors and not to report near misses or close calls, even events. More deplorably, the leaders (from first line supervisors to senior managers) tend to dismiss incidents when observed or reported by the employees, for the very same reasons. Consequently, under these tendencies by the employees and leaders, organisation(s) slowly start to institutionalise concealment of reporting by manipulation, such as establishing situational, variable/ambiguous or even personal and artificial thresholds for reporting and trending. This is a very dangerous environment and vicious cycle that leads to a real and complete failure of FMMP, and more importantly, it may lead to more FMI events and more severe blame, penalty or disciplinary actions than it would at the beginning.

To prevent and neutralise this environment, the corporate FMM policy has to be based on a ‘no-blame’ principle which needs to be declared and demonstrated at every level of the organisation with everybody knowing and agreeing the following terms of this policy:

- Every human is prone to error. Although the errors committed are important, there are usually more important deficiencies in the programme or organisation than simply and solely an individual causing an event or creating a close-call at specific time, place and activity, unless it is proven to be otherwise, such as a wilful act, a deliberate violation, or gross negligence;
- Reporting errors of own or colleagues are not to blame or assail anybody. They are, rather, the path to know, understand and resolve issues that allowed an error to occur, whether it ended up being an event or could have been an event, such that the error can be prevented in the future;
- Learning the precursors and failed defences of an FMI event, and similarly, the conditions for setting of a close-call, i.e. ‘what, ‘how’ and ‘why’, are more valuable to the programme than ‘who’ in almost all cases;
- Although the number of events or near misses is an indication of inadequacy of the programme and an indication of deficiencies and imperfections associated with it, the number of repeated commitment of errors, with similar events and near misses re-occurring or number of unreported events and near misses that are determined latently are more significant since they indicate an inefficient, declining or even fatal programme and its failed individual/organisation/management that does not systematically improve by learning from errors and which allows their repetitions, or conceal them;
- Performance of an individual or a leader — and associated penalty, discipline or monetary and merit incentives — are not measured based on the error committed but rather judged by the individual’s and organisation’s reaction to the error (such as whether the error was reported or concealed and the causes and associated issues are properly identified, adequately followed-up and timely corrected or dismissed). In other words, the performance criteria are established to reward/penalise the understanding and learning from a mistake, rather than to penalise making a mistake.

5.3.7. Learning and informing

From the above subsections on various traits of an FMM culture, i.e. awareness, observation, reporting, etc., a common theme emerges: Learning. Learning is a fundamental element and the key ingredient of a successful FMMP. In a lifecycle of an NPP, FMM process is never complete and learning and improvement never ends. Thus, the ultimate responsibility of every individual is to observe, recognise, question, identify, report, investigate, assess and apply not only to correct but also to improve which commonly known as ‘double loop learning’ from their own and their colleagues’ activities and behaviours [55, 56]. This responsibility applies to both learning from errors and learning from success of own and others, both inside and outside the owner/operating organisations.

Anchoring the value and willingness of learning in an organisation and sharing own experiences with others, can be accomplished by:

— Utilising the ideas, experiences and concerns of staff at all levels in the organisation;
— Collecting, analysing and applying internal and external feedback and operational experience;
— Regarding any problem or incident as an opportunity to learn and to improve;
— Being critical, especially of rules, procedures and processes for FMM and conduct of activities, in exploration and adaption of better methods rather than apathetic compliance;
— Being receptive and comfortable to learn and inform by coaching and correcting each other and being coached and corrected;
— Sharing experiences with others, exchanging ideas by participating in internal and external, including regional and international FMM group discussions and meetings;
— Seeking out best practices, benchmarking;
— Anticipating issues, extrapolating findings to other possible applicability;
— Investing in building skills, information, knowledge and experience regardless of past successes.

Furthermore, the issues and associated findings and resolution ought to be communicated to the work groups involved and to others in the organisation, as well as the industry (or similar industries) worldwide, not only to disseminate the information but to receive feedback and support. The nuclear industry is an industry that has been keen to share experience internationally and common issues such as FMI events have a considerably high volume and valuable collection of experiences.

5.4. ASSEMBLING PROGRAMME GOVERNANCE AND ADMINISTRATION

As discussed in Section 4.5, an effective FMMP implementation requires use of a systematic and proactive approach that provides a framework and organisational structure for administering and managing the programme and coordinating with all other programmes, processes and activities involving FMM.

The programmatic framework establishes an overarching and common understanding of FM anticipation, prevention, protection, exclusion, evaluation in order to systematically and standardly managing, controlling, monitoring and mitigating FM that has a potential to enter and impact plant equipment and personnel. As such, this framework of FMMP governance and administration mainly addresses:

— Policy and expectations for FMM and FMMP;
— Compelling rules/regulations and compliance requirements;
— Definitions and descriptions of FMMP and FMM aspects, criteria, conditions and boundaries;

— Requirements and processes for planning, implementing, checking, monitoring, performance measuring and correcting/modifying the FMMP;
— Governing (administrative) and standard instructions, methods and tools;
— Programme ownership, roles and responsibilities, internal and external interfaces;
— Interaction and coordination requirements with other programmes.

In accordance with this framework, decision making, governance, ownership and administrative responsibilities and accountabilities for the FMMP need to be assumed by the individuals within the owner/operating organisation. There would be distinct roles and accountabilities for decision making on, and responsibilities for, governing, implementing, maintaining and improving the FMMP at different levels.

When a decision making on, and implementation of, the tasks, priorities and plans occurs, there is a collegial relationship among all departments and all parties to ensure that the decision has a collectively agreed priority and adequacy for safety and quality. This collective agreement, which necessitates an effective coordination, also assures that all concerns are appropriately and completely addressed, including the FMM aspects and concerns that are relevant to the FMMP. Therefore, FMMP governance activities and roles in these levels are particularly distinctive, as explained in the following subsections.

5.4.1. Assigning programme administrators

The owner of the operating license for the facility is accountable to the public (and other stakeholders) for the proper implementation of the plant's programmes, processes and procedures for safe and reliable electricity generation. This proper implementation also includes the FMMP and associated processes, procedures and practices for *foreign material free operation* as a part of ensuring nuclear and radiological safety and performance.

Furthermore, it is the ultimate responsibility of every individual to observe, recognise, question, identify and report not only in the correction of immediate issues but also in the improvement of current and future state of the programme. However, specific ownership and governance responsibilities and accountability of the FMMP are assumed by the individuals based on the levels of decision making, administration, coordination and execution levels, for example, similar to that is shown in Figure 16.

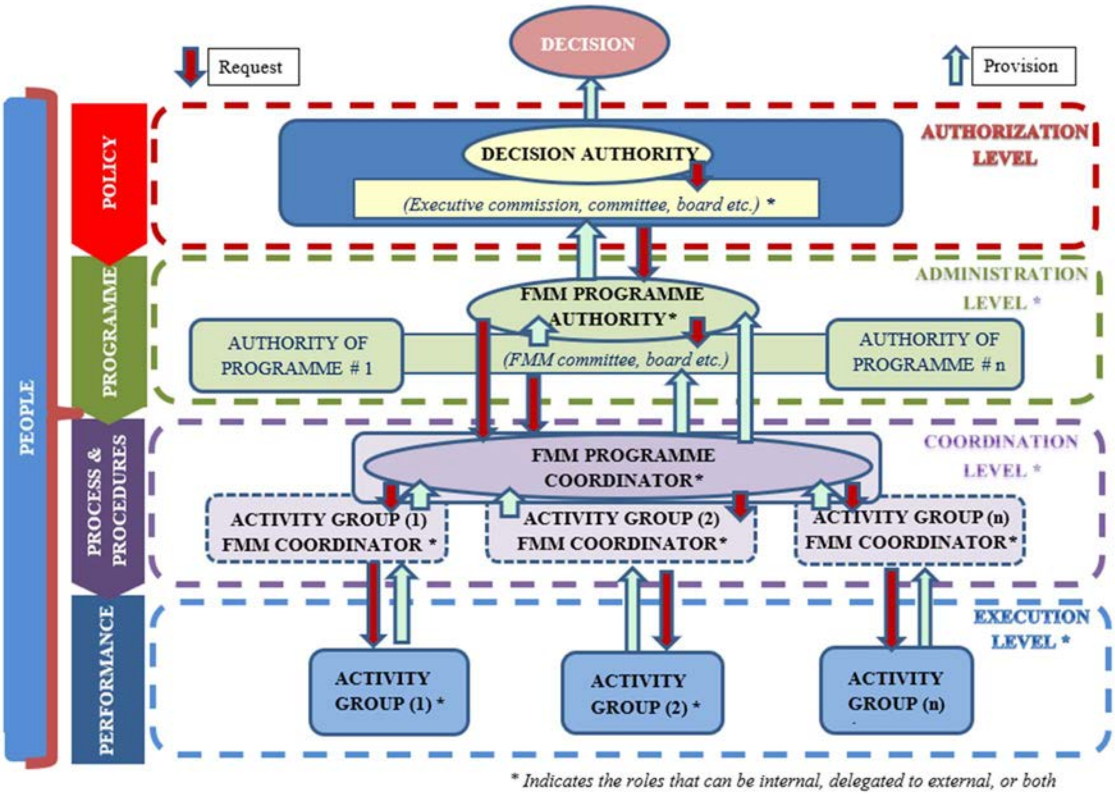

FIG. 16. Different decision levels of foreign material management (FMM) governance and implementation.

Assigning individuals and organisations to these specific roles, responsibilities and activities will be in accordance with the programmatic tasks that are determined to be necessary with considerations of optimum way to perform them, examples of which are discussed in Section 5.6.

It is also important that decision making boundaries and authorities on programme administration, coordination, implementation and improvement need to be clearly established and communicated to the entire organisation to be completely understood and agreed. For example, all project/plant personnel need to understand that FMM Programme Coordinator, shown in Fig. 16, may have some degree of decision making authority that is only applicable and limited to activities involving processes and procedures at the *coordination level*, while carrying role and responsibility for providing specific advice and perspective on the programme implementation and performance.

The following subsection describes key FMMP administrator roles to be filled from the highest-ranking officer down to the people conducting the FMMP related activities, i.e. from the *authorisation level* to *execution level*. Section 5.6 further discusses the specific individual and organisational responsibilities for the programme governors, together with the roles and responsibilities all plant personnel and organisations implementing, maintaining and improving an effective FMMP in every task.

5.4.1.1. Decision authority

The individual who is at the highest level of management on a nuclear plant/project site with the most authority, responsibility and accountability for overall governing decisions for the plant is the **decision authority**. He/she is authorised to make executive decisions on behalf of the ultimate decision making body (plant or project owner, board of governors, executive board/committee, etc.) by considering all the factors and perspectives (e.g. legal, financial and human resource allocation, programmatic, administrative or practical, etc.) at the *authorisation level* in an integrated and binding manner [57]. The decision authority will make decisions in various phases of nuclear power plant/project development and utilisation, starting with consideration of and commitment to nuclear energy in the energy mix and continuing until the nuclear power plant is safely and efficiently decommissioned. Although the title of the highest level may differ in different phases, the responsibility and accountability for making that governing decision need to be assigned to one person at the highest level in the decision making entity at a certain phase of project/plant lifecycle (e.g. government, nuclear power plant project company, nuclear power plant owner/operating organisation). The responsibility and accountability for making that governing decision at a nuclear power plant/site/project is always assigned to one person[8] and cannot be delegated.

In a typical organisation of a nuclear plant/project, the **'Plant Manager'**[9] is the ultimate decision-making person with the most authority (i.e. the decision authority, as described in Section 5.4.1.1) in the plant/site/station. As the person who is the ultimate decision maker and sets the plant/project goals, expectations and policies in accordance with the corporate commitment, the decision authority is also responsible and accountable for establishing and communicating FMM policy, expectations and objectives for all activities performed by everyone (including contractors) at the site. His/her executive decisions will be the foundation of the FMMP framework and will set the direction for administering and managing the FMMP and coordinating with all programmes, processes and activities relating to FMMP.

5.4.1.2. Programme authority

An organisation needs to establish and assign a high-level programmatic and administrative authority role, responsibility and accountability to a person in the organisation who will make management level (i.e. *administration level*) decisions with authority on the governing programmatic and administrative activities. **Programme authority** is the person with this responsibility and accountability for making decisions and directing the administration and implementation of a specific policy and associated programme activities.

As such, the FMM programme authority, typically called **FMM Programme Owner**, determines, describes, controls, manages and assesses FMMP. The responsibility and accountability for owning and overseeing the FMMP is assigned (by the decision authority) to a senior manager in the next layer of management below the decision authority[10] to assume the

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[8] As noted in Ref. [57]: "although it is a common practice to have decision making body (i.e. a group of people such as an executive committee or commission), the decision authority can accept or reject the view of such a committee or commission, as he or she is the person carrying the accountability and authority".

[9] The term *'Plant manager'* can have different titles in different Member States and different NPPs, such as, chief nuclear officer, chief engineer, site manager, executive vice president, executive president, etc. The title used herein indicates the highest level of manager in a nuclear plant/project (e.g. nuclear power plant project company, nuclear power plant operating organisation) who is responsible for overall executive decision making for the site/project which cannot be delegated. Therefore, hereafter, it will be referred in quotation as a representation of the position, not the title.

[10] In other words, the head of leading organisation, for example, the *vice president of operations* of a nuclear power plant organisation as it may be structured for a particular operation phase.

responsibility and accountability for the development and continuous improvement of the FMMP towards *foreign material free operation* and *no-adverse effect of foreign material* goals for safe, reliable and efficient generation of electricity, as described by the FMM policy. Section 5.6.1.2 provides FMM Programme Owner's specific responsibilities, in detail.

As discussed in Ref. [57], unlike the decision authority, the programme authority (but not accountability) could be delegated to a responsible individual (e.g. the high-level technical manager in responsible support entities).

In some owner/operating organisations, due to significant involvement and performance of activities that may have direct impact on FMMP and plan, certain directors/managers may be delegated to carry the ownership and administration level decision making authority for the FMMP as the FMM programme authority, commonly referred as the **FMM Programme Manager** (see also Section 5.6.1.3). This delegation is proposed by the FMM Programme Owner and needs to be approved by the decision authority based on premise of certain department or group having more opportunities for implementation, prevention and improvement.

For example, the construction manager may be appointed to own, implement and assess the programme as the FMM Programme Manager during the construction phase while operations manager may assume that role during the commissioning phase. Similarly, during the operation phase, the maintenance manager, for example, may assume responsibility as the FMM Programme Manager of the plant for the ownership, administration, implementation and improvement of the FMMP towards prevention and elimination of FM hazards and events at the facility.

5.4.1.3. Programme coordinator

The **programme coordinator** in an organisation is the individual with ownership of the information and knowledge to understand and assess the programmatic aspects in decision making at the *coordination level* and the ability to convey and explain the programme's basis, criteria, status, requirements and characteristics, as well as objectives, expectations and good practices. Accordingly, the **FMM Programme Coordinator** is an individual with FM and FMM expertise who is the owner and conveyor of FMM information and knowledge and understands and assess the FMMP aspects to make decision on FMMP coordination. He/she is the focal point and the coordinator of FMMP administration, implementation and maintenance at the site.

The FMM Programme Coordinator is appointed by, and reports to, FMM Programme Owner/Manager and is given sufficient authority and organisational freedom to observe, control, identify, report and implement FMMP activities and measures, whenever and wherever necessary or requested. He/she assumes the roles and responsibilities as FMM expert (or expert 'body') of the nuclear power plant (project and/or plant) in coordination level decisions on the implementation of tasks relevant to the administrative aspects of the FMMP (see Section 5.6.1.4 for FMM Programme Coordinator's specific responsibilities, in detail).

5.4.1.4. Programme conscience

The FMM **programme conscience** of an organisation is a group of experts with ownership of FMM information and knowledge to interpret and to convey the programmatic and technical aspects in decision made at the *execution level*, i.e. at the task level. The programme conscience roles and responsibilities can be delegated to various individuals and/or organisations, such as departmental FMM programme coordinator(s) or departmental, internal and external subject matter experts and consultants.

5.4.2. Establishing administrative framework

A robust FMMP administration would require a framework for the structure, processes and activities that address all the FMM goals of the organisation and ensures achieving those goals in a safe, efficient and effective manner. This framework, which consists of clear objectives, scope, guidance and precise administrative instructions, needs to be established to ensure an integrated, common, comprehensive and coherent implementation of the programme. References [45] and [50] provide guidance for establishment and application of a management system in nuclear facilities and activities. This guidance could be beneficial for the users of this publication to review their FMMP framework and its alignment with the requirements of plant's/project's management system.

Based on the guidance provided in Refs [45, 50], the FMMP framework defining and describes a standard application FMM arrangements and processes, which is aligned and integrated with the plant's/project's management system, need to include:

- Process map of the implementation system, including the interactions between other processes;
- Roles and responsibilities and internal and external interface arrangements organisations that are in each area of activity, including the communication methods and conditions;
- Measurable objectives and measurement of those;
- Specific activities to be performed and controlled, including the individuals and organisations who are responsible and accountable;
- Reference to all supporting and relevant information;
- Identification of key activities and requirements for their planning to ensure that activities are conducted safely, systematically and expeditiously in an integrated manner.

Specifically, the administrative framework for FMMP needs to set, as a minimum, the following:

- FMMP requirements and criteria for process, procedure, performance and people;
- Definitions and descriptions of scales (grades, criteria, levels, thresholds, weightings) and norms (scope, standards, rules) of the graded approach to be used in planning, application and conduct of tasks;
- Activity planning, coordination and communication controls for FMM;
- Methods, concepts, techniques, mechanisms and tools for process, procedure, performance and people, including organisational and human factor matters;
- Key metrics, their basis and interpretations for programme monitoring and measuring effectiveness;
- Organisational and individual responsibilities in the programme and associated processes.

5.4.3. Documenting administrative framework

Once a high level[11] administrative framework of FMMP is established, it needs to be documented and agreed by the management of all organisations, and consequently,

[11] Depending on the corporate strategy and character 'high level' discussed herein would be a Level 2 in the communication structure, as a minimum, in accordance with the levels defined in paragraphs 2.53 and 2.56 of Ref. [45].

communicated in order to be referenced and followed by everyone in the organisation in every task.

Therefore, a high tier programmatic governing document, such as a *descriptive* FMMP administrative procedure, that contains the objective, scope, roles and responsibilities, requirements and expectations of the FMMP is developed to effectively establish, implement, maintain, oversee and improve the programme. This descriptive administrative procedure would also include common definitions, elements, methods, goals and assessments needed to implement and improve the programme and establish the basic reference for the low tier, prescriptive implementing procedures.

Here, it should be noted that, depending on the corporate strategy and practice for procedures, manuals or instructions, the FMMP administrative procedure may also include some *prescriptive* instructions — instead of creating another set of low tiers, discipline/work area/task specific implementation procedures, although it may be advantageous to have a 'one stop' procedure. However, it should be kept in mind, a single procedure that contains both overall administration of the FMMP and the specific work implementation instructions may quickly become a large and complex. When the administrative procedure contains too many prescriptive and task specific instructions, a check sheet approach may be considered to help the administration of specific FMM requirements associated with the conduct of common tasks.

Regardless of the procedural structure and style, the governing procedure needs to document the established framework for standard application of FMMP in every discipline/work area/task (see Ref. [45], paragraphs 2.52–2.62).

The governing documents for FMMP are typically controlled and managed by the most concerned division with FMM under the ownership and accountability of programme authority, i.e. FMM Programme Owner/Manager, as described in Section 5.4.1.2. Contents and instructions of the FMMP governing administrative procedure are agreed by all relevant organisation, including cross-organisational/cross-functional entities, e.g. FMM panels, boards, committees (see Section 5.6.2), as reviewed and approved by their leaders and is endorsed by the highest level of management on a nuclear site, i.e. the overall decision authority, described in Section 5.4.1.1.

This FMMP governing procedure typically documents standard methods and tools for task review, preparation and implementation, such as those for the determination of preventive, protective and mitigative controls based on FM hazards and FMI risk levels (determination of which are also prescribed in the governing procedure with clear definition and boundaries of probability and consequences). These methods and tools are applied in the planning of the activities and to be reflected and used in work processes and in the implementing (task specific) procedures and work orders. It is also important that the administrative procedure needs to establish criteria and prescription for exemptions and deviations from the standard methods.

As such, content of a FMMP administrative procedure would typically be consisting of the following information:

- Corporate policy and/or executive management expectations and goals;
- FMM regulations, requirements, industry standards and codes that compel the establishment, implementation and maintenance of FMMP;
- FMMP objective and scope (and exemptions from scope with reasons/justifications);

— Glossary defining and describing key terms used in the programme, e.g. FM, FMM, FMI, FMC, to set standard terminology and concepts for the plant/project;
— Organisational and individual roles and responsibilities for FMMP administration and implementation;
— Common control and conduct of FMM standards and practices in work activities, such as:

- FMM prevention, protection, exclusion, mitigation, evaluation definition and scope;
- FMRL definition, criteria, methods, tools (e.g. checklists, flow charts) and guidance for assessment, determination and designation of FMRLs;
- Definitions, determination and requirements of FMCAs, including setting up permanent and temporary FMCAs to support/facilitate work, preparing and inspecting equipment, work area, tool, material and parts and activities/tasks, managing and controlling personnel and equipment entry/exit, etc.;
- FMM planning requirements and expectations, including the job area and task preparation methods, tools;
- Training and qualification requirements;
- Methods and conduct of change management, i.e. changes in plans, management and control due to changing plant conditions and activity environment and personnel;
- Human performance requirements, tools and foreseen/recommended conditions of application;
- Identification and references/links to standard forms or tools to utilise in programme implementation, including the guidance on their designation and applicability determination;

— Requirements, criteria and methods for, and conduct of, exemptions/deviations from standard FMM programme, processes, procedures and practices;
— Interface and communication requirements and methods for activities with relevant organisations and personnel;
— Training level and scope requirements, objectives and designation/determination methods to apply FMM training, including graded approach based on functions and skills of individuals and organisations, as well as criteria for task properties, e.g. for complexity, rarity, specialty;
— Incident identification, reporting and resolution requirements, including clear definition and description of organisational and individual roles and responsibilities and applicable programmes and processes:

- Criteria and methods for classification and designation of FMM issues, particularly events, near misses and close calls, for reporting;
- Selection of reporting processes and references to the applicable programmes/procedures;
- Issue resolution request requirements, methods and references to the applicable programmes/procedures;

— Programme health review and assessment requirements, which include:

- Identification of data to be collected and analysed and data collection and analysis methods;
- Definition, description and interpretation of key performance indicators/metrics;

- Requirements for periodic (and special or as requested) programme assessment, audit and continuous improvement action plans, including the conditions for special review and assessment of the programme;
- Definition and description of review and assessment instructions, methods and roles and responsibilities in initiating, conducting, assessing and closing such assessments;
- Requirements and processes for continuous improvement and timely update of the programme;

— Requirements, processes and instructions for mitigation and recovery from FMI events, including clear definition of criteria for mitigation entry and exit conditions, description of organisational and individual roles and responsibilities and applicable programmes and processes;
— Requirements, processes, methods, tools (or reference to those) and organisational and individual roles and responsibilities of tracking of unrecovered foreign material in the design and facility records.

The controls and guidance provided in the governing procedure may also specifically target an activity, an environment and/or the personnel performing activities and, in some cases, may define how the activity overall can be carried out controlled and attentive manner with as low as reasonably achievable risk, as to:

— Special training, qualification and authorisation;
— Special activity plan with exclusive FMC measures;
— Modified activity steps;
— Special tools;
— Increased hold and review points;
— Protections against foreseen events that would adversely affect risk and ramification;
— Heightened area entry/exit protocol;
— Exceptional and expanded storage, transport and use of material conditions;
— Rescheduling of nearby activities;
— Identification of steps to be taken in the event of an FMI to minimise consequences, etc.

Section 5.5 discusses the key administrative controls, and their descriptions, that are developed in the administrative framework and documented in the governing procedure.

5.5. ESTABLISHING AND DESCRIBING ADMINISTRATIVE CONTROLS

Foreign material controls, as a key element of FMM, consist of both hard and soft barriers that will be placed/used for anticipation, prevention, protection, exclusion, mitigation and evaluation of FM, noting that:

— The soft barriers are administrative controls and guides, such as written guidance and rules in the forms of procedures, work instructions, work orders, hazard and risk assessment forms, zoning requirements, criteria and determinations, etc. This type of barrier relies solely on individuals and/or organisations to adhere to administrative requirements and guidance to control FMM and prevent FMI events;
— The hard barriers are the physical or engineered restraints which will prevent intrusion (or potential for intrusion) by way of a solid and tangible devices, such as covers, plugs,

caps, tarps, tents, tethers, filters, strainers, etc. However, use and application of such hard barriers are also governed by administrative controls and guides.

As discussed in Section 4.5, a grading process will primarily determine the necessity, type and extent of the application of FMMP administrative controls, checks and requirements, based on the characteristics of the activity that include:

— Risk level for nuclear, industrial and radiological safety, quality and reliability;
— Magnitude of potential adverse impacts on plant performance, production goals and expectations;
— Degree of probability and potentiality of FM incidents based on the existing/generated/introduced FMs, FM paths and FM targets during the entire activity, particularly owing to changes to activity sequence, condition, area and people;
— Frequency, specialty and complexity of the activity in terms of familiarity and competency and skill requirements;
— Potential adverse impacts on/from parallel activities.

The following subsections discuss key administrative controls, i.e. soft barriers as well as the administrative requirements of hard barrier applications, and their determination, definition and description.

5.5.1. Foreign material risk level definition and determination

Foreign material controls could be applied based on the level of risk of FM impact on plant safety, reliability and performance, particularly regarding consideration of:

— Nuclear, radiological and industrial safety;
— SSC reliability, operability and availability in terms of their form, fit and function;
— Economics of plant performance and sustainable, effective and efficient production.

For these considerations and overall corporate strategies/goals, it is current industry practice to categorise/classify FMRLs by a tiered system based on deterministic and/or probabilistic approaches:

— Some owner/operating organisations may choose to assign a predetermined FMRL for the application of FMCs to the activities on and around SSCs deterministically based on the safety and/or production significance/importance of that particular SSC. For example, any work that may directly or indirectly affect fuel, such as fuel handling processes or work on components with direct path to fuel, may be firmly assigned the *high risk level* to apply strict FMCs for the associated activities. Appendix I provides a sample practice in predetermined FMRL for several SSCs;
— Some other owner/operating organisations may determine FMRL based on the probability of occurrence and consequences of an FMI incident during a particular activity.

It is common in the industry to apply a method consisting of a combination of both in one form and another. Typical methods applied and practiced by nearly all NPPs are based on the existing industry guidance, such as those provided or referred by Refs [9–11]. A quick review of FMRLs used by NPPs shows that FMMPs use three FMRLs as a minimum: ‘no risk’, ‘standard (or Level 1) risk’ and ‘high (or Level 2)’ risk, as defined and described in Refs [9–11]. Such classification is illustrated in Appendix I together with examples of FMC requirements checklist for particular FMRL used by several plants. For specific and locally special circumstances, some owner/operating organisations also find it useful to employ four (or more) risk levels selectively, if the programme is not overcomplicated.

Ultimately, the number of levels will be determined by the use of a defined graded approach for the organisation. Regardless of number of FMRLs, as a minimum, the following aspects need to be considered when determining risk level:

— Probability of FMI, e.g. consideration of ‘will this work cause a breach/opening?’, ‘will there be FM (tool, debris, etc.)?’, ‘can debris enter to the system/equipment from the opening?’;
— Severity of consequence associated with nuclear and radiological safety, health, environmental, security, quality and economic performance;
— Complexity in the management of risk (i.e. degree of controllability of probability of occurrence and/or consequences);
— Importance/significance of the activity or SSC to nuclear and radiological safety, health, environmental, security, quality and economic performance.

For the purpose of this publication, a sample approach with four FMRLs: *no risk*, *low risk*, *standard risk* and *high risk*, as depicted in the flow chart in Fig. 17, solely based on these aspects listed above.

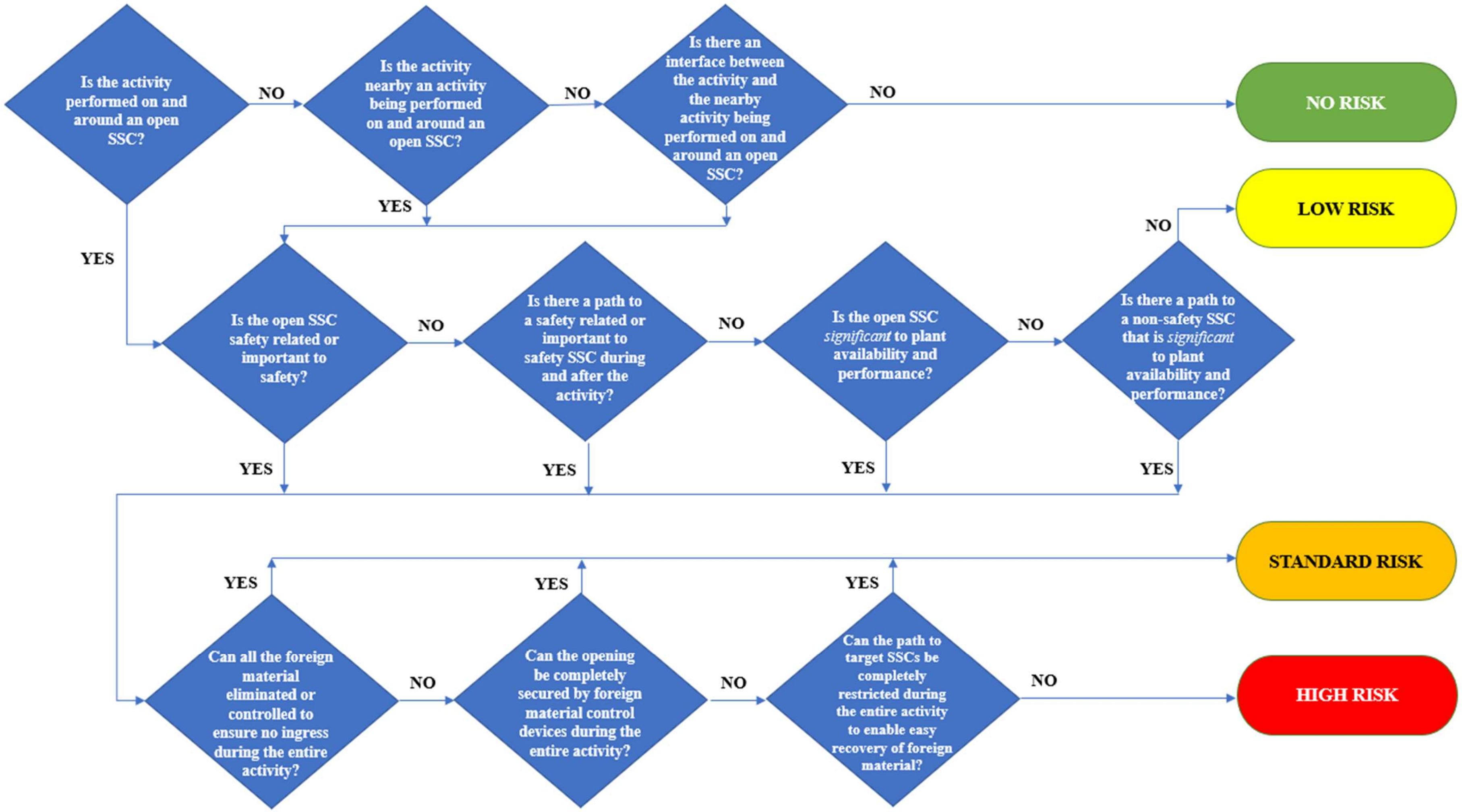

FIG. 17. A sample FMRL determination flowchart. SSC —system, structure and component.

In some FMRL determinations, considerations are also given to mitigation aspects equally as prevention, protection and exclusion, adding difficulty of mitigation of consequences, such as setting criteria for the possibility and difficulty for foreign material detection and retrieval/recovery after an FMI event, as shown in the methods in Appendix I.

One point to make in Fig. 17, the term *'significant'* (as emphasised in the Figure), will depend on the value assigned by the organisation, e.g. an amount of financial value (dollars, euros, etc.) of significance, an amount of collective radiation dose, an amount of day in critical path of an outage schedule.

It has to be emphasised that the FMRL assessment guidance, methods and tools (e.g. criteria, checklists, flowcharts, maps, diagrams) need to be clearly defined in the FMMP administrative procedure (or, if the instructions are structured in a set of implementing procedures, in the separate implementing procedures for risk level determination).

5.5.2. Foreign material control area determination

Foreign material control areas (FMCAs) are the activity areas/regions (i.e. confines, sectors or subsectors) that determine the appropriate and adequate level of FM awareness, behaviours, instructions, skills, qualifications, as well as the degree, arrangement and specialty of prevention, protection and exclusion measures and controls. FMCAs (mostly referred in some industry guidance as *FME AREAs* or *FME ZONEs*) are used to control personnel, tools, equipment and materials, as well as to instruct housekeeping, cleanliness, checks, inspection of areas where (or near) work is being performed.

Similar to the definitions and determination of FMRLs, there are various ways of grading and weighting the applicability, adequacy and effectiveness of prevention, protection and exclusion methods, tools and means, and therefore, several different definitions in the industry (and other non-nuclear industries), typically ranging three to five distinct areas, as presented in Appendix II.

Regardless of how the FMCAs are defined and established/erected, there are necessary considerations in defining, determining and establishing area controls:

— Minimising the probability of foreign material introduction, transport, intrusion into SSCs by keeping adequate separation and distance;
— Minimising the complexity in the management of risk (i.e. degree of controllability of probability of occurrence and/or consequences);
— Maximising the appropriateness adequacy and effectiveness of tools, equipment and people in the management and control of FM while performing the activity correctly;
— Minimising the interference, impact or restrictions on work activities, equipment and personnel movement and general or other work areas and timeliness of the activity;
— Minimising changes during the activity;
— Not creating/causing/resulting from the FMCA settings:

  - New FM, FM path and FM target prior to or during the activity;
  - New or increased probability or consequence of foreign material introduction, transport, intrusion into SSCs;
  - New or increased complexity in management of the risk.

Typical practices in setting FMCAs meet the following criteria and principles (noting that the specific level and degree of these will be determined by the determination of the applicable FMCA requirements, expectations and controls):

— FMCA need to be as small as practical so as not to impede or restrict work activities;
— The boundary and the equipment breach may be the same in some cases;
— Some factors which may affect the boundary definition are:

  - Access to area;
  - Nearby work or equipment;
  - System configuration;

— FMRLs and FMCA identifications/signage are posted and include FMCA owner and contact information;
— FMCA boundaries need to be erected and the inside areas are cleaned prior to breaching SSC or equipment;
— FMCA boundaries remain in place until the system is closed and risk of FMI is eliminated as confirmed by the closeout inspections and the breach closure validation (and if used, the conciliation of tool and material logs);
— Access to FMCA need to be limited to required and qualified people only;
— Access points to FMCA is minimised (unless impossible, limit to one ingress/egress access point);
— Particular attention is to be paid to the area above and around the FMCA and the SSC or equipment breach, for example overhead, cranes, walkways, lighting, as well as nearby ductwork and HVAC systems (and their intakes and outlets).
— Cautions need to be taken to avoid impacting other permanently installed system, material or equipment in or near the FMCA and activity area from possible FMI;
— All tools, materials and equipment which are not failsafe are ensured to be secured (e.g. by lanyard or other approved means);
— Packaging and similar material ought not be taken into the FMCA (buffer zones could be set up immediately outside of the FMCA, for example), as discussed in Section 5.5.6.1;
— If the packaging needs to stay until use (for example, due to fragile or sensitive content), the material needs to be unpacked cautiously and packaging material needs to be removed from the FMCA as soon as the packing material is no longer needed to protect the material;
— All waste products generated inside the FMCA are collected and transported out of the area as soon as possible;
— Regular cleaning and integrity checks need to be performed on all tools and material remaining in the FMCA;
— Only items that will be used can be taken into FMCA and they are removed from the area when no longer required (avoid storage of items unless the storage in FMCA is absolutely necessary);
— Transparent materials, wire brushes, cable ties or wraps with metal fasteners, metal grommets and wire twist ties are not permitted to be inside a FMCA, unless special precautions can be taken to prevent an FMI event (for example, in the case of transparent materials, increasing the visibility of item);
— To the extent practicable, personal items ought to be removed before entering a FMCA.

Definitions and determination of FMCAs are primarily based on these principles, the acceptable FM risks and hazards and the applicability, desired levels of layered defence and corresponding adequacy and effectiveness of prevention, protection and exclusion methods, tools and means to eliminate or minimise FM to reach FM target. For example, in construction phase (which could be also applied to operation phase), the FMCA categorisation could be similar to the housekeeping zone requirements defined in industry regulations and standards, such as those defined in Refs [40, 42, 58] which defines zones based on the restrictions regarding to: clothing and overclothing; filtered air; material precleaning; material and personnel accountability; and use of tobacco or eating. (These zones are discussed in more details in Appendix II).

Using the example in Fig. 3 in Section 2.6 (which was a simplified hypothetical activity of disassembling a valve and connected pump to work on an opened system with four known/anticipated FMs and FM targets (the valve and the pump) with several FM paths), Fig. 18 illustrates how FMCAs can be decided and constructed.

In Figure 18, for example, Circle 5 shows the protection against FM (FM 1) by excluding FM 1 from the work area by FM barriers that establish a specific FMCA. Furthermore, Circle 6 shows the exclusion of work zone — where opening that leads to Target 1 through Path 7 and Target 2 by Path 4 to Path 7 and from all FMs — as a FMCA that is smaller in size but presents less risk and hazards, as well as less FMC measures.

FIG. 18. Establishment and erection of FMCAs. FM —foreign material, FMC —foreign material control, FME —foreign material exclusion.

Appendix II provides examples of defining FMCAs and associated requirements for various aspects based on these principles and the other requirements and good practices discussed in Section 5.5, in its entirety.

It should be also noted that, during work activities, it might become possible, necessary or justifiable to change FMRLs and FMCA. This can be done either to increase awareness and controls for the current scope of work or enhance the efficiency of an evolution without compromising FMM requirements and controls (see Section 5.5.9.2 for field change management).

5.5.3. Personnel, tools, and material reconciliation

To maintain accurate control and tracking of items entering, exiting or remaining inside the FMCAs, tools, materials and personnel are typically controlled by keeping records which are to be reconciliated during and after the completion of the activity (sometimes referred as ‘accounting’, or as taken from the medical industry: ‘sponge count’).

Reconciliation requirements and controls are generally associated with the FMRLs and FMCAs and may differ. Also, different methods could be used for recording personnel, tool and material which to be later reconciled and accounted for.

Keeping and reconciling records by FM Logs is a common method in the control and management of tools, materials, equipment, component, parts and people in and around FMCAs. When a FM Log is used, tools, people and materials going in and out of a FMCA are recorded, i.e. ‘logged’, and their movements are tracked. Although it is a good practice to log and track items individually and separately, in some cases, such as those when a person cannot be separated from a personal item, they can be associated in one entry. For example, although the removal of all personal items is required before entering a FMCA, it may not be practicable for some personal items, such as prescription eyeglasses, hearing aids. In such cases, the person and the item could be logged in together and the personal item is tracked to the person as an alternative to multiple log entry and separate tracking.

The frequency of reconciliation and verification of records in a given FMCA may also differ based on the scope and duration of the task. However, a final reconciliation and verification needs to be completed prior to system closure and FMCA disassembly, as it is also prerequisite for the execution of closure requirements (see Section 5.5.5.4).

Therefore, personnel, tool and material reconciliation requirements and expectations, for example:

- The criteria for accepting the tools, material and people in the FMCA;
- Requirements for securing the tools before entering and during the time inside the FMCA;
- Methods, frequency and tools for logging, recording, reconciling;
- Processes for checking and reporting lost and missing items, materials, tools (including broken or missing tool pieces and details).

are to be established, well defined and clearly described in the FMMP administrative procedure (or in the separate implementing procedure, if the instructions for personnel, tool and material reconciliation are permeated and structured in a set of implementing procedures as practiced by some organisation in the industry). They are also typically specified in the task specific FMMP instructions and the FMM plans (see Section 5.5.10.1).

Some common examples for the requirements, principles and practices of logging and reconciliation include:

- Logging of items need to provide enough detail to be able to accurately account for items when they are entering and are being removed from the areas. Therefore, tools, material, equipment and components need to be checked for moving, loose, broken or missing parts prior to admission to the FMCA and for complete and accurate reconciliation, their parts may also be logged/recorded;

- Initial ingress inventory, including the tool check results, need to be recorded, and all items that are to be used in the activity (including in-place FMM measures, such as FMC devices, FMCA barriers and signs, etc.), as well as any substance that may potentially carry or become FM, are logged for later reconciliation;
- Either paper or electronic logs can be used as long as they maintain an accurate list of items in the area necessitating diligence and completeness. With technological advancements, radio frequency identification (RFID) is also being used more and more for the inventory, location and management of tools. As the RFID may provide real time knowledge of tool locations at all times, it can be utilised as another method to automate the logging, recording and reconciliation;
- To the extent practicable, personal items ought to be removed before entering a FMCA. In cases when the removal is not possible (for example eyeglasses or hearing aid), such items need to be accounted in the log entry with specific association/link to the person carrying them;
- In the case that items are found that were not recorded in the reconciliation log and/or there are discrepancies after reconciliation, this is a non-conformance and has to be reported and resolved.

Typically, the examination of tools, parts, equipment and components for moving, loose and missing items prior to and after use is a required step, as discussed in Section 5.5.6.2. It is also a good practice to record such items, as practicable, prior to admission to and after the exit from to the FMCA to ensure everything is accounted for and, that is not supposed to be a part of the SSC, is not left behind as a potential FM. As an example, from OPEX:

> "An event that occurred at a nuclear plant resulting in an outage extension of 7−10 days, owing to the insufficient pre-use integrity check, shows the importance of examination of equipment prior to admission to FMCA. In this event, during a post work tool integrity check, a 5/16-inch nut was discovered missing from a chain hoist that was used in the FMCA during main generator work. A search was completed; however, the nut was not found, extending the outage until a resolution was reached. Consequent investigation found that pre-use integrity check was less than thorough, and the nut was already missing prior to hoist use".

5.5.4. Foreign material control devices selection and application

Foreign material control devices are engineered physical barriers to protect the target SSC and/or the FM path to target SSC. The FMC devices may be permanently built in into the SSCs by design (including those that are replaceable, such as filters and resin beds) or they are installed to temporarily cover, plug, dam, secure SSC openings or FM paths as needed, prior to or during the activities.

These devices are the features which are decided and applied based on the anticipation of potential exposures to and the conceptualisation of protection from FM.

5.5.4.1. Temporary foreign material control devices

Temporary FMC devices (also commonly referred as 'FME devices') are used when protecting/shielding open systems or critical equipment against the ingress and/or impact of FM (or potential FM). They are used during the time when they are needed, i.e. when there is a risk of FM ingress, and they are removed, which can be very essential, afterwards:

> “Removal of temporary FMC devices after its use is very important to remember and to be aware of, as there have been many occurrences in various industries where FMC devices are becoming the FM themselves because they are forgotten to be removed. As an example, in a well-known event (which is also commonly used in FMM trainings), significant damage was done to gas standby generator when an FM plug was inadvertently left inside an oil supply line when reassembled. Many events have occurred where ‘shipping plugs’ in valves were not removed prior to installing in the system”.

Typical times and places of use of temporary FMC devices include:

- Prior to or during the activities, when systems/equipment are open, to protect the SSC and FM path from existing or generated FM (e.g. welding slag, cutting/grinding debris, dust, dirt, grit, water, oil, small tools, parts and objects) from getting into the system, component or equipment;
- When FMCA boundaries are established and material ingress (and egress to enter or impact nearby equipment) need to be minimised or eliminated to exclude any FM, or potential foreign material, being transported into/from FMCAs and critical areas/equipment;
- During activities when securing tools and material is needed, such that they do not become lose and be a FM (as the FMs created from inadequate and ineffective lanyards have been a particular issue in the industry, and therefore, appropriateness of, and requirements for, lanyards is commonly noted and their selection and use have been explicitly specified in the FMMPs);
- During transportation of components and equipment, when there is a risk of FM ingress and impact, to protect the internals of SSCs from adverse conditions, such as inclement weather or other environmental effects;
- During storage of components and equipment, where equipment and SSCs are unused or any openings are unattended, to prevent FM ingress, generation and accumulation inside, including protection of internals from adverse ambient conditions.

As such, the type and shape of FMC devices vary to include covers, tarps, caps, plugs, pipe dams, bag plugs, tents, cases, totes, sealed bags, tethers, lanyards, tool control/secure attachments, boundary barriers (including markers and signs), etc.

Due to the large variety of system, equipment, components, areas that can have breaches/openings, it is important to ensure that the proper FMC device is selected for the application. In addition to size, fit, form and function of the FMC devices, the ambient conditions, such as ventilation, high temperatures, electromagnetic impact, access and easiness for installation and removal are all factors that need be considered when selecting the proper FMC device. For example, although caps, threaded plugs, bag plugs, tarps may all be applicable for pipe closers, threaded plugs and hard caps are the preferred FMC device to prevent from an inadvertent loss of the device into the system by pressure changes. Another example is the magnetic devices, which cannot not be used in some application where they could interfere with electrical panels.

In addition to the preference of being easy to install and remove, from the common guidance and principles based on the OPEX and lessons learned, the selection and utilisation of temporary FMC devices considers them to be:

- Appropriate and approved for a given application;
- Clean and free from debris, splinters, etc. and not allow the introduction of FM into the system due to their installation or removal activities;
- Sturdy and secured so they will not be drawn in or blown away, for example by a pressure drop or surge of the system, and therefore, paper dams for gas purges, clear plastic bags, rags, or similar materials cannot be used as FMC devices;
- Engineered and marked with weight capacity if located in an area where personnel may have to walk on the device (in case that they are not designed to support a person, then they ought to be clearly marked with 'NO STEP', or similar wording);
- Rigid, strong or thick enough to avoid damage to underlying surfaces, for example when covering vertical openings that are susceptible to falling or heavy objects that could damage or penetrate the FMC device;
- Clearly marked by wording and/or colour consistent with the site specific FMMP colour and wording to prevent inadvertent removal or damage (for example, learning from experience, brightly coloured FMC devices are observed to be an excellent method to promote recognition);
- Resistant to melting, breaking, tearing, or other damage prior to or during use;
- Where practical, used on the removed/unattached/disassembled component (e.g. valve bonnet, flange, junction box cover);
- Properly qualified and approved to prevent component degradation and/or damage to the system, component and equipment upon use (for example, in terms of material compatibility, not to cause any type of chemical reaction, e.g. galvanic corrosion);
- Not used on/in pressurised systems unless pressure boundary is evaluated, justified and approved;
- Fire-resistant or fire-retardant;
- Not susceptible to breakage (shattering or splitting);
- Withstand temperatures encountered during task evolution (for example, lightweight nylon covers may melt if placed on hot piping);
- Not deteriorate or decompose with time;
- Not impact SSC's structural conditions or design functions (which was the case in one well known FM related event when, in one nuclear power plant, the demineralised water storage tank imploded (collapsed and ruptured) as a result of FMC device being left on the vent line, disabling design function of a venting equipment by blocking air penetration/venting paths);
- Installed and secured such that their accidental removal or displacement is prevented.

Also, as they may become contaminated with dirt, dust, oil, debris, etc. during the course of the activity, before removing any installed FMC device, a thorough inspection of the device and the area surrounding the device need to be performed to ensure that no FM has built up on the device or around its edges. Therefore, it may be necessary to clean FMC devices before removal.

Similarly, as most of temporary FMC devices may be reused, it needs to be assured that between the use and reuse, they remain clean and preserve their quality. Therefore, in selection of FMCs that are reused, a thorough cleanliness and appropriateness (e.g. sturdiness, intactness, fitness) check is needed to allow their reusability.

Based on their training and knowledge, line workers and line management (as well as the programme coordinators) need to be able to anticipate and recognise when and where the use of which temporary FMC devices is warranted and understand and interpret the implications and limitations relating to their use or reuse.

5.5.4.2. Permanent foreign material control devices

As discussed in Section 3.2, in anticipation and considerations at design phase, engineered FMC devices/components/equipment are incorporated into the facility design for FM prevention and protection of SSCs. These FMC devices are designed and permanently installed to prevent ingress and transportation of FM. These devices are mainly in forms of filtration, ventilation, flashing and purification systems (e.g. filters, strainers, fuel guards/grids, drains) but also include structuring of particular parts of the system elements, such as debris traps, vent orientations, carefully sized tolerances and shapes in the openings and transportation paths.

It is needed to clearly identify the analysis and design of features that address specific design aspects of permanent FMCs in the original plant design documents. The plant owner and operator later can use this information to establish and incorporate into their comprehensive FMMP during operation. Therefore, design methodologies and tools, as well as the design and operation requirements and functions of permanent FMC devices, need to be clearly defined in the design documents and incorporated in the operational procedures, as applicable. It may also be a good practice to provide a list of particular design features that serve as the permanent FMC control device in the FMMP documents.

However, existence of such design features ought not to lead to complacency or justification for the use (or not use) of temporary FMC devices since the design basis input and assumptions address only specific functions and conditions applicability for designed and permanently installed FMCs.

5.5.5. Inspection requirements and controls

Management and control of FM includes verification and validation activities to ensure the SSCs, equipment and areas are and remain free of FM or risk of FMI incident is minimised or eliminated. One part of this verification and validation is accomplished by inspection of SSCs, equipment, tools, material and areas, some of which may be performed at the activity area while some are performed at other locations than the activity area.

The FM inspections at the work area aim verification of conditions regarding FM (including verification of cleanliness, as well as the identification and recording of FM existing in the system if removal is not possible) in, on or around:

— Work area, tool and immediate surrounding of system, component, equipment before the activity starts (i.e. before the system is opened or dismantled), i.e. *initial inspection*;
— System, component and equipment, immediately after dismantling or opening, i.e. *as-found inspection*;
— Work area, tool and immediate surrounding of system, component, equipment at certain stage(s), checkpoints or evolution(s) of the activity, i.e. *checkpoint inspection*;
— System, component and equipment, just before assembling or closing, i.e. *as-left inspection*;
— Work area, tool and immediate surrounding of system, component, equipment when the system is closed, i.e. *final inspection*.

The FM inspections at the other locations than the work area, such as *factory*, *receipt*, *warehouse inspections*, are also performed in order to verify that systems, components and equipment are manufactured, packed, transported, received and stored in foreign material free conditions.

Methods of inspections range from visual to use of simple or hi-tech devices, such as mirrors, borescopes, video cameras, metal detectors, X ray, radiography, fibreoptic technologies, as applicable. Inspections can also include verification and validation of processes, such as controls and procedures, specifications, vendor certification for cleanliness, housekeeping by observing worker behaviours and document reviews.

Regardless of the inspection type, method, performance stage or place, there are two typical roles and responsibilities:

— Activity performers: In any FMMP, it needs to be required to have the activity performers to conduct the one-layer inspection, i.e. self-inspection/verification of SSC, tool and work cleanliness, in every activity as a minimum. The activity performer makes certain that the work area, SSC and equipment and tools are clean from a FMM perspective and ensures that the possibility for FMI threat, hazard or incident is minimised or eliminated before, during and after the activity.
  For one-layer inspections, the FMMP governing procedure needs to identify and define key aspects of conducting such inspection as to their scope, extent and recording requirements in accordance with the corporate policy and level of FMM culture, as applicable (particularly the level of awareness, ownership, cleaning and housekeeping traits). These aspects, then, could be described and the instructions could be structured in the implementing procedures for the specific activities;

— Independent inspectors: While a one-layer inspection is required in every activity as a minimum, independent inspectors would witness the conditions of work area, SSC and equipment and tools with trained eyes and attest to that the possibility for FMI threat, hazard or incident is minimised or eliminated. This, in turn, provide assurance in a qualified and/or certified manner by an independent second party verification. As such, the FMMP governing procedure needs to identify the specific activities where additional second party inspections are required and define the associated requirements. As a good practice, FM inspections performed by independent second party inspectors could be considered in all cases.
  The independent second party inspections, whether onsite or offsite, are to be performed and documented by trained and qualified personnel and the requirements for training and qualification of inspectors needs to be defined for specific activities. It is necessary that the inspectors are familiar and knowledgeable with the activity and the SSCs which are being work on, as well as their surroundings in order not to adversely interfere with activity and to take appropriate precautions to prevent and protect FMs from entering systems, equipment, parts, material or components during inspections.

It also needs to be emphasised that the one-layer inspections ensure the cleanliness (and other requirements of FMM) of the SSCs, equipment and areas. As such, self-inspections make certain that SSCs are free of FM or the risk of FMI incident is minimised or eliminated. The independent second party inspections, on the other hand, are there to verify and validate that FMM requirements and expectations are ensured.

It is essential that the inspectors (both self and independent ones) are familiar and knowledgeable with the SSCs to recognise, identify and interpret FM in and around them. This importance was apparent in aforementioned event of imploding demineralised water storage tank as a result of FMC device being left on the vent line:

> "It was also noted in the collapsed and ruptured tank incident that, although the personnel were FMM trained and qualified they were not familiar with

the design of the tank or did not have any design drawings. Owing to this missing knowledge and information, they did not recognise that the FMC device (butterfly FME cover), which was blocking the vent valve, was not a part of the tank per design, and in fact it had become a foreign material for the SSC".

Common to all inspection requirements, any unknown and foreign material or any non-conforming/non-satisfactory condition discovered during the independent second party as-left inspections will be documented, logged, reported and removed before proceeding with the activity. Additionally, it may be a good practice to keep a record of any unusual findings during the cleaning (and one-layer inspections by the activity performers) to be further discussed in the post job briefing and to be used in future activity planning and performance. Regardless of the inspection/inspector, if there is discovery of a non-compliance with the requirements during the inspections, the finding has to be reported in accordance with the applicable condition reporting processes and entered into the CAP.

From OPEX, some lessons learned and good practices to be considered in establishing inspection requirements and expectation include:

— Maintaining FM diaries is essential in the execution of FM free activity requirements, including keeping a good record of inspection performance and findings;
— Recording and documenting the inspection results with photos or videos (particularly in case of bad inspection findings, e.g. not meeting the cleanliness requirements, which would require preserved evidence in photos and videos) for evaluation of causes as such visual material is useful for training purposes to demonstrate what good and bad look like, as well as for analysing and learning to improve the deficient or failed parts of the FMMP;
— In some activities, there may be cases and periods where some components or systems could be inaccessible for independent inspection. In such occasions, strict monitoring of uninspected work could be necessary, as well as continuous tracking of activity steps and documentation, in order to ensure that the uninspected work is performed in accordance with the FMM requirements and conditions to identify the first available time when they become accessible for inspection.

The following Sections discuss particular characteristics of various inspections governed by the FMMP. It should be noted that this is not a complete and explicit list of all types of FMM inspections performed. For example, the *security inspection* is not listed as a separate inspection type but discussed in Section 5.5.5.6 as coupled with the receipt inspections. Also, in some organisations, as-left and final inspections (Sections 5.5.5.4 and 5.5.5.5) are defined as one inspection, typically named as *closeout inspection*.

5.5.5.1. Initial inspection

In order to prevent FM from existing and entering the system while it is being opened, it is necessary to perform a thorough inspection and verification of cleanliness and conditions of the work area before the work starts and system/equipment is ready to be opened for the activity.

This initial inspection also involves verification of requirements and controls to ensure that the system is ready from FMM perspective, i.e. FMM and cleanliness requirements are met. The initial inspection also verifies that the work area is free of dirt, dust, debris, oil, lose or flaking rust and residue from grinding, chipping, welding, blasting, or other prior or ongoing activities.

The initial inspection is a stage for verifying that all items, that are being introduced in/on (or nearby) the SSC breach point, are identified and recorded to be later accounted for and removed prior to system closure. As such, it also confirms that the only required tools, materials and objects that belong to the activity (and that they are in good condition from the FM aspects, i.e. generating or becoming FM), are brought near the SSC opening. Accordingly, all items that are to be used in the activity (including in-place FMM measures, such as FMC devices, FMCA barriers and signs, etc.), as well as any substance that may potentially become FM, are logged as the *baseline material log* (see Section 5.5.3) for later reconciliation which will be the method to ensure and/or verify meeting the system closure requirements.

The initial inspection and confirmation of system opening requirements being met is the end of all general activities or people/equipment movement in the zone before the system is opened, except the ones required for the activity. Also, the findings of initial inspection need to be resolved before the system opening. Therefore, it requires an advance planning of activities in and around the work area to prevent any non-activity related people and equipment.

5.5.5.2. 'As found' inspection

Immediately after dismantling a component or opening a system, a FM *as-found inspection* needs to be conducted on and in the SSC or equipment that is opened, to ensure that the component or system is clean and free of FM. As-found inspections also identify unexpected/abnormal system conditions, such as excessive amounts of silt, corrosion, broken internals or unknown material which does not belong to the system, component and equipment, i.e. pre-existing foreign material in there.

'As found' inspections apply to new or refurbished parts or components prior to installation in the system, as well. As aforementioned, although FMC devices are typically factory (or warehouse) installed to keep internals clean during transportation or storage, new or refurbished parts may still come with debris or other FMs inside. Thorough inspections at the work site to confirm internal cleanliness, as well as the removal of shipping and storage FMCs of new parts/components to be used can prevent future equipment failures (such as, aforementioned, 'shipping plugs' and 'butterfly FME cover' events).

In addition to documenting, logging and reporting the unexpected/abnormal system as-found conditions in accordance with the applicable condition reporting processes and entering them into the CAP, the engineering/technical support organisation also need to be notified when system, equipment of material degradation indications (for example, unexpected silt, corrosion, broken internals or unknown material) are discovered. Unknown and foreign material — after recording it in photos and/or videos — is to be analysed and assessed and will eventually need to be removed to proceed with the activity. However, it may be necessary to preserve them for subsequent engineering evaluation to determine cause or origination of the FM and to identify the impact from/to design and operation of SSC for corrective action and improvement.

5.5.5.3. Checkpoint inspections

During the course of activity, there may be some planned or unplanned stages, check or hold points or change in status of work at hand and nearby activities where the activity, work area, system, component and equipment inspection need to be performed to confirm to proceed with the next tasks of the activity. These *checkpoint inspections* are typically marked and performed when, for example:

— FMRLs are changed and FMCA can be transitioning to different category (see Section 5.5.9.2);
— Unexpected conditions are encountered;
— Work stopped for some time to accommodate other plant evolution;
— SSC configuration is changed;
— Next level of work in the internals of opened system or component is starting;
— A new equipment with the necessity of packing or assembly brought into the work area;
— Occurrences which may affect or compromise the original FMM plan (see Section 5.5.9) happened.

Requirements for checkpoint inspections throughout the activity depending on the area, system and component status and they may also include specifically required/requested inspections. For example, technical support (engineering) organisation may determine some hold and checkpoints for special system inspections.

In addition to the generic requirements, special requirements for checkpoint inspections as to their timing, extent, performers and performance methods need to be defined in the FMMP governing document. The activity plan further needs to specify special inspections and their milestones, entry conditions with the associated key verifications, while the work plans and order need to place check or hold points in the activity instructions to stop work and perform inspections in accordance with the specific needs and the general requirements set in the governing FMMP procedure.

5.5.5.4. 'As left' inspections

Upon the completion of work on an opened component or a system, a thorough cleaning of the SSC/equipment and its immediate surrounding is performed in order to prevent any FM from remaining and migrating through the plant SSCs. This includes the removal of tools and materials, internal and external barriers and other FMC devices used in the activity, as well as any substance that is (or eventually may become) a FM, such as dirt, dust, debris, oil, lose or flaking rust and residue from grinding, chipping, welding, blasting or other maintenance activities.

Subsequently, a FM *as-left inspection* is conducted on and in the SSC and equipment to verify that the internals and immediate surrounding is being left clean and free of FM and the open component or system is ready to be closed.

As-left inspection is the final barrier for detecting FM intrusion. During the final inspection it is checked and verified that all foreign substance that were introduced to the SSC/equipment and its immediate surrounding have been removed.

The importance of as-left inspections (self or independent second party) could be seen in the example of FMI event provided in Section 1.1.2 as one of the industry's most significant FMI events when:

> "A unit was taken off-line due to several SG tube leaks which determined to be caused by an accelerated stress corrosion cracking as a result of a high content of lead. Visual inspections (after the event/during investigation) found debris in the form of metal grommets from two lead blankets used during an earlier activity which could have been discovered during the as-left inspection of the SSC".

On the other hand, there are 'success' examples of proper as-left inspections, such as the following one that was reported by one plant:

> "Following a maintenance outage, a final cleanliness video inspection of the steam generator cold header found a 4x8 mm stainless steel bolt; 15x2 mm piece of plastic clamp; two 10x10 mm pieces of black coloured reinforced hose. This final inspection prevented what could have been significant damage to primary components had the unit started with these items left in the system".

It should be added that the as-left inspections also need to confirm that any material to be left in the plant SSC(s) is thoroughly evaluated and concluded to be so, as discussed in Section 7.

5.5.5.5. Final inspections

In order to prevent FM from existing and entering the system while it is being closed and to ensure that SSC or equipment is closed and returned to service in a clean and FM-free condition, it is necessary to remove all equipment and tools (except the ones needed to close the system) including in place FMM measures, such as temporary FMC devices and internal/external barriers. Also, any potential FM substance in the area needs to be removed/cleaned in order to ensure that the work area for closure activities is free of FM. This also includes that all material which were identified and recorded in the baseline material log (see Section 5.5.3), and by any updates to the material log thereafter, are accounted for and conciliated prior to system closure to ensure meeting the system closure requirements.

Subsequently, a following thorough *final inspection* at and around the open SSC/equipment and the surrounding work area needs to be conducted to verify that all tools and material, that were introduced in/on (or nearby) the SSC breach point and the surrounding area (i.e. FMCA and adjacent areas), have been removed from the FMCA and adjacent areas upon overall work task completion. The final inspection also validates the conciliation of material log during the initial inspection (Section 5.5.5.1).

The final/closeout inspection is the last confirmation that the open system can be closed and returned to service without a possibility of any FM remaining or entering. Therefore, the final inspection, i.e. the verification and validation of system closing requirements being met, has to be the end of all activities other than those needed for the system closure. After the completion of inspection of compliance with the system closure requirements, no people/equipment except the ones required for the system closure activity/steps will be permitted to enter or move in and around the zone. This requires an advance planning that all activities in and around the area are completed between the final inspection and the system/equipment closure.

5.5.5.6. Factory inspections

Generation and ingress of FM in parts, components and equipment can occur at any stage of manufacturing process, e.g. during the production, assembly or storage by the manufacturer. Factory inspections are also conducted for the verification of foreign material free parts, components and equipment before packing and shipment by the factory. These inspections, accordingly, are performed at the manufacturer's site or factory by the trained and qualified staff, typically, of the manufacturer under their management system. Therefore, it is important for the project/plant owner/operating organisation to establish an interface and mechanisms to control FMM aspects (or to ensure their control) with manufacturers/vendors, including the factory inspections, utilising:

— Procurement contracts — that define and set (with supplier's agreement) the process obligations, requirements, specifications and expectation for the supplier (and their subcontractors) — to articulate the FMM requirements, specifications and expectation, including those for factory inspections;
— Vendor/manufacturer qualification to ensure that the suppliers have a management system (i.e. QAP) that includes acceptable verification, confirmation and validation processes for manufacturing, including FMC aspects;
— Project/plant personnel of the owner/operating organisation to perform, to participate in performance or to observe the factory inspections during manufacturing, packing and shipment of component or equipment that are critical to safety or economics, such as fuel assemblies, steam generators, primary system components, e.g. safety valves, pumps, piping;
— Vendor certification of 'foreign material free product' and/or the *factory inspection report* provided by the manufacturer to verify compliance with FMM in the factory. Here, it is important that:

  - The supplier's factory inspection report needs to include a list (with types, recognition signs, such as colours, tags, writings, and locations) of internally and externally installed FMC devices to ensure removal before the installation and operation of material, parts, components and equipment;
  - The report also needs to describe existing tamper-proof and tamper-evident packaging material on the item such that they can be verified in receiving inspection as to remaining intact during shipping and transportation in controlling intentional and unintentional FM contamination.

Regardless of the methods and tools for FMC by/with manufacturer, an effective FMMP of the owner/operating organisation still requires a systematic approach to offsite inspection/verification process. Therefore, the FM factory inspection criteria, conditions, requirements, methods, mechanisms and responsibilities needs to be defined and described in the FMMP administrative procedure or, as a typical practice in the industry, they are referenced to other processes and procedures, such as QAP's procurement process. However, in the latter case, FMMP administrators need to ensure that the factory inspection requirements, methods, tools, criteria and instructions are acceptable and incorporated or reflected in those processes and procedures. Additionally, in such cases, the criteria and requirements for designation and interface with such process and procedures need to be defined in the FMMP governing procedure.

5.5.5.7. Receipt inspection

Receipt inspection are performed at the plant/project site to verify that there has not been any FM generation and ingress (or possibility and potential FM generation and ingress) in the systems, components, parts, materials and equipment during shipping.

Typically, the FM prevention, protection and control requirements and specifications for packing and shipping by the manufacturer/vendor are developed and included in the contracts for the procurement of materials, equipment and components. However, FM hazards and unintentional/unexpected FM ingress and generation may occur owing to, for example:

- Environmental conditions (e.g. ingress of moisture or salt to internals, damage to FMC devices that are placed in the factory due to extreme cold or heat);
- Poor transportation (e.g. vehicle, harnessing equipment, non-compliance with driving instructions);
- Defective/inadequate packaging work.

Therefore materials, parts, equipment and components that are procured and received ought to be inspected upon delivery to plant/project site, typically by trained and qualified warehouse and storage staff. However, in very exceptional cases, such as the item being directly delivered to the activity area or workshop, it may become necessary for local workers to perform the receipt inspection of the delivered item. Such local inspections follow the same requirements and methods of the inspections performed by procurement and warehouse people, process and procedures.

Specifically, the receipt inspections are performed to verify that:

- All FMC requirements for packing and shipping are met, including the tamper-proof and tamper-evident packaging material, if required;
- No missing FMC devices:
  - FMC devices were installed sufficiently and adequately by the manufacturer;
  - All FMC devices remained installed during shipping;
- No damage or degradation of FMC devices occurred during the transportation;
- If any of the conditions above is not confirmed, it is checked and ensured that there are no FM generation and ingress in the materials, parts, equipment and components received.

If the delivered item arrived without a necessary FM prevention and protection measures, or arrived with damage and degradation to those, this state of the item needs to be identified and recorded during the receipt inspection. The consequences (or no consequences) of such insufficient FMCs are inspected, evaluated and mitigated by either (or both) of the following actions:

- Confirmation of internal cleanliness or removal of FM, if any, and putting the appropriate FMCs in place (if such action will not violate the contract and warranty requirements);
- Rejection and return of the item to supplier if internal cleanliness or impact on item cannot be confirmed or right away.

It is also important to review and discuss the terms of warranty or other contractual obligations to confirm that it is a deficiency and before deciding on whether any mitigation necessary and, if so, deciding on the mitigatory and corrective actions.

Failure to meet FMM requirements and expectations by the vendor would be reported as a nonconformance in accordance with the applicable condition reporting processes and entered into the CAP. Furthermore, the supplier is to be notified of the nonconformance and be requested to investigate the condition followed by a communication of the investigation result to the owner/operating organisation.

When the items cannot be completely and thoroughly inspected for FM and FMC devices owing to the nature of design, manufacturing/construction or shipping — such as those are packed in tamper-proof and tamper-evident packaging material that can only be unpacked just before the item is used — the item is tagged or labelled indicating the item is 'NOT FM INSPECTED'.

During receipt of materials the storage personnel need to take appropriate measures and precautions and have to maintain housekeeping and cleanliness to prevent parts and components from FMI and the probability of foreign material entering the part or component is minimised. This brings out another important lesson learned regarding the security inspections:

> "FMC devices that were removed to facilitate security inspection were not restored to their pre-inspection or they were damaged during the inspection and left at those conditions after the inspection, resulting in FM incident".

Based on this and similar OPEX, it is very important to also note here that security checks or inspections of equipment and materials entering and exiting the plant/project may precede which makes those checking actions a part of shipping/transportation process that may result in FMC interference, and even failures. Thus, security personnel need to have FM awareness and FMC knowledge to understand that their security inspections may potentially result in an FMM issue. It is also important that, the security personnel need to know and take appropriate precautions to prevent FM from entering parts or components when a security search and the removal of FMC devices are required. Furthermore, the removed FMC devices have to be properly reinstalled as soon as the search has been completed. Therefore, and gaining and maintaining FMM information and knowledge by the security personnel (and/or having a trained and qualified FMM inspection staff present during the security checks) may be essential.

5.5.6. Storage controls

5.5.6.1. Warehouse storage of components, equipment, parts and materials

Once the component, equipment, material or part is delivered and the receipt inspection verified the FMM requirements being met, it will be stored in an onsite warehouse (which typically consists of a central storage facility for the entire site and several dedicated storage areas nearby the activities or activity groups, e.g. maintenance workshop). In order to ensure that parts and materials provided to the plant/site/station remain free of FM between the performance of receipt inspection and the time when they are prepared for installation, FMC processes and practices need to be applied to protect the stored component, equipment, material or part from FM ingress and to prevent generation of FM in, on or around them.

Considering that the storage period could be long —sometimes lasting for decades — and the storage conditions may vary during such a long time, sustained and adapting FMM efforts are essential from the asset management point of view. Especially in long-lasting or suspended construction phases, during which the component, equipment, material or part more likely to be stored outdoor facilities for decades, extra efforts to protect assets protection become very important, as it has been shown by one well known industry experience:

> "In an Argentinian NPP project, the construction was put on hold for nearly 30 years after most of the plants components and equipment were delivered to the site. This required FM protection and prevention tools, methods and activities to maintain the material FM free for decades. Successful equipment

protection including FMC resulted in only 10 per cent of the material ended up being needed service or disposal".

Therefore, the FMMP administrative procedure needs to define and clearly describe the FMM requirements and controls for onsite storage, particularly during construction and operation phases. The FMMP procedure may also refer to the administrative (or task specific) procedures and processes of other programmes, such as the procurement programme, for descriptive instructions. In such cases, however, the FMMP administrative procedure still contains the criteria, requirements and responsibilities for designation and interface). Furthermore, FMMP administrators need to ensure that the storage instructions regarding the FMM are correctly and completely incorporated (and maintained/updated) in those processes and procedures.

The key element for FMC during storage, of course, is maintaining cleanliness in the warehouse and all storage facilities by:

— Keeping the areas clean, tidy and free of debris and other FM in accordance with the applicable housekeeping and cleanliness requirements and standards and 'clean as you go' practices (for example, by keeping general warehouse floors, aisles free of scrap material, packing wraps, cardboards, wood, straps);
— Routinely inspecting the storage areas/warehouses holding equipment or components to ensure that housekeeping and cleanliness standards are met.

In addition to reiterating or emphasising those general cleanliness requirements, the FMMP governing document needs to identify and describe specific requirements, controls and actions for FMM during storage, which are typically applied during three distinctive stages of storage, such as:

— Controls for accepting the components, equipment, material or parts to the warehouse:

  - Items are delivered/returned to warehouse with all proper FMC devices in place and intact, with internal and external cleanliness is acceptable for storage;
  - In the cases of missing FMC devices, the subject material can be accepted for storage only after verifying that no FM in, on or around the item and applying necessary FMC devices for storage;
  - The items that are received with 'NOT FM INSPECTED' tag/label are accepted only if it is logged as 'not FM inspected' and they are moved to storage with such tag/label is intact;

— Controls during the time of storage of the components, equipment, material or parts in the warehouse:

  - All items ready for storage have FMC devices are clearly identified and marked with standard FMM markings/labels/tags, which contain clear, accurate and complete information for FMM aspects and are consistently placed on the outside (or on the outer package), such that they need to be visible without moving the item;
  - 'NOT FM INSPECTED' tags/labels remain on the items during the entire time of storage, for those that were not completely and thoroughly inspected for FMM measures and FMC devices;
  - FMC devices, when they are temporarily removed for internal access for a required service or inspection of a stored item (such as valves that require periodic inspections and cleaning to remove dust, dirt or any other FM, particularly from

seat surfaces when in long term storage), are reinstalled immediately after the service is completed;

- Movement of items within the warehouse facility is avoided or minimised such that the risk of damage to the equipment, component or parts, as well as to the installed FMC devices, is reduced;
- Parts, materials, components or equipment are stored in accordance with the manufacturer's storage specifications including those for the FMC and such requirements may be specified (or emphasised) in the FMMP governing procedure, particularly those that are related to the SSCs with high FM risk, for example, as noted by an international expert:

  > "One FMMP procedure specifically mentioned the manufacturers specification for the storage of safety-related check valves to emphasise and increase awareness of storage conditions which were specified by the manufacturer as: "in an area with minimal dust and dirt; on a flat service; in an indoor dry warehouse where the item is not exposed to sunlight and the temperature and humidity are kept constant; and away from flammable or explosive materials and preferably in a ventilated room"

- In case of absence of specific conditions, the storage area is selected by using a graded approach to minimise or eliminate conditions for:

  - o FM existence and generation around the items while in storage (for example, by selecting appropriate storage place for FMM, i.e. indoor or outside, aisle or wall, segregated or together with cardboard crates/boxes, to protect from dust and dirt);
  - o Degradation, deterioration or erosion/corrosion of parts, materials, components or equipment, including the FMC devices, due to the environmental conditions, such as heat, cold, sunlight, dryness, moisture, corrosive material nearby (for example, storing indoors or covering while outdoors for minimising sunlight impact), or physical factors (for example, vertical or horizontal orientation of valves, stacking of bendable items);
  - o Restrictions/obstacles for serviceability and movement (for example, storing on aisle versus wall side, shelving high or low) that may impact FMCs;

— Controls during the discharge, transfer and preparation of items, by the warehouse staff, to the activity area for the installation:

- Ensuring that FMC devices and covers remain in place during the delivery;
- Preparing/staging in a location where there is none or minimum possibility of FM ingress, i.e. not opening and staging the component where dust or debris from nearby activity could be blown, scatter or fall inside the component/equipment when the packing is opened and FMC covers are removed;
- Unpacking the items before bringing into the FMCA or, if it is impossible to do so (such as in cases when the packaging needs to remain on the material until use, for example, due to fragile or sensitive content), unpacking them cautiously — possibly under the observation of a second bystander — and removing the packaging material from the FMCA as soon as the packing material is no longer protecting the material.

It is also important to be understood by the workers, who will receive and install/use the item, that storage, delivery and staging requirements do not ensure that items are cleaned to a level that is acceptable for installation into the plant when prepared for use/installation by the warehouse staff. Therefore, the activity workers are still responsible for checking, confirming and/or establishing cleanliness of items prior to installation in accordance with system cleanliness and FMM requirements.

5.5.6.2. Storage of tools and FMC devices

In addition to warehouse storage of equipment, material, parts and components, a unique process of FMM is the storage of tools and FMC devices in small and local facilities around the site for nearby availability, easy access or radiological considerations.

In most plants, there are implementing procedures, as well as assigned 'tool rooms', for maintaining and controlling tool inventory and tool conditions, including those for FMM. Otherwise, the FMMP administrative procedure establishes and describes a FMM process to store, maintain, account for and control tools (including personally owned tools, if permitted) to prevent and protect the SSCs from FMI caused by inappropriate or faulty tools. Additionally, the governing programme document needs to establish requirements and controls for FMC devices and FMM materials (which may be stored in FMM cabinets, bins, shops around the common activity areas (as discussed in Section 5.5.4)) for their integrity, availability, accountability and maintenance.

Regardless of where it is described and instructed, in an effective FMMP:

— Tool and FMC device/material storage, maintenance, accounting and reconciliation controls include the requirements and expectations for identification, inventory, location and condition tracking of tools and devices, recordkeeping methods;
— Governing FMMP procedure (or implementing procedures) addresses the requirements for servicing and preservation of good FMM conditions for tools (e.g. tool integrity, cleanliness) and FMC/FMM materials, including those for their requests, procurement and delivery to the activity areas;
— Inspection of tools for moving, loose and missing items prior to and after use (see Section 5.5.3) is a required process (or a high priority expectation, as a minimum);
— Process for inspecting returned tools and, if identified, reporting lost, damaged, broken, incomplete, dismantled, fragmentary and defective tools is clearly described with the requirement that the tools to be collected and returned to the staging area as soon as practical.

Also, typically, there are strategically placed permanent or mobile cabinets and cribs for in general areas or activity specific locations to store other FMM materials, such as stickers/signage/boundary markers, tool controls, clear and coloured plastics, nylon panels, magnetic and Velcro straps, loops and hooks to attach and secure nylon or cloth panels to each other and to anchoring structures (e.g. handrails or guardrails, bottom to kickplates) to secure nylon or cloth panel skirting to floor structures.

It is a good practice to establish catalogues of available tools (including special tools, such as inspection, cleaning, search, recovery and retrieval tools), FMC devices (see Section 5.5.4) and FMM material, as well as their storage locations, i.e. tool and material rooms, tool cribs, material cabinets, bins, boxes, etc. This catalogue needs to be made easily available to site personnel, preferably electronically, and as applicable, in hardcopies.

5.5.7. Workshop practices

Maintenance, machining and other workshop areas may have multipurpose, for example as an activity area where work performed on components or a storage for parts, materials, components, tools, etc. Therefore, workshop requirements need to align with the requirements outlined in the FMMP governing document for activity, personnel, tool, material and their selection, use and storage which have been discussed in Sections 5.5.1–5.5.6 in addition to the programmes and processes for housekeeping and cleanliness that is discussed in Section 5.3.3.

Additionally, the FMMP administrative procedure may specify any other applicable requirements for inhouse manufacturing, refurbishment, repair performed in workshops. Examples of requirements and expectations in workshop practices that could be defined and described in FMMP include:

- The components being worked on being manufactured are to be protected against FM and FMI when worked on, left unattended or in storage to prevent FM ingress, generation and accumulation inside the components, including protection of internals from adverse ambient conditions;
- Again, particular attention needs to be paid to any internal FMC devices or shipping plugs which may have been installed in new, refurbished and being refurbished components;
- Shops ought to be kept to a high housekeeping standard and 'clean as you go' principles applied at all time;
- When working on or delivering items to/from the workshop, shop personnel need to make sure to place and keep FMM covers in place;
- Places/surfaces where the components are (or to be) worked on need to be carefully selected and staged such that FM is not inadvertently introduced into a component, i.e. not staging repair platforms on the floor where dirt might be blown into or fall inside of ends when the component is opened;
- During storage of components and equipment, where equipment and SSCs are unused or any openings are unattended;
- FMC/FMM devices to be installed and kept prior to the onset of refurbishment or fabrication of items that are worked on, such as raw pipe, need to be defined.

5.5.8. Training and qualification requirements

As discussed in Section 4.7, The FMM training and qualification programme results in only qualified people being assigned to corresponding particular roles and tasks in particular activity area/zone associated with FM risk level. Therefore, FMMP administrative procedure needs to clearly identify the qualification requirements and controls for each FMRL, FMCA and/or special activities. Subsequently, FMMP governing procedure provides and describes the key factors for the identification of training and qualification needs, target personnel and the development of training material, delivery and evaluation methods, as well as the type and frequency (initial, periodic and as needed) of specific FMM training.

The competency of information gained by the training, is ensured by both the conduct and the evaluation parts of knowledge acquisition and transfer. Hence, the FMMP administrative procedure needs to define controls and expectations for FMM training, for example:

- FMM training needs to be provided to an agreed programme and be recorded;
- As part of the training programme, an assessment of knowledge, awareness and skills gained on FMM is necessary. For particular tasks and personnel, this may require

undergoing formal qualification (certification) and authorisation for task performance and responsibilities, including those for FMM (for example, for maintenance staff);
- An evaluation of FMM training effectiveness, that is governed by the evaluation process within the training programme, needs to be performed. The evaluation is done against the approved FMM training needs and FMM training programme and process descriptions, as well as the formal QA requirements of SAT based training procedures.

As aforementioned in Section 4.7, the development of the training to support the FMMP needs to be in line with SAT methodology, but to simplify, the basics of the training can be covered by looking at the ‘5Ws’ of training: why, who, what, where and when, which indicate purpose, audience, content, delivery method and time and frequency, respectively, as discussed in the following Sections.

5.5.8.1. Purpose of training

The ‘why’ of delivering FMM training is relatively easy. For a project/plant FMMP to be fully effective, the personnel intuitively and continuously recognise the appearance of FM, its interpretation, e.g. its potential to intrude during task performance, and the prevention techniques needed to eliminate or minimise the hazard and risk. Communicating clear expectations to workers and including the purpose of the programme via the training programme provides the base knowledge to support the proactive approach of preventing FMI events.

It needs to be clear that training conveys information and provide knowledge to individuals and results in that qualification/certification which is a management system action that grants permission to individuals to perform certain roles or tasks per requirements and expectations described in the FMMP procedures. The FMM training is followed by a test or objective evaluation of the person’s skills and abilities so that management has a basis for granting authorisation to individuals to fulfil the role or perform the task in accordance with the skill, competency, experience and knowledge requirements and expectations of FMMP.

5.5.8.2. Training audience

The ‘who’ of training is a little more complicated. Dependant on specific worker responsibilities, the definition and identification of training audience may differ from one owner/operating organisation to another. Moreover, depending on the type, specialty, significance, complexity, routineness or frequency of activities, the audience will be different among the disciplines and organisations of the same site. However, common programme requirements include:

- A basic or introductory level of FMM training needs to be provided to all personnel who have unescorted plant access;
- Everybody at site need to have training to reach the same levels of FM awareness, understanding the purpose of the FMM and FMMP;
- Everybody on site needs to learn and understand their specific (required and/or expected) roles and responsibilities for FMM and for support the implementation and improvement of the programme;
- Both regular site staff and the contract/supplemental personnel understand the importance of a successful and effective FMMP and are familiar with FMM concepts and the FMMP requirements and expectations;
- Everybody at site has to have a basic understanding of the consequences of a loss or failure of cleanliness and housekeeping and/or control and management of FM.

Beyond these basic FMM training audience, the training is no longer 'one fits all'. Therefore plant's/project's FMMP defines the applicable FMM qualifications and the necessary training for these qualifications, which are to be geared and targeted to the different levels of FMMP involvement that exist amongst the work groups or levels within the organisation. Particularly, these work group include, as a minimum: maintenance, work management, operations and fuel handling, engineering, chemistry, radiation protection, QA/QC inspectors, supply/procurement and warehouse and security. It is necessary that both front line workers and contractor of these disciplines, as well as their management (i.e. frontline team leader/supervisors and departmental and divisional managers) attend these targeted trainings.

Also, among the particular roles that require specific training, the FMMP administrators (FMM Coordinators) and experts (FMM Conscience) are unique audience owing to their additional roles and responsibilities and required expertise, experience and knowledge in FMM and FMMP.

5.5.8.3. Content of training

All FMM training need reflect the basic FMM concepts and any specific FMMP requirements. Reinforcing FMCs are needed to anticipate, prevent, protect the SSCs from FM hazard, risk and impact, and to eliminate, minimise or mitigate a FMI incidents, as well as the importance recognising, identifying and immediately reporting of any potential FM hazard and risk to SSCs and FMCs are the basics of the 'what' of FMM training.

Again, the objectives, levels or degrees of training and extent or details of the courses are dependent on the assigned responsibilities of the training audience; however, the development of the training for the specific qualifications needs to align with the SAT methodology. Training material are to be prepared based on a set of determined and defined objectives, which may vary dependent on the target audience and the type, significance, specialty, complexity, routineness or frequency of activities.

Personnel who perform hands on work with plant SSCs ought to receive a higher level of training material and concepts. To be more effective, the plant/project worker training, that is geared to the tasks that particular individual or work group performs, may focus on, as applicable:

- FMM culture (topics related to the traits discussed in Section 5.3);
- FMRL assessments;
- Application of FMM requirements and expectations in task planning;
- Setting, maintaining and modifying FMCAs and FMCA buffer zones;
- FMM briefing and communication requirements;
- Control of personal items;
- Application, use, restrictions and exceptions on FMC devices, such as bungs, tethers, plugs, etc.;
- Material storage requirements;
- Activity generated FM control;
- Liquid and gas FM and their control;
- Conduct of FMM inspections and verifications;
- Reporting criteria, methods and tools for FM events, near misses, close call, identified issues;
- Conduct of FMM observations;
- FM recovery activities, tool and techniques;

— FMI recovery and evaluation requirements;
— Housekeeping and cleanliness requirements and behaviours.

All these focused training contents also include relevant OPEX to demonstrate and reinforce the consequences that poor FMC practices can have, and have had, on nuclear safety and performance across the industry, as well as other high risk/high consequence industries, such as aviation, food, medicine, pharmaceuticals, etc. Using OPEX to demonstrate how significant poor (or effective) FMM practices can be, is very helpful to connect the requirements and expectations to actual and real consequences.

Due to the important oversight, programme management and administrative functions that they perform, it is recommended by the industry experts that FMM Coordinators and FMM Conscience have additional information and knowledge over and above plant management and worker trainings. Similarly, owing to the significance of their responsibilities, independent inspectors and area monitors need to hold special qualification and receive training over and above other plant worker trainings. This special training and qualification need to reinforce the importance of their role and contain instructions for their roles, as defined/specified in the FMMP governing document, including:

— Accurate tool and material logging and reconciliation;
— Inspecting and controlling FMCAs and buffer zones;
— Loss of FMCA integrity identification and reporting;
— Conduct of tool integrity checks;
— Training qualification verification;
— Closeout inspection verification.

5.5.8.4. Training delivery methods

Design, development and delivery of training that meets the specified requirements of FMMP can include a e-modules, classroom, laboratory or simulator (i.e. mock-up and hands on) training. This can be referred to as the ‘where’ element of the training and, again depends on the nature of particular role, responsibility and activity. For example, hands on or mock-up trainings can be highly effective and strongly complement computer based or classroom trainings. These types of training may involve a dynamic learning activity (DLA) and needs reflect, as closely as possible, the conditions that would be expected in the field. FMM aspects need to be incorporated into all mock-up and hand on trainings for activities in which FM controls be required, needed and used.

The delivery method can also include audio-video material, e.g. books and notes for self-reading, OPEX videos for self-viewing, as well as daily office or field-based mentor and protégé approaches to transfer tacit knowledge.

Training methods for particular activities, as applicable and required, may be specified in the FMMP administrative procedure (or they may be referred to the administrative or task specific procedures and processes of other programmes, such as the training programme, for descriptive instructions. The FMMP administrative procedure still contains the criteria, requirements and responsibilities for designation and interface) in such cases and the FMMP owner and coordinator ensure that instructions regarding the FMM training are correctly maintained in those processes and procedures.

5.5.8.5. *Timing and frequency of training*

All plant/project personnel need to receive an introduction to the FMM and FMMP, immediately upon initial access to site, typically in conjunction with general employee training (GET). This course would provide the purpose and importance of FMM and FMMP and the general employee's responsibilities relating to FM awareness and management as discussed in Section 5.5.8.2.

More in-depth, higher level, specialised training may contain one or multiple times of delivery:

— *Initial task training* needs to be provided to workers and managers relating to their specific areas, disciplines and assigned tasks for being qualified or permitted to perform independent work;

— *Just-in-time training* may be used prior to a performing a specific task or supporting a project or program, for example, FMM monitor role, outage work, component replacement or modification. This type of training could involve communication of project requirements, DLAs or practice on mock-ups;

— *Continuing training* is an excellent opportunity to enhance and expand workers' FMM knowledge and awareness, particularly based on new information and knowledge, including the OPEX. The frequency of the continued training is typically set by the SAT methodology.

The following topics need to be considered for delivery during these sessions:

— Management expectation reinforcement;
— FMM programme, process or procedures changes, such as:

  - Restrictions and use of particular FMC devices, e.g. internal FMC devices, lanyard/tether applications and use;
  - Restriction and use of particular tools, e.g. wire wheels and brushes;
  - Internal FMC devices use;
  - Specialised FMC tool availability and use;

— Use of own and others' OPEX to improve performance:

  - FMM trend results and finding by CAP cause investigations;
  - Lessons learned relating to encountered FM related events, close calls and near misses during an outage;
  - Observation programme results;
  - Industry event or trends.

5.5.9. Activity planning

As discussed in Section 4.8, a complete, comprehensive and timely planning and preparation of the activity — with consideration of all associated human, environmental, material and financial conditions, as well as the resource needs and availability — is a cornerstone for achieving safe, efficient, and thorough task performance. The forethought, visualisation, organisation and preparation of the activity in terms of FMM aim safe and effective performance towards the completion of task(s) without an FMI event.

Based on all available general and task specific FM information, knowledge and experience (see Section 4.1.1), the activity planning involves FMM considerations to anticipate, identify and determine all aspects, including:

— Applicability of rules, requirements and expectations for the activity and its management;
— FM paths and FM targets that are (and could be) possible throughout the task performance;
— FM risks and hazards that would/could exist or be created during the task performance;
— Prevention and protection against the FM risk, hazards and their potential impacts and associated FMCs;
— FMM methods, tools, skills;
— Human and material resources that may be needed, support and interface required or needed and their coordination with all the involved individuals and organisations;
— FMM critical points during the activity, including information exchange; hold, review and check points, verifications;
— Job sequence, i.e. the order of task performance steps, that is the safest and most effective from the FMM perspective;
— Changes to plant conditions, area restrictions, process limitations and the course of activity performance;
— Arrangement and schedule of the tasks and task areas, including those of other activities that will surround/interface with the task area;
— Unusual, special and unique elements of the activity, particularly for those that would be performed for the first time;
— Contingency response for situations involving a high probability of loss of FMCs.

As a good practice, the planning also includes the considerations and recommendations for the optimisation of FM prevention, protection and control for, for example:

— Other possible and safe options for the order of activity steps, based on foreseen potential bottlenecks;
— Training and qualification of the activity workers and other personnel in terms of their numbers at a given activity step and time for dispersion of people to the work area (i.e. right people at the right time);
— Timing for appropriation of tools and facilities for gather/delivery to or storage in FMCA and surrounding areas for optimising inventory and movements of people (i.e. right tool at the right time in the right place);
— Types, scopes and intervals as to accomplish the purpose by self, second party or independent checks/inspections.

Accordingly, the FMMP governing procedures need to define and describe critical FMM and FMC requirements and expectations that are necessary and required to be considered in the planning for the task review, area and support review and schedule and arrangement review, which were defined in Section 4.8. Those definitions and description will establish a minimum common understanding and pre-set arrangements of aspects, particularly those that are discussed in Sections 5.5.1–5.5.8, to eliminate, minimise and manage FM hazards and risks during the actual performance of the activity.

Additionally, the governance of the FMMP need to define and describe the roles, responsibilities, competencies and skills tools for planning and planners, as applicable, including interfaces, communication methods. Noting that the FMM planning is a part of overall or departmental work planning, e.g. maintenance work planning, and FMM plans are typically considered and addressed within the main work package, FMMP needs to set the framework for the integration of FMM plans with overall work planning and work control programmes, processes and procedures of the facility/project.

The governing procedure may also recommend or require specific methods and tools for planning of particular task, its output and communication, as well as the contingency planning, which are discussed in the following sections.

It is also a recommended practice by the industry experts to standardise the FMM considerations in work planning (or the work packages at large) for the repeated and routine tasks. In such practice, the next performance of the task will only evaluate the difference (a.k.a. deltas) in the activity conditions from the standard plan (e.g. difference in the conditions around the work area) and will only consider new information and knowledge since the previous planning and performance of that specific activity.

Following Sections discuss, in more detail, the key steps in activity planning: preparation, documentation and change management.

5.5.9.1. Understanding the task and its conditions

Understanding the task and its conditions at planning stage can be established by many methods for various aspects of the task performance, for example:

— An initial and follow up joint walkdowns by the planners and performers visually would identify potential FM hazards and risks associated with job conditions, task and area controls;
— Risk and ramification, as well as the proper order of activity steps, may also be better understood by simulated and/or mock-up performances of tasks with the people who will perform the activity or have the same or similar skills, competencies and experience in performing the activity. (Including people with different skills, competencies or experience in the simulation/mock-up could also be beneficial for a better understanding of activity performance by the provision of different perspectives to avoid 'tunnel vision' and 'group think'. It may also help to have more people become familiar with the activity to prepare/plan for potential personnel changes during the actual activity performance);
— Tabletop reviews of previous post job debriefings and gained experience notes, knowledge sheets and discussions from the previous performance of the tasks or interviews with previous task performers are usually a good source for ramifications and potential improvements;
— Reviewing internal and external OPEX helps with the anticipation and understanding of mishaps and failures that could be encountered.

Specifically, the understanding of activity includes, as a minimum:

— Activity area and surrounding areas;
— Need, purpose, type and timing of FMC during the activity performance;
— Prerequisites for, and challenges of, executing tasks;
— Special competencies, skills, methods, tools needed and their timing;
— Possibilities/obstacles of information exchange mechanisms;
— Necessities/hinderances of inspections and verification that are required or could be needed.

Additionally, the management and mitigation of a high possibility FMI that may occur may also be considered.

The governing FMMP procedure instructions particularly need to ensure that workers and planners verify that correct FMCA boundaries and FMCs are specified in the work instructions during walkdowns of job sites/areas and review of work packages. The procedure also covers the actions to take when FMM instructions in the work plan are incorrect, unclear or omitted and the subsequent provision of feedback to the plan, in accordance with existing work management feedback processes, ensuring that the conditions and instructions are corrected for the current activity and recorded for future activities.

Process and methods for determination and verification of the list of FMM materials, tools and equipment that may be needed for the job (e.g. plugs, covers and caps) and their inclusion in the work package also need to be defined and described. Again, feedback mechanisms and the process of correcting work packages for missing FMM materials, tools or equipment together need to be identified in the FMMP governing procedure (or refer to existing work control and management procedures/processes) for the current and future activities.

5.5.9.2. Foreign material management plan

Output of the activity planning is typically a *FMM plan* document (or a set of documents) that describes the elements, aspects, interfaces and well-thought implementation scheme and strategy of FMM and FMC for/of a particular activity. Overall, the FMM plan is a communication method (see Section 5.5.10.1) as it contains a formulated written cross-organisational communication of the requirements, expectations, responsibilities, actions, methods, tools, that are necessary from all organisations involved in the activity, regarding the management of FM. This is typically a living document that is drafted, published, reviewed and revised for FMM considerations of an activity from the *preliminary FMM plan* to *baseline FMM plan* for final approval and implementation. As a usually practice the FMM plan is included in the work order package.

The scope and extent of the FMM plan, per the scaling in graded approach, depends on the risk and complexity of the job, as well as the involvement of multiple organisations and activities. FMM plans for activities with a high probability or consequence of FMI may be much more detailed to ensure organisations are adequately prepared and interfaces are strongly established that those of simple or routine activities with low FM hazards and risks. Regardless, FMM plans need to define and describe the FMM specifications and interfaces for the activity:

— In enough detail to establish and communicate a baseline plan that is capable of meeting FMM needs and means by all relevant and involved organisations;
— As far in advance as possible to facilitate appropriate reviews and approvals as well as completion of any preparation, e.g. procurement and training requirements/needs as part of the activity.

The FMMP document needs to provide clear guidance and criteria on the graded approach on the scope and extent of the FMM plan, that would include the following considerations and their weighting, for example (see also Section 4.5):

— Nuclear, industrial and radiological safety impacts;
— Plant performance goals and expectations;
— Degree of probability/risk of FMI event based on the existing/generated FMs, created FM paths and FM targets during the entire activity;

— Severity of consequences of FMI regarding safety, health, economic and financial aspects;
— Rarity/frequency/specialty of the activity;
— Complexity of the activity;
— Evolutions and interfaces involving multiple work groups;
— Level of interaction with parallel activities of the same or different scale.

Section 5.5.10.1 provides further details on the content of a typical FMM plan document that communicates FMM specifications and interfaces for the activity (e.g. FMM requirements, expectations, responsibilities, actions, methods, tools) between all organisations involved in the activity for the understanding and agreement of a common strategy and implementation.

5.5.9.3. Management of unplanned field changes

As aforementioned in Section 4.8, an activity planning cannot itemise any unplanned or unexpected profound conditions and needs that may arise during the course of activity (e.g. changes in plant conditions during operation and maintenance phase, field changes during construction, equipment failures). However, it may anticipate and provide contingency and allowance for rearrangement of FMCs for recovery of schedule and coordination of resources. The contingencies could be made a part of the main activity plan or may be a supplement to it as ‘contingency planning’.

Circumstances will inevitably arise where unexpected conditions are encountered which may affect or compromise the original FMM plan. Workers are expected to stop work and consult the supervisor in the event unforeseen situations for which they do not have sufficient training or adequate procedures or if a new FMM issue is discovered, which was not anticipated when planning the work. Any ‘at risk’ activity has to be acted upon immediately and actions to reduce any foreseen potential FMI risk are to be taken. The supervisor ought to be able to advise workers of proper FMM techniques at any point or be able to seek assistance from more knowledgeable individuals in the organisation.

In cases of changes to the FMM plan, existing FMRL particularly has to be reviewed and, if a higher risk is determined, then FMCA and all applicable requirements and expectations have to be transitioned. For example, one owner operating organisation, which is using a three zone, no risk, standard (or Level 1) risk and high (or Level 2) risk, has established the following requirements for FMCA transition up and transition down:

— To transition from a Standard Risk/Level 2 FME AREA/ZONE up to a High Risk/Level 1 FME AREA/ZONE (i.e. upgrading the zone) requires to:

  - Erect boundary perimeter, if not previously established;
  - Remove unnecessary and unessential materials, parts, tools, personnel, etc, from area;
  - Perform upgraded housekeeping activities inside new High Risk FME AREA/ZONE and adjacent area;
  - Assign FMCA Monitor and inventory and log all remaining items inside FMCA;
  - Post area as High Risk/Level 1 FME AREA/ZONE;
  - Maintain the area as per High Risk/Level 1 FME AREA/ZONE requirements;

— To transition from a High Risk/Level 1 FME AREA/ZONE down to a Standard Risk/Level 2 FME AREA/ZONE (i.e. downgrading the zone) requires to:

- Reconcile all log entries for material, tools, parts, etc.;
- Secure all system openings with approved FMM devices;
- Verify no High Risk FME AREA/ZONE requirements are present in the FMCA;
- Suspend logging requirements if no longer in effect;
- Suspend FM monitoring activities if not required;
- Post area as Standard Risk/Level 2 FME AREA/ZONE.

5.5.10. Activity communications and interfaces

As described in Section 4.7, the purpose of communication is to allow for the exchange of information; which may vary from policy and programme requirement/expectation to reporting incidents; or from formal signature for delivery or receipt of interface document, such as a checklist or a procedure to perform an activity to informal person to person discussions on observations.

Since 1990s, FMI event root-cause analyses have identified 'lack of communication' as one of the contributors during the operation phase [5], as well as other phases and activities [59, 60]. In the records of OPEX, FMI events due to lack of communication have often traced back to:

— Inadequate written and verbal communication;
— Failure (or non-existence) of formal interfaces;
— Omitted, contradicting or misleading direction and instructions;
— Insufficient coordination between individuals and groups at every level of the organisation.

These are very typical causes of any event in the nuclear or other industries. Specific examples of findings in nuclear industry include [5, 59, 60]:

— Lack of communication between workers (with internal and external organisations):

> "The incoming shift, after communicating with the outgoing shift, understood mistakenly that the workplace is now ready to be closed and that no tools or equipment left behind" [5]

- Receiving organisation of equipment delivery was not informed that FM covers would be placed around the primary container, and therefore:
  - o Did not take them into account in work order;
  - o Did not check for them before and during installation and thus left them on causing the equipment damage when it was put in service;

— Lacked, poor or insufficient communication between management and workers:

- Management directions were poorly communicated to workers regarding the interface between the groups performing work in the adjacent area, such that workers from both organisations had unclear directions on priorities:

> "Management expectations have not been formulated or communicated along with the station policy for adherence to foreign material exclusion (FME)" [5].

- Omitted supervisory emphasis on FMM considerations and practices for the upcoming activity:

> "Supervisory emphasis on the foreign material control during pre-job briefings and supervision of work activities, has been very limited" [5].

- Missed supervisory assertion of FMM practices during the observation of task performance at the field;
- The worker did not report to his manager and discuss with him the FMI near miss during the post job briefing;

— Lack of communication during the planning of activities:

- The worker did not take part in the preparation or review of the work planning and was not aware of FMM provisions of the work order were for protection of equipment important to safety;
- The planner was not informed about the FM issue that was faced during the last performance of the task;

— Lack of sharing operating experience information;
— Lack of written communication:

- Insufficient information in the user's manual concerning the FMM requirements relating to the approved work order;
- Missed recording of a deviation in the procedure which adversely affected the FMC set up by the following crew.

Consequently, communication of the activity's hazards, risks, conditions, prerequisites, work environment, worker qualifications, requirements, procedures and OPEX to every concerned personnel is of an utmost importance, at all levels and all directions. An effective communication and team support will allow individuals to receive the instructions, advice, information and support that they need. Conversely, the communication will allow them to provide the necessary feedback to his/her crew, organisation, others in the internal and external organisations to consider, implement and practice FMM and to improve FMMP in prevention of or protection against FMI events.

Therefore, as a part of the requirements and controls of the FMMP, the administrative procedure needs to identify the interfaces and the types of communication methods, tools and mechanisms (discussed in Section 4.7) needed for the exchange of for necessary or required information from FMM requirements and expectations perspective. As a minimum, the FMMP governing document needs to establish requirements and controls for formal communication methods and tools that include:

— Descriptive activity and work level documents, e.g., FMM packages and plans, including roles and responsibilities of those involved in the implementation, performance and support group interfaces;
— Instructional and prescriptive activity and work level documents, e.g., work orders and instructions, including the activity plan, checklists, flowcharts, that are part of the work orders and instructions;
— Job briefings;
— Signage and marking for FMM, FMMP, FMCA and FMM awareness;
— Programme and plant activity meetings, e.g. coordination, administration, review and committee/panel meetings, including periodic programme and task review sessions;
— Incident reporting;
— Operational experience reporting;
— Procedural review and checks.

The FMMP administrative procedure also needs to clearly define and describe the applicable requirements and expectations for these communication methods, tools, mechanisms and sessions. These requirements/expectations include initiating conditions, content and timing based on the purpose, significance, urgency and nature of the information that is required or necessitated to be exchanged, as well as the relevant participants and interfaces, for activity communication. For example, in some briefings, written forms/reports may be required or expected to be completed or signed to support, document and record the communication or transfer of information. Such requirements or expectations, when exist, also need to be defined and described by the FMMP administrative procedure.

Following Sections describe key communication methods, tools and mechanisms for an activity.

5.5.10.1. Foreign material management plan document

As defined in Section 5.5.9.2, the FMM plan is a cross-organisational written communication method, that notes, discusses and describes the management of FM during an activity, included in the final work order package for implementation.

There is no 'one size fits all' form or format for FMM plan and its preparation and distribution process requirements and expectations for *communicating* FMM specifications and interfaces for the activity (e.g. FMM requirements, expectations, responsibilities, actions, methods, tools) *between all organisations involved* in the activity. Such process requirements and expectations on how to establish an FMM plan would depend on the vigour and inabilities of an organisation, its culture and character, its strengths and weaknesses of organisational (internal and external) interfaces for communication. For example, the FMMP of an organisation may determine the scope and extent of FMM plans based on the level of activity conditions, communication or work practices that have been observed and are anticipated to still exist, while another owner/operating organisation's FMMP focuses on the activities on and around high-value SSCs. Some specific examples of the key concerns affecting the scope and extent of a FMM plan, as collected from the industry, include:

— Work/task procedures do not specifically address unique FMCs for the jobs that are assessed as high or standard FMRLs and for the associated FMCAs;
— Work is being performed in a continuously exposed area (e.g. spent fuel pool, refuel pool, steam generator, turbine generator) where the high risk and consequence and strict FMCs are required;
— Work is to be performed on SSCs/equipment that are extremely sensitive to FMI;

— There will be generation of debris in or near open SSCs;
— Evolutions involve multiple work groups;
— Evolutions involve multiple simultaneous activities;
— Component replacements or modifications, including large and complex activities, such as those conducted during plant construction or refurbishment, are extensive;
— There is long-lead needs and requirements for the activity, including those for procurement, training, etc.

Although the scope and extent of FMM plans will vary from one owner/operator organisation or from one activity to another within the same organisation, the contents of an FMM plan that is effectively communicating specification and interfaces of the activity would cover at least the following aspects:

— Identification of FMM plan, e.g. name/number, activity/task(s) to be performed;
— Purpose and scope of the planned activity/task(s) that present all involving/relevant FMM and FMC criteria in details, in a simple but complete manner;
— The expected activity time/schedule, duration and resources necessary, including the identification of plant's state (e.g. cold or hot shutdown, operation at full power or decreased power, maintenance or refuelling outage);
— References to applicable requirements, standards, and other necessary documents, such as administrative and technical procedures, manuals and drawings;
— Identification of lead person, group and organisation who prepare the plan (this is typically the official owner of the activity), including:

  - The names of plan's originator, preparer, independent reviewers(s), line management (supervisor, manager, director) involved in preparation of document;
  - The names of plan preparation team members, if applicable (for example, large and complex activities which involve multiple work groups, major plant equipment, extensive plant modifications, large project resource expenditures or high level of regulatory and/or safety significance may require a team of planners who would participate and coordinate the plan to ensure that FMM, FMC and all other applicable requirements are met in an integrated and aligned manner);

— SSCs and equipment that are involved and relevant, particularly those are important to nuclear, industrial and radiological safety, plant performance and/or extremely sensitive to FM;
— Required reviews and approvals, including their timing and order;
— Specific responsibilities of those involved in the preparation, approval and implementation of the plan, including individuals, organisations and inter-organisational committees/panels/boards and;
— Specific activity details (simple but complete, including the specific emphasis of any new, different, uncommon, unusual, distinctive matters):

  - FMRLs and FMCAs to be used, including any risk level and/or zone transitioning;
  - Preparation and assistance need from specific organisations (e.g. isolation of the systems, construction of special structures, such as scaffolding, barriers, shielding, insulation);
  - General and specific FMM requirements, such as work precautions, inspection and hold points, flushing, etc.;
  - Specific training needed to perform the activity in accordance with FMM principles;

- Type and timing of job briefings to focus on specific FMM requirements, controls and responsibilities;
- Any special FMCs to be applied, housekeeping and cleanliness requirements and expectations, use of FMC devices, etc.;
- FMCA access control and any turnover requirements for FMCA owner/controller;
- Controls required to maintain material or tool cleanliness in the FMCAs or buffer zones;
- Requirements for the use of overhead cranes, rigs, hoists, tools to be used, if necessary;
- Activity inspection requirements, including the inspection specifications, performing organisations and inspection stages/times;

— Other work in the area (or in remote areas) of the plant/project that could interfere with the FMM of the activity or may require the activity to be executed in a particular time, period or manner;
— FMM plan deviation requirements;
— FMI event response actions, including any specific immediate or other reporting requirements to ensure that FM and appropriate FMC measures are recovered and restored efficiently and in a timely manner, if applicable (for example, arrangements for mitigation of or recovery from an FMI event need to be specifically included in the FMM Plan if the probability of FMI is high and it is possible that FMC measures cannot be put in place due to certain or unusual circumstances);
— Other topics that need to be emphasised, such as:

- Applicable operational experience or lessons learned from the industry (or other industries);
- Information on the performance of the same and similar activities and plans that were completed previously.

Also, when activities are to be performed adjacent or nearby each other, there could be several FMM options to be considered and optimised. In such cases, it would be a good practice to include a ‘pros and cons’ matrix or impact/value, risk and/or cost/benefit analysis of each option and ranking and recommendation in the FMM Plan.

Again, the FMMP governing document needs to clearly and concisely specify the required/expected scope and content of an FMM Plan to ensure adequate, sufficient and timely communication and understanding of FMM requirements, aspects and interfaces for a specific activity by all who has to input, feedback, select, agree and approve FMM and FMC considerations. By doing so, the FMMP administrative procedure ensures that there is a standard application of a written communication of requirements, expectations, responsibilities, actions, methods, tools, that are necessary from all organisations involved in the activity, regarding the management of foreign material.

5.5.10.2. Job briefings

Job briefings are key communication tool involving the information exchange between an individual and group(s) on a particular task and on the associated requirements and expectations, as well as the potential challenges, including FM hazards and risks. It is essential to hold job briefings as a part of any activity (using a graded approach) where the information exchange would make the at-hand (or next round of) activity safer, more effective, more efficient and timelier. As such, the briefings typically take place between the supervisors/team leads and the worker(s), experts and worker(s), worker and group(s), and so forth.

The briefings may be conducted prior to beginning a task, during a certain stage of task and after the job is completed, formally or informally. If and when possible, these job briefings need to be conducted face to face and verbally (it is highly encouraged to use 'three-way communication' to ensure correct transfer and understanding), as well as written and visual materials (e.g. drawings, plans, maps, photos) that are necessary or helpful to elucidate the information being exchanged.

Typical job briefings and their purpose, content and timing include:

— *Pre job briefings:* These are the information exchange and communication sessions in advance of the tasks (typically close to the start of the work). which addresses all or most of the following using a graded approach:

  - Confirming each person is FMM trained and qualified to perform the assigned task;
  - Clarifying FMRLs, FMCAs and any other specific FMCs;
  - Discussing the known and anticipated environmental condition, e.g. heat, humidity, lighting, workspace type, size and obstacles, that may affect the safety of worker(s);
  - Reminding the roles of individuals in the execution and support of the job for critical aspects of task;
  - Noting FMM as-found and close-out inspections, and required check and hold points;
  - Discussing any anticipated challenging, special attention and care areas, potential error-prone situations and identifying required and expected responses;
  - Noting past internal and external OPEX (challenges, issues, errors, lessons learned) in the same or similar tasks;
  - Highlighting turnover requirements, including the stages of holding other job briefings;
  - Emphasising the self and peer checks, observation and their retainment for subsequent job briefings;
  - Reminding actions in case of an FMI event, unanticipated FM hazard and risk recognition;

— *Post job briefings:* These are the information exchange and communication sessions that are held after the completion of the tasks (as soon as practical) which communicate the FMM information that had been observed on:

  - Events, challenges, issues, errors that were encountered during the performance of activities;
  - Their impact on the task and worker(s),
  - Resolutions of challenges, issues, errors that were encountered;
  - Good practices in the performance of activities, that helped safety, performance and timing of activities;
  - Personal, team and programmatic lessons learned and 'good to know' key points.
  - These debriefings aim primarily collecting and disseminating such information, typically from the workers and job leaders about the work. This information also needs to be collected, reviewed, analysed and used to improve planning, preparation and performance of later same or similar activities. It is a good practice

that all identified experiences and lessons learned are formally documented so that it can be retrieved;

— *Scheduled mid-job briefings:* These are the information exchange and communication sessions that are held periodically, and/or when the special conditions make them necessary, as the activity/task/job is being performed and in progresses. Particularly, 'transitional' information exchange, i.e. mid-job briefings conducted when there is a transition from one phase of the activity, is essential to ensure the continuity and transition, which are very important elements/expectations of an ongoing task. Such phase transitions primarily occur due to, and be marked by, the planned/known changes that transform (or interrupt) the course and nature of the activity performance due to shifts in tasks, people and area.
An effective transitional information exchange by the planned and scheduled mid-job briefings accomplish the continuity in two-folds:

- Adequately and sufficiently capturing and transferring the information on the current status of the work, including the FM and FMC conditions, hazards, risks, type and results of completed inspections, areas of special attention, etc.;
- Communicating the current and upcoming status.
Accordingly, timings and scope of these transitional briefings correspond to certain milestones that are known/planned/scheduled to be changing the task phase, task performer and/or task area conditions, such as changing the task crew (*shift turnover briefings*), start of a critical phase of the task or an adjacent activity that has special impact (*phased job briefings*).
The continuity of activity and information, including the FMM and FMC aspects, during these transitions are very critical for safe and 'FM free' completion of the activity, for example:

> "At a plant, FMC plugs (which had not been previously used for application for the task at hand) were inadvertently left in internal vent holes in a primary heat transport pump. The large pump was disassembled by one task crew (who installed the FMC plugs) and reassembled by another one. As mentioned earlier, these plugs were being applied to the pump vent holes for the first time, and moreover, they were not documented and were not included in the discussions during the briefing by the first set of crews to communicate and turn over the task to the incoming crew. This omitted information of such unusual part/process resulted in a failed communication that was to ensure that the new crew knows and understands this new application, i.e. installation of FMC plugs.
>
> In addition, the closeout inspection (potentially due to the first time application and awareness of plugs) failed to find the plugs. After the inspection, still unknowing the plugs were applied; the second crew assembled the pump. After the system was returned to service, the pump was started and the normal running temperatures were quickly exceeded. Owing to the prompt recognition and reaction by the operation crew, the pump was immediately shut down prior to harming the pump and a significant damage was averted".

— *Unscheduled mid-job briefings:* Similar to the scheduled mid-job briefings, these impromptu briefings are the new information communication sessions that are held, when necessary, as the activity/task/job is being performed and in progresses. The difference is that unscheduled mid-job briefings are held when an unexpected/unplanned/unknown occurrence, or appearance of new critical/important information, that impacts/changes the task performance and conditions (as to, for example, the activity people, plan, area, instructions). Thus, the timings and scope of these 'new information communication' briefings are solely driven by the occurrence (e.g. *stand down meetings*), or the new information (e.g. *update meetings*), and their significance of impact on the task (i.e. on the task performer, purpose, schedule, steps or area conditions). These briefings are to adequately, comprehensively and completely communicate the change as to:

  - What the change is;
  - Why and where the information is originated;
  - Impact (or potential impact) on the ongoing task, including, among others, the FM and FMC conditions, hazards, risks, type and results of completed inspections, areas of special attention;
  - Specific impact on the previously known and communicated information of the work (i.e. that were covered during the pre-job and earlier scheduled mid-job briefings).

5.5.10.3. Activity area awareness

As discussed in Section 5.5.2, activity areas have to be established and controlled in accordance with the FMRL at or around the work being performed. This information on the work area identification and controls are to be communicated to all involved in the activity and all project/plant personnel who may be in the area or the vicinity.

For the people involved with the activity, the activity plan and job briefings communicate all the requirements and expectations in and around the activity area while they are performing or supporting the activity, including the awareness of FMCA boundaries, barriers and signs.

On the other hand, for the plant (or project) personnel, who are not part of the activity but need to be in the vicinity or general areas nearby, the FMM identification, restriction and applicable controls are necessary to be clearly communicated in order to have their awareness and not to interfere with the activity or violate the FMCA boundaries. Therefore, messages for general personnel awareness need to be communicated, for example, by the following methods, tools or mechanisms:

— FMCA identifications, such as signs, barriers and boundaries are posted with sufficient visibility and information (restrictions and cautions);
— FMC devices are clear for recognition, marked by wording and/or colour consistent with the site specific FMMP colour and wording (for example, as mentioned in Section 5.5.4, brightly coloured FMC devices to promote recognition);
— When changes to the activity areas occur, all signs, barriers and boundaries for general plant personnel are updated;
— Training covering activity area and controls are provided to all personnel to identify, recognise, interpret FMM devices, signs and associated reactions and requirements, including those for housekeeping, cleanliness, observation and reporting when around FMCA.

FMMP governing procedure needs to clearly specify the types, characteristics and placement manners of FMM signs, wordings, barriers, boundaries, etc., for the identification, recognition, interpretation of FMCs by all plant personnel. The administrative procedure also sets the general FMM training scope and topics for FMCA awareness, to maintain the integrity of activity areas, to understand and meet FMM requirements/expectations and to prevent and protect the health and safety of both activity workers and other plant staff.

5.5.10.4. Event, near-miss and close call notifications

When an FMI incident occurs, there are at least two stages of communication of the information about the event based on the purpose and timeliness: *Immediate communication* for notification and, subsequent, *systematic communication* for reporting the event and communicating detailed information:

— *Immediate communication*: This is the notification to all involved or relevant plant personnel of the FMI event for their prompt knowledge, review and assessment of the incident and existing and potential impact on the people and the SSCs being worked on and other SSCs in and around the plant/site. The prompt and preliminary review and assessment of FMI will determine the adversity and or urgency of the situation and its consequences based on what is communicated. Particularly, the immediate communication will be the basis for *immediate actions to be taken* at the work area (and plant/site, at large, if deemed necessary) to prevent further incidents and impacts as a result of the event that just occurred, such as:

  - Stoppage and assessment of additional activities in the activity area and surrounding areas;
  - Stoppage of running SSCs that may be impacted by the FM;
  - Prompt operability determination, declaration of any plant SSCs being inoperable or unavailable and due to the FMI or its impact;
  - Determination of needs or requirements for addition or relocation of FMC barriers to prevent additional events and personnel;
  - Mitigation and recovery assessments.

    Therefore, each immediate communication/notification ought to provide information correctly and completely to all involved or relevant plant personnel incident, which may have a different set of contacts for each incident. For example, if the event could affect in-service components or fuelling activities, immediate notification to operations is typically required. Subsequently, the event needs to be immediately communicated according to its nature, e.g. known or possible mechanical impact on the specific system or equipment and adjacent or downstream components, water chemistry, instrumentation, the electrical systems and equipment, radiological conditions.

    The communication method of this immediate information exchange is typically verbal which may include, for example, the notification of responsible FMCA personnel, activity supervisor/lead, control room, construction coordination centre (CCC), outage control centre (OCC), in person or by phone or radio;

— *Systematic communication*: After the immediate communication and prompt actions, the FMI ‘incidents’ (at this communication phase, not only the events, but also the near misses and close calls) are communicated to report and provide detailed information on the incident for further investigation and mitigative actions, and if identified, any corrective actions. Incident reporting is a written communication that could be followed

up by a verbal communication session for further information.
The methods and tools for *reporting/systematic communications* of incidents are defined and described by the project's/plant's management system for reporting non-conforming conditions. Therefore, FMI events, as well as near misses and close calls, need to be documented via the CAP to ensure that the appropriate measures are taken to investigate, correct and prevent or minimise recurrence. Further systematic communications of the incident information, investigation results, determined corrective actions and lessons learned to others within the organisation or the industry may also prevent similar events.

FMMP governing procedure needs to clearly specify the *immediate* and *systematic communication* methods and interfaces in case of an FMI event and refer to applicable programme, process and procedure for prompt notification and reporting of events, near misses or close calls.

5.5.10.5. Operating experience

It is proven that many industry events, including those that have been related to FMM, could have been prevented if the shared OPEX had been adequately communicated and, afterwards, reviewed, understood and applied. It is even more concerning that some of the FMI events, even the significant ones, have been reoccurring owing to the lack or ineffectiveness of communication of those within the organisation and with the peers in the industry. For example:

> "After damage at the Bruce Power NPP in Canada by contamination due to a lead blanket inadvertently left in one steam generator during maintenance activities, lead shielding was also left in the steam generator of Doel NPP in Belgium and is believed to have contributed to the severe stress corrosion cracking which subsequently occurred in that steam generator [61]. Similarly, steam generators with foreign material (lose parts), subsequently, encountered in several NPPs in different member states".

FMM involves utilising a large amount of information from different internal and external programmes and processes (e.g. maintenance, operation, chemistry control, design, fabrication, installation/commissioning, research and development (R&D)). Communication of this large amount of FMM knowledge and information (i.e. the 'Core', or the 'Know' stage, of continuous improvement cycle described in Section 4.4.1) is an essential part of a FMMP. Therefore, a proper communication consists of both collection and dissemination of OPEX and learning from programmes and processes and requires involvement of different and multiple internal and external organisations in the nuclear industry (and possibly from the OPEX of other industries) throughout the nuclear project/plant life cycle.

Considering the large amount of data involved, it is important to have a good information management (data collection and record keeping) system to assure adequate and timely communication. This is also very important for sharing knowledge among all relevant staff and organisations, both internal and external for common improvement including the establishment of new programs for newcomers. Therefore, an effective OPEX programme and the communication, maintenance and update of its database is an important element of FMMP for all relevant parties.

Concerning the FMM and FMMP at a site, the process to share, receive, investigate and apply OPEX is typically defined in the plant's/project's management system [62] by a centralised organisation [63, 64]. Typically, the organisation which administers and coordinates the FMMP is responsible and capable of screening or investigating internal and external FMI events, near misses and close calls, and reviewing and applying lessons learned from. The FMM coordinators and FMM conscience would have the expertise and experience, as well as the internal and external interfaces/contacts, for collecting, reviewing, assessing, applying and sharing OPEX related to FMM.

Therefore, the FMMP governance needs to include the administrative controls for good OPEX communication as follows:

- FMMP governing procedure, as a minimum, needs to define responsibilities, methods and interfaces for OPEX communication, including receipt, report and process, i.e. investigate and incorporate into FMMP and other communication programme, process and procedures related to FMM. These responsibilities, methods and interfaces need to be identified for both internal and external OPEX sources and partners;
- Mechanisms to incorporate FMM OPEX into other relevant programme, processes and procedures, such as those for training, maintenance, work management, engineering, etc., need to be identified (or referenced) in the FMMP administrative procedure, as well as the communication methods, such as OPEX discussion session in FMM committee, panel, board and management meetings. The FMMP procedure may also include the description of process from receipt of OPEX information to implementation of corrective actions for FMM OPEX;
- FMMP administrative procedure needs to refer to applicable programme, process and procedure for reporting of events, near misses or close calls. Also, the procedure may specify criteria and priority for the types of investigation that are appropriate for any category of FMI incident (event, near miss and close call or issues).

It should be noted that the large spectrum of OPEX source and receiver organisations include ongoing nuclear power plants, projects, programmes and technical and scientific support organisations which support these plants, projects, programmes. Also, technology vendors, designers, EPC contractors and manufacturers, regulatory bodies, industry associations, such as WANO, INPO, Electric Power Research Institute (EPRI), and technology owner groups[12], are other sources and receivers of OPEX. These information sources could also be extended to other industries (e.g. aviation, chemical and pharmaceutical, microchip and aerospace manufacturing, medicine, food) that may have similar requirements and expectations of foreign material (or in their terminology, foreign object/body/matter) control such that the FM hazards affect the safety. Therefore, it is a good practice to follow, search and review OPEX of other industries that may have similar foreign material/object/body management requirements and expectations against the FM hazards possibly affecting the safety and reliability.

As such, OPEX communication is a global information and data sharing that primarily relies on bilateral relationships, international reporting systems by national and international organisations (such as IAEA, OECD/NEA and aforementioned industry associations and technology owner group) and connections with responsible designers and manufacturers through contractual agreements.

[12] Such as pressurised water reactor (PWR), boiling water reactor (BWR) and Canadian deuterium uranium reactor (CANDU) Owners Groups (PWROG, BWROG and COG, respectively).

5.5.10.6. Programme awareness and status

A communication strategy that has the ability to convey information relating to the *importance, status and awareness* of FM, FMM and FMMP creates the opportunity to deliver just in time material or OPEX with all personnel at a plant or project site. The programme communication reinforces general staff's attention, awareness, information and shares programme status, including trends, good practices, areas for improvement. It is also a mechanism to announce programmatic or oversight changes, introduction of new products, etc.

There are various methods and tools to communicate the FMMP awareness and status to all plant personnel; however, the following common characteristics are shown to improve their effectiveness:

— The posters, bulletin boards and other general awareness messages are placed in 'high traffic areas' all around the site, such as workshop break rooms, cafeteria, site entrance/exit routes;
— More visual effects than words are used, (particularly what good and bad look like at own site, nuclear and non-nuclear industries in photos, videos, i.e. not many words);
— Videos segments of workers' and managers' testimonies (good and bad) that particularly illustrate the demonstrations of cultural traits, such as ownership, observing, reporting and not blaming are sharing/shown in, for example, training sessions, workshops, group meetings;
— Websites, electronic catalogues, blogs and newsletter articles published to provide opportunities to communicate, for example:
— Experiences, issues, opinions on FM, FMM and FMMP of workers and managers;
— 'Good/success stories' that share exceptional FMM practices, methods, events at the site during a period of time, e.g. month, quarter, year, outage;
— Face to face programme and/or status roll out meetings are held in small groups both in a specific discipline and mix of different lines of work;
— Metrics that measure the programme status are posted/shared in high traffic areas with the purpose of translating their meanings to day-to-day activity of a worker or a manager;
— Pictures, and if possible, actual samples of FM found in the activities and/or walkdowns within a period of time, such as monthly, quarterly, yearly, per outage, etc. are posted in high traffic areas.

Additionally, this *awareness and status communication* materials are to be made available to the temporary, supplemental and vendors' staff/workers in easily accessible and understandable ways, should their activities have the potential to impact the FMMP on site.

Similar awareness and status communication mechanism utilised by non-nuclear industry also provides good sources for finding, selecting methods and tools. For example, Appendix V provides some communication practices in the aviation industry.

As one last note, the methods for awareness and status communication may become more complicated (but very important) when working with multi nationalities, cultures and languages during plant construction and refurbishment, for which IAEA has observed several good practices [65]:

> "Several NPPs provided guidance, manual, procedures in different (workers') languages or employed interpreters. For example, at Ringhals NPP, guidance information was placed in the plant's reference system both

in Swedish and English languages. In Temelin NPP, a pocket size outage information guide describing the objectives of the outage, health and safety protection of personnel, fire protection principles, FME provisions, and other outage related item related to the expectations of behaviour of personnel was developed and issued to personnel involved in outage activities. This guide was produced in Czech and English to allow for a wider distribution and understanding of the important information needed to be adhered to during a plant outage. As a result of the issuance of the booklet issues arising out of coordinating activities were being rapidly and frequently communicated by working level contractor personnel to the outage management organisation. This condition prevented waiting for the next daily meeting to be the forum to raise the issue or concern. (The IAEA OSART team noted as early as 2000 that it was unusual in the industry for plants to be using such a communication tool while it is still in the start-up phase of operation)".

5.5.11. Programme assessment and improvement requirements

Management (and frontline) needs to be aware and informed of the strengths and weaknesses of their own organisation, other organisations and interfaces in establishing, administering, maintaining and applying FMM and FMMP. Lack of an effective and structured process to identify, analyse and correct (and keep records) issues, deficiencies and weaknesses in FMMP and FMM practices, as well as the expression of views to the decision and programme authorities, would result in accumulation of errors and deficiencies in conduct of and processes for FMM. Consequently, this accumulated errors and deficiencies, some of which would go unnoticed until an impact appears, could lead to significant FMI events that jeopardise safety and reliability and/or efficient and effective performance of the nuclear power plant.

Therefore, the plant/project management needs to proactively check, identify and correct weaknesses in FMMP and associated programmes, processes, practices and procedures, which requires their (and relevant plant staff's) active support for routinely observing, reporting, monitoring, trending and assessing to identify any areas for improvement.

More importantly, improvement process also necessitates the establishment, application and improvement of tangible measures and metrics to assess the status of FMMP, its implementation and FMM practices regarding the detection of declining (or improving) performance or measuring effectiveness, which are discussed in the following Sections.

5.5.11.1. Measuring effectiveness

To maintain an effective FMMP, the organisation needs to develop measures to identify whether the activities relating to FM and FMM are deteriorating or are being maintained or improving, and more importantly, to determine actions to control, manage and improve the programme and its implementation, as stated in a widely referred quote by Dr H. James Harrington:

> "Measurement is the first step that leads to control and eventually to improvement. If you can't measure something, you can't understand it. If you can't understand it, you can't control it. If you can't control it, you can't improve it".

Before any further discussions on the methods and tools for measuring, it is important to emphasise a few points for the measurement process and efforts:

— The purpose of measuring programme effectiveness is to understand, and consequently, to identify actions to manage and improve, the programme and its implementation;
— Measuring programme effectiveness is a part of the learning and informing culture towards continuous improvement and sincere organisational commitment to the safe and efficient operation.

Moreover, numerical measures (e.g. indicators and metrics) for measuring programme effectiveness:

— Are to understand and to interpret programme's status and trends;
— **Are not** criteria for rewarding or punishing individuals or organisations;
— **Are not** for counting events/errors/failures.

As stated by the INSAG, in the publication INSAG-13:

> "Numerical measures must always be subject to careful interpretation and be used as part of an overall judgement about performance. They should not be regarded as an end in themselves" [66].

Therefore, the measures (e.g. indicators and metrics) are to be selected and tailored primarily towards identification of the underlying causes and precursors of any defect and deficiency (as well as the strength) in FMMP and associated process and procedures. This identification, in turn, will lead to determination and implementation of corrective (or, in cases of strengths, cultivating) actions.

Additionally, the performance indicators serve to ensure that decision and programme authorities become, and remain, aware of actual practices and values in the field, including those of external organisations (working either at the owner/operating organisation's site and facilities site or at their offsite facilities). Measures also provide avenues to set/revise performance goals and expectations and gaps in overall performance, and to communicate them to plant/site personnel.

Therefore, effective organisations develop and use metrics/indicators to monitor, measure and improve performance — including the FMMP performance — both reactively and proactively, by observing, collecting, analysing and assessing such indicators and their trends. Development of metrics for activities and processes could be undertaken in a manner similar to that described in Ref. [66]. For example, a set of indicators for FMMP may reactively measure effectiveness of:

— Recent and current performance of FM and FMM related tasks;
— Current awareness of past performance;
— Effectiveness of determination and implementation of preventive and corrective actions;
— The attitudes and behaviour of staff, managers and authorities.

It is also important to establish and use forward looking (sometimes referred to as 'proactive' or 'leading') metrics/indicators to measure the awareness, identification and recognition of potential efforts to improve FMMP, the associated processes and FMM practices in the conduct of future activities. While such proactive measurements provide opportunities to anticipate, predict and pay attention, for example, to developing or accumulating issues, they indicate early signs of declining performance and processes in order to take proactive measure to correct or change path and trend towards inevitable failures.

The indicators could also be quantitative or qualitative, latter of which, particularly forward looking, could be very difficult to develop and tangibly assess. For example, measurements of general, or task specific, personnel behaviour and attitudes in FMM are typically qualitative in nature. On the other hand, the quantitative indicators (metrics) are relatively easier to develop and assess and provide a more practical input to the monitoring and assessment of performance of activities with the observance of FMM. Quantitative indicators can also be tailored to measure the health of FMMP, and associated processes and procedures, by monitoring, for example:

— Number or consequences of errors in communication of FMM information and errors in the execution of activity (such as both in its performance and in its inspection) which may provide indications of:
  - Lack of competencies and skills;
  - Insufficient or deficient work instructions, procedures;
  - Insufficient or inadequate training;
  - Values/importance of FMM to staff and management;

— Repeated FMM incidents and deficiencies — when underlying errors and deficiencies could be quantified — which typically provide a measure/indication of:
  - Failures or defects in the CAP as to the determination and implementation of adequate, timely or effective corrective actions after the earlier incidents/deficiencies;
  - Organisational problems, such as not being a learning organisation, particularly in such cases where the errors are the same as the ones that occurred in the past (internally or externally);
  - Issues with the correctness and adequacy of previous assessments or with analysis and communication of OPEX (which may also point to issues, for example, with OPEX programmes and processes).

Concerning the last bullet on repeated incidents and deficiencies, it should be noted that both consequential (FMI event) and non-consequential (FM near miss or close call) incidents usually have similar, if not the same, underlying causes. Therefore, being aware and correcting the causes of non-consequential also contributes to the measurement of the effectiveness of the programmes and processes and help to take corrective or improving actions to prevent potential future events. Accordingly, the monitoring and assessment of all incidents need to be included in the FMMP improvement.

5.5.11.2. Key performance indicators

If one considers the extent of administering, maintaining and applying FMM and FMMP in addition to interfacing/interacting programmes, processes and procedures, there may be a large amount of performance indicators either in the FMMP or, since the management system integrates them, in other relevant programmes. However, a smaller set of high value (as to measure and be informative towards the improvement/correction) performance indicators/metrics that would represent substantial portion of characteristics of past, current and future status and performance with low impact (as to requiring resources), to monitor and assess FMM and FMMP, as the ‘key’ indicators — which are called *key performance indicators* (KPIs). The KPIs are, therefore, selected and used to measure the significant portion[13] of overall FMMP health status and trend.

The selection and use of KPIs are primarily based on the corporate strategy, safety and performance goals and FMM commitment and policy as to why something needs to measure and what needs to be measured for that purpose. Therefore, FMMP KPIs maybe different for each owner/operating organisation; however, an organisation does not need to start from scratch to establish their FMMP KPIs since:

— There have been joined efforts by nuclear plant owner/operating organisations that established a set of common FMMP KPIs. For example, INPO [9] and WANO [11] have published industry developed and adopted metrics which categorise FMI events based on the severity or consequence of the events. A points system is then used in conjunction with level of significance and is presented on a monthly basis as well as a rolling average which is used as an indicator for measuring the overall number and significance of FMI events. Appendix III provides an example of this KPI and the metrics associated with it. A variation of this indicator, in addition to others, can also be found in EPRI guidelines [10];
— There may be already existing KPIs for the other programmes and processes within the plan/project organisation;
— There are already established KPIs for FMM, FMMP in many other industries, such as aviation, medicine, pharmaceutical.

Accordingly, an organisation could use such existing KPIs (or adopt a derivation of/from them) for their FMM and FMMP performance measure, if the existing KPIs or a link/derivative of those are adequate and sufficient. For example, there might be an existing KPI used by the plant/project organisation for measuring the Maintenance Programme performance, say: ‘actual versus expected maintenance duration’, which can be derived into a FMMP KPI as ‘outage extension due to FMI’.

Some organisations may still desire, however, to measure other aspects that is not associated with any existing or derived indicators and, thus, need to create a totally new KPI indicator that is more suitable and applicable to their specific or unique conditions, strategies and areas of interest/attention to help with continual improvement.

It should be noted, from the OPEX, that sometimes performance indicators that is not significant for programme/process improvement are erroneously considered as ‘key’, which can be detrimental as follows:

> “As a result of considering performance indicators that have no or little value to the improvement of FMM or FMMP erroneously considered as ‘key’, tracking, managing, assessing, reviewing and reporting efforts, and as such dedicated resources (human and financial), unnecessarily increase. Large amounts of unfocused/untargeted/useless (i.e. non-key) indicators that deemed as ‘key’ without a basis or with no application to improvement, eventually become a burden for the entire organisation. This burden continues to increase to a point that the management could totally stop using

[13] As a commonly known rule of thumb, the 80-20 approach (commonly referred as the Pareto principle), i.e. 80 per cent of consequences come from 20 per cent of causes, could be a good practice in starting the selection of KPIs.

all programmatic KPIs, including the good ones, as performance indicators seem not adding too much value but having too much impact on the human and financial resources”.

Regardless of numbers or types of KPIs, the FMMP governing procedure needs to clearly specify and describe programme effectiveness measurement KPIs as to:

— Meaning of (i.e. what it is measuring) and reason (i.e. why it is measuring) of KPI;
— Grading scale and associated criteria/thresholds/rules;
— Weighting and the basis of weighting;
— Analysis and assessment methods and tools;
— Reporting requirements (as to role and responsibilities, scope and content, communication type, media and periodicity, etc.);
— Management review response and feedback process;
— Process of reporting and resolving adverse results and management feedback.

Again, it is prudent to reiterate that the reasons for selecting and the application of KPIs are:

— Foremost and certainly, not about establishing criterion for rewarding or punishing individuals or organisations;
— Not for counting events/errors/failures[14];
— Not about having or creating artificial or ‘to go on the books’ metrics that have no use for programme assessment and improvement — as unnecessary KPIs will cause a blurred vision of the programme status and trend resulting in incorrect or ineffective management decisions and actions that are not effective or that create more issues.

5.5.11.3. Observation and reporting programmes and processes

The primary input to programme assessment and improvement is the checked, identified and recognised issues, challenges, adverse conditions and weaknesses (and strengths) in activities, people or environment involving FMM and associated programme, processes, practices and procedures. The collection of this input requires management’s and relevant plant staff’s active support for routinely monitoring, observing and reporting to identify and correct/improve.

Typically, monitoring and observation of FMM activities at the field need to be done at several levels:

— By workers during their (and their peers’) activities;
— By FMM experts (i.e. the FMM Conscience of the plant/project) during, administration, coordination and field verification of the programme and associated activities;
— By supervisors, managers and executives during their field visits and inspections;
— By certain plant staff that are performing routine non-FMMP related tasks in the general areas, for example, operations and security personnel;
— By all plant/project employees during their general routes, areas and activities.

As discussed in Section 5.3.2, (although the clear ownership of the FMMP itself is assigned to certain organisation and people) people at all levels within the organisation have ownership of

[14] Noting that, in some industry groups, this is one of the KPIs for FMM and FMMP ; however, it has a particular purpose, which is to have a standard criterion to compare/grade plants and to assess overall industry performance; and is not considered directly to indicate/measure the improvement of people or programme by a specific organisation, within the context of their corporate strategy and culture.

their activities and ownership in oversight, assessment and improvement of the programme. Accordingly, everyone (including the management) is responsible to ensure that periodic observations are conducted to monitor compliance with (and practice of) FMM requirements, expectations and behaviours.

For example, plant managers and supervisors conducting observation by way of frequent tours of plant areas can confirm, by seeing it first hand, that standards are maintained and that any deficiencies are identified, controlled and eliminated and activity workers; and other frontline personnel can observe and report conditions that may cause FM and FMM problems. Security personnel can be provided with FMM training on types of items and situations that they can observe during their patrols, so that the FMMP can be enhanced by taking advantage of these additional field observations.

To ensure observations are detecting and correcting at risk behaviours, observers need to be adequately knowledgeable of the FM, FMM and FMMP, to identify, recognise and interpret the observed/monitored issue. Therefore, it is necessary to consider, for example, to:

— Provide appropriate and sufficient training (as described in Section 5.5.8) at each level in accordance with their required, expected and desired involvement in monitoring, observing and reporting;
— To conduct paired observations (for example, walk down teams consisting of FMM/FMMP expert(s) and frontline and management staff) to ensure those performing observations are adequately skilled to spot deficiencies and provide the proper timely input for correction needed.

Therefore, plant's/project's observation programme(s) need to specifically identify the needs to observe FMM practices during appropriate work activities. As such, the FMMP governing documents need to define or describe observation activities as to where and when to look for what and how to report it. These governing descriptions include the settings, e.g. during job briefings, activity implementation and general area walkdowns, to discuss and ascertain whether, for example:

— Pre-job briefings address specific FMM activities and expectations;
— FMCA controls are determined and implemented;
— Appropriate barriers and signs are installed and clear to understand;
— Personal items are secured or controlled;
— Tools going in and out of FMCAs are inspected, are clean and serviceable;
— Lanyards are used as required or tools are failsafe;
— Lay down or disassembly areas are established as necessary;
— FMM documentation in the work packages is complete;
— FM reconciliation logs are established and kept properly;
— The use of FMC devices and techniques conform to the plant/project standards;
— 'Clean as you go' and other behaviours for cleanliness and housekeeping is practiced.

These definitions and descriptions from the FMMP governing documents might be incorporated into the implementing procedures or formulated to provide quick and easy reminders of what to look for during job briefings, activity implementation and general areas.

Overall, it is essential that the tracking of observations and findings are sincere and systematic to allow, for easy review and assessment to assist with program health evaluation, and more importantly, to encourage desired ownership, observing and reporting behaviours.

5.5.11.4. *Assessments and audits*

In an effective and continuously improving FMMP, all the elements of the FMMP are subject to periodic or causal assessments and audits, in accordance with the established programme guidelines and processes. In depth assessments and audits may be performed regularly or in response to trend or event findings and may involve document reviews, observations or interviews with individuals who regularly perform, coordinate, oversee manage and direct work, tactics and strategies with FMM implications.

It is important to note that, the assessment and audits ought to focus on the programme, processes and procedures and deficiencies/defects in the management, coordination and implementation system, rather than the examination and critique of the individual performances.

Assessments and audits can be performed by parties who are internal or external to the programme owner within the owner/operating organisation (i.e., self-audit) or the site organisation, at large (i.e., peer audit/evaluation). Self-evaluations, i.e. the self-assessments and audits conducted in a target organisation or at the overall owner/operating organisation levels, achieve improvement through:

- Building common commitment to corrective action and key attributes within the owner/operating organisation;
- Getting management and staff of all involved entities in the identification of problems in their own and peer organisations;
- Providing experience and assistance in identifying, assessing and correcting problems;
- Focusing on programmatic performance problems and deficiencies at all levels;
- Providing training in observation, assessment and auditing skills, competencies and expertise.

On the other hand, the peer evaluations, audits and assessments are very effective in identification and documentation of problem (or are to be problem) areas. Even in the self-assessments, it is a good practice to involve some external experts to provide an objective and unbiased peer view as well as the assistance with identifying and introducing good practices used elsewhere. (Here, it should be noted that when they are considered to be adopted, 'Good' practices of other plant/project owner/operating organisations need to be carefully evaluated for their effective applicability with the same process or to obtain same results. One's good practice may be 'not good' when applied to own organisations owing to the differences in organisational culture, skills, competencies, experience, work processes, corporate strategy).

Whether it is self or peer assessments or audits, the line management of the FMMP line management (and the line management of the department(s) that was targeted in the assessment) is responsible and accountable to resolve the identified issues, i.e. finding. Similarly, only high-level management is capable of making the changes to improve decision making processes. Moreover, for these assessments and audits to ultimately result in improved FMMP and FMM performance of the entire plant/project organisation, there needs to be a strong executive and line management commitment for finding the 'truth', for receiving and accepting the results and timely implementation of appropriate corrective actions within the organisation. Furthermore, in the case of findings pointing to external organisations, the executive management ensures that they are communicated, and the corrective actions are implemented in those organisations.

The assessments need to be designed to verify how the FMMP, requirements, expectations, principles and objectives are being implemented and cover the following aspects, as a minimum:

- Standards, guidelines, procedures and expectations used for the FMMP;
- The definition and implementation of responsibilities for the FMMP;
- The incorporation of FMM and FMCs into work plans and work instructions;
- Maintenance practices and techniques;
- Inclusion of FMM specifics in job briefs;
- Availability and accessibility of FMC/FMM materials and tools;
- Management and supervision knowledge, behaviours and practices;
- FMM specific training for the direct staff and contractors;
- Contractor and vendor FMMP knowledge and compliance;
- Warehouse storage and transport standards;
- Housekeeping and cleanliness standards, behaviours and practices;
- Identification and reporting criteria and practices for FMI incidents and trending;
- Communication and use of OPEX, internal feedback, including the analysis of FMI events;
- Effectiveness of previous corrective actions;
- Results of self-assessments, independent reviews, peer reviews and benchmarks;
- Performance indicators and their effectiveness for FMMP status and improvements.

In addition, results of regulatory reviews and inspections, as well as results of peer reviews and benchmark need also be taken into account in the assessments of the overall effectiveness of the FMMP. Corrective actions and opportunities for improvement need to be identified and implemented.

The FMMP administrative procedure needs to identify and define the requirements and expectations for conducting an assessment or audit. These definitions include the type, scope and periodicity, as well as the possible causes, for conducting and receiving assessments (self-assessment, peer assessment) or independent audits at all levels of the organisation. The administrative procedure also needs to identify and define (or refer to other programmes/processes) the methods for evaluating the assessment/audit results and implements corrective actions.

5.5.11.5. Recognition of declining programme effectiveness and conduct

The results of regular and consistent monitoring, observing, assessing and trending provide important input to the viewing overall instructional and compliance picture, while the results of assessments and audits provide in relation to FMMP administration, coordination and implementation in an organisation. However, they all need to be interpreted and understood in order to recognise and act upon the attributes of declining performance for the improvement FMMP. Based on OPEX and past observations, typical attributes of declining performance include:

- Lack of management commitment and support for the FMMP;
- Inadequate or no communication of expectations and standards for FMM to those concerned (plant/project staff and contractors);
- Bypassed or worked around FMCs because either seen as obstacles or delaying meeting schedule demands;
- FMM and FMMP are seen as a burden and useless;

— Relaxed FMRLs on case by case basis but inconsistently;
— Poor delimitation and/or enforcement of FMCA boundaries;
— FMC equipment and tools not readily available and/or not used;
— Poor housekeeping practices and inattention to cleanliness are tolerated;
— Lack of ownership for the FMMP and FMM (the programme is seen as the responsibility of particular groups, e.g. maintenance, or individuals, e.g. FMM Coordinator(s));
— Poor quality of FMM procedures;
— Recurring FMI incidents;
— FMM requirements, equipment and tools are deemed to be not a part of activity and not need to be specified in work packages;
— Insufficient focus of FMM as part of the training, job briefings, etc.;
— No or relaxed independent verification of implementation of FMCs;
— Unspecified FMM inspection requirements (for activities, as well as for receipt of pre-assembled parts and equipment supplied by vendors);
— Poor reporting of FMM issues;
— Lack or inexistence of systematic and/or consistent communication or use of FMM OPEX and lessons learned.

Additionally, close observation of attitudes and behaviours (as well as changes to those) of the frontline and management staff provides additional, and as important, information in the identification of declining performance and compliance. The attitude of the organisation, management and staff can also be an indication of causes of declining performance in any programmes, processes and practices, including FMMP and FMM. Typically, the primary common behavioural signs, organisational and personal pitfalls of declining performance and effectiveness include, for example increasing cases of:

— Complacency (‘we know everything’, ‘we never had an issue with that’, ‘it is as good as it can get’);
— Hubris (‘we are the best experts and workers’, ‘we do not need anybody else to tell us what to do’, ‘the industry come to us to learn what good is’);
— Not learning from experience (‘we had that issue before’, ‘we heard about a similar issue from another plant a while ago’);
— Lack of exploration or innovation for improvement (‘if it works don’t fix it’, ‘we have always done it this way’).

5.6. ASSIGNING ROLES AND RESPONSIBILITIES TO INDIVIDUAL AND ORGANIZATIONS

Ultimately, the owner of the operating license for the facility is accountable to the public (and other stakeholders) for the proper implementation of the plant’s programmes, processes and procedures for safe and reliable electricity generation. This proper implementation also includes the FMMP and associated processes, procedures and practices for ‘foreign material free operation’ as a part of ensuring nuclear and radiological safety and performance. Therefore, the responsibility of FMMP and different programme elements need to be a part of the owner/operating organisation and the roles are assigned (or delegated) effectively throughout the organisation — in accordance with the activities at different lifecycle stages as discussed in Section 3. In effective implementation of a FMMP that every person in the organisation understands and owns his/her roles and responsibilities in the programme to achieve ‘no-adverse effect of foreign material’ on safe, reliable and efficient operation of the plant. To ensure ‘foreign material free operation’ and to eliminate adverse effect of FM on safety and performance, it is essential that the roles and responsibilities for all levels of the organisation are *clearly* defined, documented, communicated and agreed.

Firstly, it is necessary to acknowledge that the need and scope for FMM differ in each phase of nuclear power plant project and nuclear power plant lifetime. Accordingly, the organisation first needs to determine what programmatic, administrative or practical activities will be necessary and, then, selects the preferred ways to coordinate and perform these activities before establishing roles and responsibilities at a given stage of NPP's lifetime.

Furthermore, when the programmatic, administrative or practical tasks are coordinated and executed, there is a collegial relationship among all involved departments and all concerned parties to ensure that the activities are conducted based on collectively agreed roles and priorities. This ensures that the tasks are implemented with all FMM aspects are appropriately, mutually and completely addressed. For that purpose, cross-organisational channels need to be defined and put in place to communicate input from (and output to) those who are working together in different organisations and different tasks. This makes it necessary to prevent overlap or contradiction of responsibilities with assigned authority and responsibility by clearly defining an agreed, followed and respected task distribution throughout the organisation.

Again, there is no 'one size fits all' approach for assigning roles as they can be distributed in many different manners at different stages (and activities) of a plant life cycle. However, there are common practices, that can be observed in effective organisations, for *assigning tasks to the right person at the right time*. As discussed in Ref. [57], the effective organisations follow a systematic approach that is conducted in the following order:

(1) Knowing and understanding the programmatic, administrative or practical activities and tasks needed and the time when they are needed, as to:

- The nature, area, discipline of the activity;
- The area of the activity;
- Systems and materials involved in the activity (and consequence of material being left in that system);
- The duration and periodicity of the activity;

(2) Determining the level of competencies, skills and methods/tools needed;
(3) Evaluating available (or potential) means and resources against needed tasks and competencies;
(4) Planning, deciding and organising based on the 'needs' and the 'means' (i.e. human and financial assets) that are at hand, available and accessible;
(5) Arranging and sizing the organisation such that people and responsibilities are assigned according to the tasks, rather than arranging tasks according to the size or form of the organisation or the personnel at hand;
(6) Setting up clear functions and scopes for each organisation such that there is no overlap of scope, no shared responsibility and no competing authority;
(7) Defining formal and structured interfaces, for example, with:

- A single point of contact for internal and external interfaces;
- Responsible individuals in other key organisations who contribute to better and quicker understanding of interorganisational needs and capabilities (who also act as eyes and ears for the programme owner and coordinator(s) in the field);
- Interface documents, such as baseline information documents and checklists;

- Communication protocols, including scheduled or unscheduled bilateral and multilateral meetings.

Therefore, specific and rigid organisational structure for FMMP is not a primary factor provided the core FMM activities, roles, tasks and interfaces are correctly identified and performed in a timely manner and satisfactory FMM is provided for a safe, sound decision to be made. As such, in order to establish, implement, coordinate and maintain a FMMP effectively, it is particularly important to first focus on the core activities and scope (i.e.: *'what needs to be done?'; 'what skill, competency, authority is needed?'; 'how fast/often it needs to be done?')* rather than, a predetermined rigid organisational structure or titles, i.e. focusing on '*who needs to do it?'*.

For example, one of the common tasks in the implementation of an activity in the entire industry is the 'activity planning', for which one can walk through the process to find the best person as follows:

— Task at hand is the preparation of the FMM plan (which is **what needs to be done)**;
— One owner/operating organisation may require the preparer of the FMM plan to be a person who completed and met the requirements of the '*proficient level FMM/FMC training'* and *'maintenance FMM training'* and hold a *'maintenance FMM qualified'* certification, while another plant/project may additionally require the completion of the *'maintenance work planner training'* and *'hazard identification and analysis training'* and hold a *'low risk radiological work planner'* qualification. Moreover, the requirement may include activity lead and above authority (this is **what skill, competency, authority is needed)**;
— The FMM plan is for a routine preventive maintenance of a specific system which is performed every outage (which answers the **how often it needs to be done)**.

In an organisation, there may be several people who can meet the qualification requirements and can prepare the FMM plan. Then:

— The task can be assigned to an organisation where it can be done in the most effective and timely manner, for example, it could be a maintenance lead or supervisor, or it could be a lead outage work planner;
— Alternatively, one plant/project may choose to have several people involved, for example one non-lead staff for the hazard identification and analysis (for which he/she is qualified), another non-lead staff to develop the FMM plan (for which he/she is qualified) and another, who is a lead and have authority to review and finalise the FMM plan;
— Even another alternative could be preparing a standard FMM plan for this task (since it is same task repeated every outage) and perform the full task if there is a deviation from the standard task, e.g. new FM hazards, new FM targets due to a new adjacent activity. This would enable to minimise or eliminate work and time of qualified people (or organisation) when it is unnecessary.

Regardless of particular structure or method for accomplishing tasks, following Sections provide several examples of how specific roles and responsibilities may be assigned to NPP staff positions or departments involved in FMMP. Again, it needs to be noted that these are only examples that are typically observed in the nuclear and other industries. They are collected and presented together as comprehensive lists. Some organisation may have all of them, while some distribute the same roles and responsibilities in a shorter (or different) list of individuals and organisations.

When reading the organisational examples in the following subsections, it has to be kept in mind that the basic premise is 'what needs to be done', and then, which individual/organisation needs to maintain adequate and proper capacity, capability and cooperation/collaboration and needs to be organised, based on: (1) individual and organisational need and scope for FMM; (2) individual and organisational competencies and qualifications needed for FMM. Consequently, the roles and responsibilities (as well as titles) will be assigned throughout the organisation.

Therefore, the organisation needs to focus on the roles, tasks, responsibilities and qualifications listed in these examples, rather than who is assigned (by title or position) in the organisation.

5.6.1. Typical individual roles by position in the organisation

Every staff (from the highest ranking officer down to the people conducting the daily activities) in all organisations participating in the FM related activities and tasks need to clearly know and understand what their role in the FMMP is and how their workplace, skills and knowledge are to be used in achieving sound decision making on the issues regarding the FMM. This necessitates the identification of which decision making, on what aspect of FMM, is applicable to who in the organisations. For example, role and responsibility for 'FM awareness' is applicable to everyone in every organisation in the plant/project, because everyone needs to be able to recognise FM and interpret it for its potential hazard. On the other hand, some staff will have additional specific role and responsibilities (such as the programme owner who has additional decision making on maintaining and improving the programme).

Following subsections provide a typical list of individuals and their roles and responsibilities starting from the highest-ranking officer down to the people conducting the daily activities. It needs to be emphasised again that, regardless of rank and place in the organisation, every position, role and decision is equally important for implementing, maintaining and improving the FMMP, and therefore, the sample list provided herein is not in a particular order of importance of decision making on FMM[15].

5.6.1.1. Plant Manager

The **'Plant Manager'**[16] is the ultimate decision-making person with the most authority (i.e. the decision authority, as described in Section 5.4.1.1) in the plant/site/station. His/her authorisation level decisions include those for setting the plant/project goals, expectations and policies for all programmes, processes and the activities performed by everyone (including contractors), as well as those for creating and maintaining a culture and work environment for safe and efficient nuclear power generation.

The role, responsibilities and accountabilities of 'Plant Manager' for FMMP, as the decision authority, involve ensuring establishment, implementation and maintenance of an effective

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[15] The point of this emphasis is that some cliché slogans, such as 'frontline workers are responsible for FMM' or 'the FMM programme coordinator is responsible for FMMP', may be detrimental and skew to responsibility to one individual or organisation.

[16] The term *'Plant manager'* can have different titles in different Member States and different NPPs, such as, chief nuclear officer, chief engineer, site manager, executive vice president, executive president, etc. The title used herein indicates the highest level of manager in a nuclear plant/project (e.g. nuclear power plant project company, nuclear power plant operating organisation) who is responsible for overall executive decision making for the site/project which cannot be delegated. Therefore, hereafter, it will be referred in quotation as a representation of the position, not the title.

FMMP with a strong foundation, framework and an aligned direction for its integrated application in overall facility programmes, processes and activities, including:

— Establishing and communicating FMM policy, expectations and objectives in accordance with the corporate commitment;
— Ensuring that a FMM culture, such as ‘no blame culture’, exists in the organisation for encouraging reporting of FM incidents;
— Fostering awareness, ownership, accountability and communication in the organisation on FMI event prevention objectives (for example, ‘zero FMI event’, ‘foreign material free operation’ goals) as a part of nuclear and radiological safety and performance;
— Communicating site FMM policy, expectations and objectives to the offsite vendors, suppliers, contractors to ensure compliance;
— Ensuring that the site implementation of the FMM policy, programme and plans regularly reviewed against the objectives and the FMM objective reviews and programme status updates are included in periodic senior management meetings;
— Demonstrating personal commitment to the FMM policy and showing personal involvement in the application, understanding, alignment and permeation of good FMM practices throughout the organisation (for example, by conducting frequent informal visits to the activity areas, shop floors and training classrooms, general or organisational FMM review meetings/briefings to observe the conduct, to obtain first level feedback from implementation).

5.6.1.2. Foreign material management programme owner

As defined in Section 5.4.1.2, programme authority for FMMP is the FMM Programme Owner, who is the person with responsibility and accountability for owning and overseeing the programme and with authority for making *administration level* decisions on the governance of FMMP. The FMM Programme Owner role is assigned by the ‘Plant Manager’ to a senior manager in the next layer of management (typically the highest level manager of the division that is most concerned with FMM, i.e. the head of leading organisation, for example, the *vice president of operations* of a nuclear power plant organisation as it may be structured for a particular operation phase).

The FMM Programme Owner assumes responsibility for the development, implementation and continuous improvement of the FMMP towards *foreign material free operation* and *no-adverse effect of foreign material* goals. As such, the FMM Programme Owner controls the concept, framework and contents of FMMP and makes administrative level decisions on the provision, application and preservation of the FMMP to establish and integrate all FMM principles, requirements and expectations into daily activities at the plant/project/site together with the owners/authorities of other programmes.

Specifically, the FMM Programme Owner’s roles and responsibilities include:

— Controlling and managing FMMP and its administration by deciding on the determination, coordination and oversight of programmatic governance, implementation, as well as the associated resources, information and assessments;
— Providing necessary information, tools and financial and human resource allocation to individuals and organisations who perform activities for administration and coordination of FMMP, including the approval of acquisition of FMM information and knowledge means and needs;
— Cultivating FMM culture by supporting and encouraging all organisations to perform their assigned work properly, e.g. by identifying the targets of ownership in order to have

those individuals and departments to understand and assume the ownership of their part in the FMMP;

— Providing input and advice from the FMM perspective for an executive decision to be made by the ‘plant manager’ and/or by the executive committee(s), i.e. by the decision authority. Here, it should be noted that, in some cases, it may be possible that ultimate decisions are made heavily and/or primarily based on the FMM facts, such as a decision on FM mitigation method or timing following an FMI event. In those special cases, the FMM Programme Owner (or delegated programme coordination authority and decision maker) can have a major role in the final decision making (including vetoing, or requesting change to, the decision solely due to solid FMM concerns). It is important that prerequisites, criteria and steps for such special cases need to be defined in the relevant programmes and procedures of the organization;
— Developing (or reviewing) and approving strategies, plans and processes for FMMP and FMI event prevention in accordance with the corporate strategy and schedule;
— Developing of long-term plans for resource and knowledge management for the continuously effective FMMP administration and implementation for FMI event prevention with quality and longevity;
— Reviewing and assessing the FMMP and making decisions on revisions, when deemed necessary;
— Reviewing key performance indicators for monitoring the health of FMMP and its implementation (lagging), as well as for identification of weakening/degrading areas or potential future issues (leading), and accordingly, establishment/approval of metrics to measure effectiveness against the FMM objectives;
— Presenting programme status and assessment result/conclusions in periodic senior management meetings to provide forward opinions and suggestions, as well as to solicit feedback, regarding the areas for improvement and strength of FMMP;
— Deciding on self-assessments or peer reviews of FMMP with internal/external participants;
— Addressing the FMMP implementation problem areas that are identified by trend analysis and assessments;
— Ensuring that the programme requirements and expectations (and changes to those) are communicated to the entire organisation involved with FMMP and the compliance with unique FMM requirements affecting certain organisations is checked and verified by:

  - Proposing and designating the preparation of FMM training, including the review and approval of training modules, enabling objectives and curriculum;
  - Ensuring that all FMMP requirements are being incorporated in departmental training, procedures, work orders, instructions and they are followed by the personnel;
  - Creating, and overseeing the activities of, FMM review group(s) that consist of representatives from all relevant departments which meet periodically, and when necessary, to communicate and discuss FMM and FMMP issues, ideas, concerns;
  - Ensuring the assignment of departmental focal points in each department;
  - Ensuring FMI events are thoroughly investigated and corrective measures for preventing recurrence are identified and implemented;
  - Ensuring near misses and close calls are being reported and properly investigated and, if any, lessons learned for preventing future occurrences that could lead to an event are developed and incorporated in the FMMP and other programmes, processes and procedures;

- Ensuring timely implementation of corrective actions related to FMMP and FMI prevention throughout the organisation;
- Requesting evaluations from other internal/external organisations to prevent, detect, monitor and correct potential FMI precursors;
- Ensuring the coordination of FMMP requirements, expectations and practices throughout the organisation by:

  - o Assigning expert(s) and focal point(s) for the coordination of programme administration, implementation, maintenance and improvement;
  - o Providing such expert(s) and focal point(s) with ownership, authority and organisational freedom to identify and request implementation of FMM measures whenever and wherever required;
  - o Obtaining an understanding, recognition and agreement from everyone in the organisation(s) on the authority given to such expert(s) and focal point(s);

— Conducting regular scheduled and unscheduled visits to the areas and activities controlled by the FMMP, as well as group staff meetings, training classrooms and shop floors, etc., to:

- Share values and vision by sincere and wanted interaction;
- Observe implementation of the FMMP, compliance with its requirements and expectations, effectiveness and awareness;
- Point out and discuss (good or bad) observations with workers, work area supervisors;
- Collect prompt and first-hand feedback.

5.6.1.3. Foreign material management programme manager

In some operating organisations, due to significant involvement and performance of activities that may have direct impact on FMM and FMMP, certain directors/managers may be delegated to carry the administrative responsibility and the coordination level decision making authority for the programme. In such organisation structure, the **FMM Programme Manager** is the individual who implements and oversees the FMMP with delegated programmatic and administrative authority and responsibility, assuming all (or some) of the responsibilities of the FMM Program Owner that is listed in Section 5.6.1.2. This delegation is proposed by the FMM Programme Owner and approved by the 'Plant Manager' based on premise of certain department or group having more opportunities for implementation, prevention and improvement. For example:

> "The construction manager is typically appointed to own, implement and assess the programme as the FMM Programme Manager during the construction phase while operations manager may assume that role during the commissioning phase. Similarly, the maintenance manager assumes responsibility as the FMM Programme Manager of the plant for the ownership, administration, implementation and improvement of the FMMP towards prevention and elimination of FM hazards and events at the facility during a typical operating organisation".

FMM Program Manager also reviews and manages the assessment of programme implementation, the FMMP status/needs and presents his/her conclusions, opinions and advice on the FMMP and its administration and implementation to FMM Programme Owner and/or

‘Plant Manager’ as input to executive decision making. He/she could also present, if exist, to the decision-making bodies/groups, such as an executive committee or board.

Again, the boundaries for delegated decision-making responsibility and authority on the programme administration need to be clearly established and communicated to the entire organisation and they are understood and agreed. Also, in cases where the FMM Programme Manager has a major role in the final decision making, prerequisites, criteria and steps for accomplishing that role need to be defined.

5.6.1.4. Foreign material management programme coordinator

All the aspects of FMMP (including associated processes, procedures, requirements, expectations, rules, essential information, knowledge) are obtained, verified, understood, interpreted, communicated and expressed in the daily tasks and practices. These activities that involve FMMP need to be coordinated with a high degree of expertise, applicability, accuracy, completeness and timeliness around facility in order to achieve a safe, sound FMM decisions at every level. This coordination is accomplished by a dedicated group of staff, who have competency, proficiency, expertise, knowledge, experience in FMM and FMMP and hard and soft skills in the organisation, led by the **FMM Programme Coordinator**.

Appointed by, and reports to, FMM Programme Owner/Manager, the FMM Programme Coordinator is the focal point for FMMP and its implementation and maintenance. He/she is the primary interface between the management and the frontline for the management and improvement of FMMP and FMM practices at the nuclear power plant (or project) to:

- Provide input and advice to both plant personnel and managers — typically through FMM Programme Owner/Manager and committees/boards — on effective FMM and improvement of FMMP;
- Collect feedback and suggestions from both managers and plant personnel for FMM and FMMP and incorporate those into the programme, as applicable;
- Support determination, acquisition, provision, sitewide coordination and oversight of programmatic information, knowledge, status and assessment.

As the site FMM expert (or the leader of expert group), the FMM Programme Coordinator, assumes the roles and responsibilities for decision making at the coordination level with sufficient authority and organisational freedom to observe, control, identify, report and implement FMM practices and FMC measures.

Therefore, the roles and responsibilities of a typical FMM Programme Coordinator in the industry cover a large spectrum from provision of administrative and procedural perspective of FMMP to practical and technical presence/involvement in the field implementation and performance of tasks. In this large spectrum, his/her specific responsibilities include:

- Maintenance of the FMMP administrative (governing) procedure to ensure its adequacy, correctness, completeness, clarity, applicability and timely use;
- Preparation (or supporting preparation) of FMMP administrative and implementing procedures (including the supporting/supplementing documents, tools and means, such as checklists, logs, report forms, etc.) to establish the standard framework for FMM application throughout the organisation;
- Review and validation of all the aspects of the FMM plans and programmes are being addressed and implemented in the procedures and processes of relevant departments;

- Preparation and communication of FM anticipation, prevention, elimination, exclusion, mitigation and investigation instructions and key knowledge sheets;
- Request and collection of evaluations from other internal/external experts to prevent, detect, monitor and correct potential FMI precursors for reporting to the FMM Programme Owner/Manager and other relevant departmental leadership;
- Conduct of area walkdowns for activities, that are controlled by the FMMP, to:

  - Observe and collect feedback on compliance, effectiveness and awareness;
  - Recognise the FMM culture in action (including good and bad cultural traits, e.g. awareness, housekeeping, cleanliness, application in general plant areas);
  - Point out and discuss observations (good or bad) with workers, work area supervisors in a constructive manner (i.e. coaching and praising), in the context of FMMP and from the FMM and FMMP expert's perspective;
  - Note and report possible areas for programme improvement to the FMM Programme Owner/Manager;

- Participation in special activity coordination meetings, such as daily outage meetings, work planning meetings;
- Following up on FM related events, near misses and close calls to:

  - Confirm that they are properly reported and investigated ensuring their adequacy and completeness from FMMP perspective;
  - Provide expertise and input to investigations, when needed;
  - Incorporate lessons learned, if any, in the FMMP and associated processes, procedures and instructions;

- Coordination of, and participation in, scheduled inspections and audits of the work areas, procedures and processes of related departments with the oversight organisation(s);
- Determination of applicability of external FMM and FMMP implementation issues to the plant organisation(s) by reviewing and analysing OPEX in industry databases and any other relevant sources, such as nuclear and/or non-nuclear industry studies, events, practices;
- Participation in benchmarking activities and industry working groups to follow, observe, learn and share industry good practices and lessons learned;
- Recommendation and/or incorporation of updates to FMMP based on the lessons learned by, for example:

  - Area and activity walkdowns (his/her own and others') and collected post job briefing notes and task knowledge sheets;
  - Following up on FM related events, near misses and close calls;
  - Reviewing results of investigations, evaluating the adequacy of corrective actions and recommendations for corrective action, if necessary;
  - Reviewing OPEX from the plant and nuclear or other industries;

- Provision of assistance and FMM expertise in the identification of training needs and target audience, as well as supporting the development of training material, delivery and evaluation of training (initial, periodic and as needed);
- Identification and coordination of procurement and supply of FM prevention and control methods, devices and tools to the requesting/needing departments;
- Maintenance of metrics/performance indicators to monitor and measure health and effectiveness of the FMMP, including:

- Performing trend development, analyses and identification of internal FMMP implementation problem areas by using the results of analyses;
- Preparation of technical results and observations to provide them to FMM Programme Owner/Manager and relevant organisations;
- Preparation and dissemination (site wide posting) of effectiveness review results, particularly those areas with exemplary improvement or degradation, to the site personnel or relevant specific departments/sections through the appropriate communication media;

— Maintenance of FMM campaigns, such as FM Awareness postings, FM Alerts and other FMM and FMMP related communications to the entire organisation;
— Reporting of all FM related issues (including periodical updates on the programme status) to the FMM Programme Owner/Manager (and, if requested, to 'Plant Manager') and providing recommendations for the improvement of FMMP elements.

Although it may be a good practice to have a focal point (i.e. a single point of contact, SPOC) for FMMP coordination and maintenance at a plant/project, as it can be seen above, the FMM Programme Coordinator usually has a large amount of responsibilities and tasks. This has presented an issue, by itself, for effectiveness (or even existence) of FMMP, as it is observed in the OPEX:

> "Overloading of FMM Programme Coordinators has been a challenge throughout the world for both the FMM Programme Coordinators and the NPPs, particularly creating problems in maintaining and managing the programme, such as:
>
> — Burning out of FMM Programme Coordinators with overwhelming tasks resulting in frequent turnover of the personnel that has required hiring or developing technical staff, who have competency, proficiency, expertise, knowledge and technical and soft skills, assuming the roles and responsibilities.
>
> — Organisation(s) and/or FMM Programme Coordinators starting to prioritise responsibilities and tasks which results in only the tasks with this 'perceived and accepted' high priority getting done completely and comprehensively while the others get done 'when time is available.
>
> This, in turn, has caused:
>
> — Omissions and deficiencies in those activities owing to cursory work.
>
> — Slowly eliminating tasks, that are under the responsibility of FMM Programme Manager, by inadequate or false justifications/reasons (mostly based on artificial priority criteria and bases) or establishing situational and shortened lists or frequency of tasks in the same manner.
>
> — Increasing costs of FMMP and its maintenance and management, resulting in questioning the cost/benefit of the programme.
>
> These three main problems have resulted in degrading FMM practices and ineffective FMMP, decreasing attentiveness, seriousness and meticulousness

> of FMM Programme Coordinators and plant staff or, even worse, slow and eventual elimination or marginalisation of systematic and formal FMMPs.
>
> Consequently, in some Member States, plants are considering the elimination (or they are eliminating) FMM Programme Coordinator position altogether by process changes as a part of change management plans for efficiency increase and cost reduction" [67].

Some plants/projects chose to solve these problems by systematic and conscience actions to maintain or improve effectiveness of FMMP coordination, maintenance and implementation tasks and activities. Primarily, these plants/projects have driven the programme coordination to 'shop floors' and/or 'expert groups', for example, by:

— Permeating responsibility in the organisation to perform most of FMMP coordination tasks/activities correctly and effectively after identifying/determining the core responsibilities of an FMM Programme Coordinator and then assigning other responsibilities in one or both of the following manners:

  - To individuals who are distributed in the departments, where the programmatic responsibilities for field implementation and performance of tasks could be accomplished more effectively, providing clearly defined interfaces and protocols between them and the site FMM Programme Coordinator, who remains as a focal point;
  - To committees of representatives from departmental levels and layers that can perform review and assessments and can provide consensus recommendations to the FMM Programme Coordinator and/or to the FMM Programme Owner/Manager;

— Centralising responsibilities in a group of staff, who have competency, proficiency, expertise, knowledge and technical and soft skills, in a dedicated FMM Programme Coordination Group, under the leadership of FMM Programme Coordinator, as the *FMM and FMMP conscience* of the plant/project (see Section 5.6.2.13).

Sections 5.6.1.5 and 5.6.1.6 discuss these permeated and centralised FMMP administration arrangements that are implemented by the management of various owner/operating organisations, respectively.

5.6.1.5. Foreign material management department coordinator

In order to resolve the challenges with the large number of responsibilities and tasks assigned to the FMM Programme Coordinator, several plant/project organisations have chosen to permeate some roles and responsibilities of the FMM Programme Coordinator — specifically those which had less to do with the programme management and had more involvement with the field implementation of tasks/activities — and created **FMM Department Coordinator** positions.

The FMM Department Coordinators are local (e.g. in/of a department or a line of work) FMM experts with competency, knowledge and technical and soft skills for FMMP and its coordination and execution, in addition to their core work proficiency and skills. They are delegated to carry FMMP coordination responsibilities in/for their department and are the primary interface between the FMM Programme Coordinator and the frontline (i.e. as a bridge integrating the FMMP administration and execution for the management and improvement of

FMMP and FMM practices). Furthermore, they are given sufficient authority and organisational freedom to observe, control, identify, report and implement FMMP activities and measures at the department level. Therefore:

- An FMM Department Coordinator is appointed by his/her departmental manager with a request and approval by the FMM Programme Owner/Manager and the FMM Programme Coordinator;
- The responsibilities and accountabilities of an FMM Department Coordinator, as well as his/her authority to locally coordinate and/or implement FMMP activities and measures, need to be clearly defined and described the FMM Programme Owner/Manager and the FMM Programme Coordinator (and agreed by the departmental manager and the employee).

Possessing the awareness, ownership and the channels of communication on both FMM/FMMP aspects and the tasks of his/her department, with their FMM and FMMP expertise, information and knowledge in both areas, they would be able to:

- Coordinate specific FMM tasks/activities, that are related to their own profession and departmental task performance, more closely and specifically;
- Provide expert opinion, input, feedback, suggestions and recommendations on FMM and FMMP related issues and areas for improvement (or overall programme improvement) to FMM Programme Coordinator and their line manager from task performance perspective;
- Identify and evaluate FMI precursors, hazards and risky conditions for prevention, detection, monitoring or elimination/minimisation in departmental activities;
- Provide input and suggestions to the workplace frontline personnel on awareness, recognition and solution of FMM challenges and on the effectiveness of FMM and FMMP implementation in their activity execution;
- Collect feedback and suggestions from line manager and workplace colleagues for FMM and FMMP and communicate those the FMM Programme Coordinator, as applicable for the FMMP improvement.

The specific responsibilities of FMM Department Coordinator, which are a set of the responsibilities of the FMM Programme Coordinator at the departmental level, typically include:

- Ensuring the FMMP administrative (governing) procedure and departmental implementing procedure are adequately, correctly and timely aligned and harmonised;
- Supporting development of departmental implementing procedures (including the reflection of supporting/supplementing documents, tools and means, such as checklists, logs, report forms) to comply with and reflect the standard framework for FMMP implementation and application in own organisation;
- Following up on all the aspects of the departmental input and feedback on FMM plans and programmes are addressed and implemented, as applicable, in the procedures and processes of own departments;
- Conducting walkdowns of the areas and activities of own department to observe and coach programme and implementation effectiveness and culture in action (also observing good and bad cultural traits, e.g. awareness, housekeeping, cleanliness in general plant areas);
- Discussing (coaching and praising) observations (good or bad) with workers, work area supervisors from a local FMM and FMMP expert perspective, as well as reporting the

observations that point out areas for potential programme improvement to the FMM Programme Coordinator;

- Following up on FM related events, near misses and close calls in the work area to confirm that they are properly reported;
- Identifying and communicating procurement and supply of FM prevention methods, devices and tools to the FMM Programme Coordinator and line manager;
- Collecting and reporting departmental metrics/performance indicators FMM Programme Coordinator and line manager;
- Ensuring that FM Awareness postings, FM Alerts and other FM related communications are provided to own organisation.

Generally, having local programme coordination persons, such as the FMM Department Coordinators, at the 'shop floor'/execution level is deemed as a good practice with some observed advantages, for example:

- Departmental programme coordinators are closer and more frequent to the activity areas, shops and the issues, and therefore, they can provide more focused FMMP execution and FMM support for the task at hand which they are familiar with;
- Combined ownership and commitment may provide stronger and faster response and resolution of needs, such as proper identification and coordination of acquisition and provision of FM prevention methods, FMC devices and tools, owing to internal prioritisation and allocation of the needs;
- As the organisation consists of all parties familiar with the tasks/activities, all similar task aspects can be considered together with the similar FMM and FMMP aspects for an integrated preparation and implementation;
- FMM support is generally specific, and the FMM Department Coordinators is likely to be familiar with the majority of the tasks owing to the routine, repetitive or similar nature of the tasks, and therefore, the application and implementation of FMM and FMMP requirements, expectations and instructions are more effective.

However, disadvantage of such practice may arise from isolation and division (for example, from FMM needs and solutions of other departments, from the FMM Programme Owner/Manager or from FMM Programme Coordinator). Another disadvantage may be associated with overlapping responsibilities and authorities, for example, with those of the site FMM Programme Coordinator.

These disadvantages necessitate preventive measures and administrative controls on adequacy and control of interfaces and communication (particularly between the FMM Department Coordinators and both departmental staff and the FMM Programme Coordinator), as well as on clear roles and responsibilities for each coordinator's tasks. These measures need to include formal periodic meeting of FMM Departmental Coordinators and FMM Programme Coordinator. It also needs to describe methods and tools to exchange FMMP coordination information as to when and how to communicate on a regular and *ad hoc* basis.

5.6.1.6. Programme coordination organisation staff

Another organisational manner of solving issues and challenges about large number of responsibilities and tasks assigned to the FMM Programme Coordinator and associated challenges, some projects/plant may choose to centralising responsibility in a dedicated group of staff in a single division (or section/group), such as a FMM Programme Coordination Organisation.

FMM Programme Coordination Organisation is the group of staff who have competency, proficiency, expertise, knowledge and technical and soft skills that is the *FMM/FMMP conscience* of plant/project for coordination. This section consists of experts from key organisations with primary tasks/activities in the implementation of the FMMP, such as maintenance, procurement, warehouse, operations, radiation protection, engineering, training, chemistry, etc., in a matrixed pattern. This pattern is ‘provider based’ and intends to provide long term services to all disciplines of the plant/project through a single organisation providing FMM and FMMP coordination support and technical conscience.

Typically, FMM Programme Coordination Section is placed under the FMM Programme Owner/Manager, i.e. ‘FMM programme authority’ (see Sections 5.6.1.2 and 5.6.1.3), is the focal point and the coordinator of FMMP implementation and maintenance at the site. At the coordination level, the section is responsible for coordinating the performance of tasks relevant to the practical, technical, procedural and administrative aspects of the FMMP, as well as for expressing and reporting to the FMM Programme Owner/Manager the relevant technical input and perspective (see Sections 5.6.1.2 and 5.6.1.3).

Advantages of a centralised FMMP coordination support structure include the following:

— The section is under the FMM programme authority and the owner of the FMMP, and therefore, all aspects of FMMP coordination, control, assessment and maintenance are addressed comprehensively and efficiently;
— The staff consists of experts in key areas and functions, and thus, the section holds extensive knowledge and experience in a variety of aspects of systems, components, activities and tasks;
— Members of the section are focused on and dedicated to FMMP coordination and FMM;
— The staff are close to each other and familiar with each other’s technical, programmatic and personal capabilities and competencies;
— The sectional personnel have not only formal interfaces with the site personnel, but also informal interfaces with the organisations in their area of expertise;
— A consistent standard is applied to all members in the section, with the associated consistent set of instructions, processes, procedures, expectations and training for the FMMP coordination;
— Overall plant/project FMM and FMMP priorities can be addressed by concentrating personnel on the big issue(s) at hand.

On the other hand, there are drawbacks associated with a centralised structure, noting that these are less problematic than having one single FMM Programme Coordinator. Some of those disadvantages (and potential tactics to prevent or overcome them) could include:

— Having one group serving many customers can cause prioritisation problems in the coordination of support, although. This can be resolved, however, by reaching an understanding and agreement on the priorities between the section, the customer and the programme authorities;
— The section is not close to the activity performing organisations and therefore may not fully understand the recipient’s issue and environment and may not be able to determine a perfect solution or options for the issue. This can be prevented by keeping close contact with the recipient organisation (e.g. frequent visits, walkdowns and discussions with the activity performers, observing the issue by being present in the recipient’s environment, talks with staff who identified or described the issue);

— The members of section may focus too much on their own and closely associated areas of expertise in key areas and functions, systems, components, activities and tasks which may cause segregated perspectives and actions. This may necessitate standard and/or formal guidance and processes (e.g. peer review, cross-training to ensure integration.

The staff being in close proximity and closed in FMMP responsibilities and expectations may result in FMMP coordination in a siloed manner. This can be prevented by joint activity review meetings and leader update meetings at the group, section and department level.

5.6.1.7. Foreign material management committees

When the FMM activities, priorities and plans are coordinated and executed, the collegial relationship among all involved people, disciplines, functions and departments necessitates that all aspects and concerns involving the FMM elements are appropriately, mutually and completely identified, discussed, addressed and prioritised. For that purpose, dedicated cross-organisational entities need to be established and defined such that periodic (or continuous) communication, exchange information and knowledge from/to those who are working together in separate organisations and line of work and reach mutually agreed decisions on schedule, priorities and resources.

As discussed in Section 4.9 and Section 5.4.1, the cross-organisational entities can be established at authorisation, administration and coordination levels for supporting the decision making (see also Fig. 16). Typically, every nuclear power/plant project assemble an authorisation level entity, such as executive committee, board, panel, to support the decision authority on overall decision making on the plant/project. Owner/operating organisations with effective decision making also establish similar entities to support decision making in administration and coordination levels to support such decisions for programmes and processes, including FMMP. Examples of such entities include design control committees, maintenance review panels, health and safety boards.

Therefore, generally, effective FMMPs establish and utilise active committees to collect input, exchange information, discuss options, perform review and assessments and provide consensus recommendations and collective expert opinions to the decision maker on specific issues, proposals and activities. As such, the FMMP Owner/Manager and FMM Programme Coordinator may find it advisable to use such role and responsibility of collective group to set priorities and help with actions at different layers of the programme, for example by establishing and utilising:

— An **FMM Steering Committee** to provide support to the decisions by the FMM programme authority (at the administration level) with cross functional representation from key organisations for the implementation of FMMP, such as operations, radiation protection, engineering, training, chemistry, procurement, warehouse, special projects and maintenance;

— An **FMM Working Committee** and/or a **FMMP Coordination Committee** which consists of FMM and line of work experts (e.g. departmental coordinators) from aforementioned organisations.

These dedicated groups of staff fulfil the role of *programmatic* and *technical FMM conscience* of the plant, respectively, and make recommendations and, in some cases, decisions on the FMM and FMMP administration and coordination tasks. It should be noted that, the decisions that are made at the administration and coordination levels would require concurrence by the programmatic and coordination authorities, i.e. FMM Programme Owner/Manager and FMM Programme Coordinator, respectively. Thus, the criteria and the thresholds for higher concurrence or approval of such administration and coordination level decisions need to be clearly described in the FMMP and associated procedures.

The members in these committees/boards/panels represent interests of both organisational (or departmental or programmatic) and of plant/project in the FMMP and their duties, in supporting FMMP owner/manager and coordinator(s), may include:

- Advising personnel for FMM issues, including job planning, FMM tools and control devices;
- Reviewing and approving FMM Plans;
- Providing oversight to ensure adherence to FMM requirements by performing field observations;
- Ensuring adequate supply of FMM/FMC device is maintained;
- Identifying the needs, and assisting, in obtaining new FMM tools and devices;
- Assisting in the development and delivery of FMM training;
- Assisting the FMM Coordinator and with FMM Programme Owner/Manager with oversight and improvement initiatives, suggestions, improvements and lessons learned;
- Acting as change advocates to drive programmatic and technical continuous improvement;
- Reviewing and providing perspective on the periodic status reports to management on pertinent FMM issues and the overall health of the FMMP;
- Providing a forum for feedback to drive improvements in the site FMMP, including the communication of FMM and FMMP requirements, suggestions, improvements and lessons learned.

The FMMP governing procedure needs to define and describe the requirements and expectations for the purpose, membership, scope of responsibilities and authorisations, as well as the terms of reference and working methods of specific committee(s).

5.6.1.8. Foreign material control area monitor

Requirements of FMCAs (particularly those where considerable FM risks and hazards exist) include access, tool and area control, i.e. monitoring and managing the ingress and egress of people, tool and material, as well as recording, accounting and reconciliating when the activity is completed or interrupted and periodically. The **FMCA Monitor** is the responsible person for overseeing and tracking movement in, out and around FMCA as a part of FM prevention and protection. As such, he/she needs to thoroughly understand the FMMP and all specific requirements for the assigned FMCA and associated FMM plan, work instructions and procedures.

FMCA Monitors are given the authority to control ingress/egress of material, equipment and personnel ensuring that the FMM requirements and expectations are being complied with and that risk to the FMCA's integrity and protection is eliminated or minimised. Typically, specific FMCA Monitor's roles and responsibilities include:

- Performing (or assuring performance of) integrity checks of tools and equipment entering and exiting the FMCA;
- Checking in the personnel entering to ensure that the required FMCs are practiced, e.g. empty pockets, tethering on personal protective equipment (PPE), removal of jewellery;

- Keeping accurate FM Logs to ensure all tools, equipment and material entering and exiting the FMCA are accounted for;
- Reconciling FM logs on routine basis (end of the day, end of the shift, etc.), as well as at the end of each task and prior to overall system activity closure, to ensure all tools, material and equipment have been accounted for;
- Reporting reconciliation results to the first line supervision, periodically or as requested;
- Reporting monitoring status and encountered issues to the management chain, as needed/required (for example, a construction organisation may require monitoring of activities in all active construction zones and reporting of FMM and housekeeping monitoring results at certain intervals, such as: shiftly report for high risk activities; daily report for standard risk activities; weekly report for low risk activities; and monthly report for no-risk/general area activities);
- Performing turnover of FM Logs to incoming shift including any special notes and instructions;
- Reporting any loss of FMCA integrity or at risk activities which could result in loss of FMCA integrity to supervision immediately.

Furthermore, the FMCA Monitors may be assigned to monitoring of work activities in the FMCA, particularly for housekeeping/cleanliness to ensure compliance to FMM plan or work instruction requirements, as time and workload permit.

5.6.1.9. Foreign material management inspector

As discussed in Section 5.5.5, FMM and FMC requirements include verification and validation activities by inspection of SSCs, equipment, tools, material and areas, some of which are performed in the FMCA and other areas around the activity. The **FMM Inspector** is responsible for the verification of SSCs, equipment, tools, material, people and areas in terms of FMCs (including verification of cleanliness, housekeeping) and the validation of absence and/or control of FM). The specific duties of an FMM Inspector include:

- Establishment or review and confirmation of check points on the activity sequence based on the time or on activity steps when a QA/QC (or other formal) inspection of FMM and cleanliness of SSCs, equipment, tools, material and areas is required or needed;
- Conduct of initial, 'as found', checkpoint, closing, 'as left' and final inspections;
- Monitoring of the work activities to independently ensure materials and equipment used to inspect systems/components do NOT contribute to a loss of FMC;
- Verification of existence and identification of FM in case of FMI.

5.6.1.10. Foreign material management support roles

Some owner/operating organisations have been observed in the industry (and non-nuclear industries) to define other support responsibilities for FMM during specific activities and/or general plant/project conditions for FMM. These roles, which depend on the plant/project lifecycle phases and corporate strategy, policy, expectations and culture (as well as the status of programme compliance) for the FMM, housekeeping and cleanliness include, but not limited to:

- **FMM advocates/champions/ambassadors** which can be a person or group of people, can take different shapes or forms from being an FMM Committee member to departmental FMM expert or single point of contact for FMM related information exchange and communication, including spokesperson for self-OPEX in trainings and awareness campaigns;

— **General area FMM monitors** who are the additional monitors during specific or sensitive activities concerning FMM in and around general areas, such as plant's/project's **housekeeping monitors** with additional specific focus on FMM when monitoring general plant/project housekeeping and cleanliness (see also Section 5.6.3.12 for security organisation support for FMM);

— **General area FMM quality inspectors** are the members of QA/QC organisation who perform surveillances to verify the proper implementation of plant/project programmes with focus on the FMMP and housekeeping and cleanliness programmes during plant/project activities and/or general conditions.

5.6.1.11. Directors and managers

All directors and managers of specific organisations carry the responsibility for implementation and improvement of the FMM programme and policies as applicable to their organisation. More importantly, managers at every level genuinely show their commitment to terms of FMM policy and understand their self and direct interest and roles in those terms. They assume the championship of the policy and show active support of FMMP, since they carry a vital role in demonstrating and disseminating the corporate vision and commitment to the control and management of FM with the understanding of essentiality for safe, reliable and efficient operation.

The leadership ought to sincerely pay attention, be visible and regularly review/listen and involve in the improvement of FMMP and associated processes by 'demonstrating and communicating by action' their continuous commitment and support to their staff and the policy. For example, it is a good practice for managers to communicate face-to-face with presence and visibility at the activities and areas such as training classroom, group staff meetings, shop floor, has the strongest effect on gaining trust and sharing values and vision, noting that these need to be their sincere and wanted interactions.

The directors/managers are specifically responsible in their areas for:

— Ensuring all FMMP requirements are incorporated in department procedures, orders, instructions are followed by the personnel and FMM practices are performed;
— Ensuring FMM training for applicable personnel is received and reviewed to ensure that it is satisfactory and that the resources devoted are adequate and qualifications are maintained;
— Ensuring investigation (or participating/supporting the investigation) and documentation of FM events, near misses and close calls in the department/division activities, communicating results of the investigation and timely implementing corrective actions to prevent reoccurrence;
— Following up with the FMM Programme Coordinator and FMM Programme Owner/Manager about departmental/divisional FMM methods, tools and training needs to the resolution;
— Reinforcing FM awareness by communicating regularly to the department personnel and contractors by special meetings, stand-downs or as part of the departmental meetings, communiqués;
— Performing regular job site visits and interface/communicate face-to-face to share values and vision by sincere and wanted interactions, to gain trust in FMMP commitment with workers, work area supervisors, as well as to collect prompt and direct feedback;

— Ensuring the coordination of FMMP requirements, expectations and practices throughout the organisation by assigning expert(s) and focal point(s), i.e. FMM Department Coordinator for the departmental coordination of implementation, maintenance and improvement;
— Suggesting departmental KPIs for monitoring the health of FMMP and its implementation (lagging) and for identification of weakening/degrading areas or potential future issues (leading) to the FMM Programme Coordinator and FMM Programme Owner/Manager, when necessary or requested;
— Providing input and advice from the departmental/divisional perspective to FMM Programme Owner/Manager, when necessary and as requested;
— Presenting the departmental status of FMMP, provide forward opinions and suggestions and solicit feedback regarding areas for improvement and strength in his/her department/division, in periodic management meetings;
— Participating in self-assessments and peer reviews of the FMMP with internal/external participants.

5.6.1.12. Supervisors and team leaders

Line management (i.e. supervisors, team leaders) has a responsibility to oversee and control work activities and tasks to ensure field implementation complies with site programme requirements. The actions of responsible supervisor and team leaders have a strong influence on FMM practices within the work group as to promoting strong FMM behaviours and habits and correcting poor FMM practices and deficiencies (or cultivating good ones). These actions include:

— Ensuring FMM specifics are included in work planning requirements, particularly the determination of FMRLs, establishment of FMCAs and assignment of key persons, such as FMM Monitors, FMM Inspectors;
— Performing work preparation walk downs to ensure FMCs are adequate for task;
— Ensuring all workers in the FMCA are qualified to perform associated duties;
— Performing pre-job brief integrating specific FMMP requirements and expectation and areas/topics that need special attention, awareness and importance before the start of work in accordance with the FMM plan;
— Ensuring that specified FMM administrative controls and procedures are utilised by monitoring work site to ensure compliance;
— Ensuring the CAP is appropriately used to document FM related events, close calls and near misses;
— Promoting high level of FMM standards in own work group.

5.6.1.13. Frontline workers

The most critical role in achieving an excellent FMMP is the frontline worker. The frontline personnel implement the FMMP at the execution level per the procedural guidance Also, first to deal with FM and FMM, and need to be constantly aware, observant and vigilant of any hazards and risks that could jeopardise the FMM in plant activities while working on SSCs. To achieve this, frontline workers have the following responsibilities in their plant activities:

— Adhering to all FMM and FMMP expectations and requirements as per site programme guidance and approved FMM plans, procedures and work instructions;
— Complying with all FMCA postings and boundaries;
— Obtaining appropriate approvals to interfere with or remove FM controls, e.g. covers or internal barriers (unless required for emergency purposes);

— Maintaining FM training and qualifications are kept current;
— Maintaining a clean work environment both inside and outside of the FMCA that reflects high cleanliness levels and good housekeeping practices;
— Using work practices that minimise or eliminate the potential for introduction of foreign material into a system or component;
— Preserving integrity of tools and equipment while inside the FMCA;
— Reducing the time that an open system or component is vulnerable to introduction of foreign material by completing work in a timely manner:
— Promptly notifying the FMCA Monitors, when one is applicable, and line management (i.e. supervisors/team leaders) of any losses of FMCA integrity or any activities that may threaten FMCA integrity;
— Providing aid in establishing or restoring FMCs;
— Confirming system and component cleanliness and ensuring self and peer inspections are performed before the final system closure;
— Providing feedback to management on FMM issues and recommendations for improvements to the FMMP;
— Observing, coaching and correcting each other.

5.6.2. Typical organisational roles by functions

As mentioned earlier, the specific organisational structure is not a major factor, provided the FMM practices in plant activities and tasks are correctly recognised and performed in a timely manner by everyone and every part of the organisation. Therefore, it is more important to focus on the core elements of FMM and FMMP and plant/project functions and activities, as well as ownership of other programmes associated with these activities, rather than a rigid organisational structure and assignment.

Saying that, certain organisations perform activities that may have more direct impact on (or impacted by) the FMMP and associated processes and procedures, thus, have more opportunities in/for implementation and improvement, while some others do not. A graded approach to assign organisational roles and responsibilities is primarily based on the nature of activity, such as owner, area, systems and materials involved, impact/value of the activity to/from FMM policy, programme, processes and procedures. These characteristics of the activity need to be considered in the foundation for organising and assigning organisational FMM roles, responsibilities, accountabilities for FMM related activities in the implementation and improvement of the site FMM and FMMP.

For example, during the operation phase, the maintenance organisation would be more often involved with infield activities where FMM practices are frequently and routinely applied and utilised. Typically, it is the maintenance managers and supervisors who would be more likely to be present and conduct scheduled, and unscheduled observation visits of the areas and activities controlled by the department. Therefore, they have more opportunities to observe compliance, effectiveness and awareness of FMMP and providing observations and coaching to area team leaders and workers to improve performance and awareness and to do so more frequently than other organisations. At the same time, the technical support organisation, i.e. the engineering organisation that is responsible for design, system, fuel/core management, would be more focusing on establishing adequate design and monitoring processes/controls in place for FMM and/or evaluating consequences and resolutions of FMI events on plant design and performance. Also, in some operating organisations where the technical support is decentralised, local engineering groups, such as reactor, maintenance or refuelling engineering, take more diverse responsibility on FMMP under their umbrella organisations.

On the other hand, during the construction phase, construction organisation is the organisation that is in charge of all the activities that are being performed and it performs or oversees tasks, while operation organisation might be in charge of commissioning activities.

Again, in any case, a common FMM commitment and policy is necessary to exist throughout the organisation, with both vertical and horizontal communication and alignment, to ensure that the FMMP is implemented collectively and effectively. In that manner, all organisations equally understand the importance of good FMM practices and the consequence of poor ones, while they are aware of FM and FMMP and uniformly know, understand and interpret FM, FM hazards and targets in their specific activities towards *foreign material free operation* and *no-adverse effect of foreign material*.

5.6.2.1. Maintenance organisation

As the organisation that is typically in charge of maintenance activities during the operation phase, it performs tasks which have the most potential for FM hazards and risks. Thus, it may the focal point and the champion of FMMP and, typically, is the FMMP owner organisation during operation phase. Routine maintenance activities include FMMP elements and FMM considerations in every task and the maintenance organisation needs to establish special (and/or standard) FMC mechanisms for unique tasks, in coordination with and support from other organisations. As mentioned earlier, such involvement also provides more opportunities for improvement of the site FMMP, thus the Maintenance Organisation is a major source of feedback to other organisations and the FMM Programme Coordinator (and in cases, such as in a particular phase of NPP lifetime, where the programme ownership lays with another organisation, to the FMM Programme Owner/Manager).

5.6.2.2. Work control organisation

Prime responsibility of ensuring the adequate task performance and the environment, in order to protect against hazards, risks and events, lays with the planning and scheduling of the activity. Work Control Organisation, focusing on knowledge and information about the FMMP in the plant's/projects tasks, anticipates and conceptualise the activity for FMM and FMCs. Carefully investigation of activity and work conditions prior to the performance of the task by work control and planning organisation identifies potential FMs, their generation, target SSCs and ingress paths (and, if needed, recovery options from an FMI), and hence, provides first-order protection that would be reflected in the work orders, pre-job briefings and FMC tools and devices. The work control organisation is also responsible for ensuring the coordination of activities that would be interfering with each other to protect equipment and environment from cross-contamination by dirt, dust and other foreign material.

5.6.2.3. Outage organisation

The greatest potential for FMI events is during plant outages when refuelling is performed and maintenance on SSCs and equipment is conducted, particularly owing to multiple tasks being simultaneously performed on and around open systems (and the site, at large) which increases the FM hazards and risks. Furthermore, during the outages, there is a higher potential of one-time or infrequent tasks being performed which require unique or particular attention to FMM aspects.

As the organisation that is in charge of all the activities during a plant outage, Outage Organisation can assist in elimination/minimising the risk of FMI events with coordination and sequential execution of work activities (particularly those to be performed nearby each other simultaneously or in series) where potential for generation, transport or intrusion of FM on open systems exist.

The OCC and the OCC teams need to be aware and understand the hazards, risks and impacts of FM on the coordination of activities, and therefore, FM, FMM and FMMP requirements and expectations need to be discussed during the daily outage meetings and awareness and anticipation for FM need to be highlighted during outage coordination.

The OCC teams also need to be informed of any FMI events that have occurred and get involved in the recovery of the material. FMI events during the outages are particularly critical since their consequences may not be realised until the consequent unit start up and operation at power when safe and efficient performance could be adversely and significantly impacted.

The outage organisation also may help with establishing KPIs for the FMM and FMMP implementation during the outages and afterwards. As these FMM and FMMP metrics/indicators can be a part of the outage goals that are tied to the overall plant/project KPIs, including those for FMMP.

Moreover, outage organisation typically requires active involvement and presence of FMM programme owner/manager and coordinator(s) in daily outage meetings during which task performances, as well as FM events, close calls, near misses and good practices, need to be discussed.

5.6.2.4. Operations organisation

The Operations Organisation perform various tasks and activities with potential for FM and FMI risks and hazards, such as filling plant systems, draining, flushing, handling and loading fuel, performing work adjacent to and over spent fuel bays, resin routines among other open system or component work, and therefore play an important role in FMM towards foreign material free operation.

In addition to creating potential for FM and FMI, operations also perform routine field inspections of the plant that can identify FM hazards, areas at risk for potential FM and FMI due to housekeeping issues, system deficiencies, missing or deficient FM barriers or other causes.

Operations may also be involved with FM and FMI identification through routine testing of systems and normal surveillance of system operation/performance, and certainly they would be involved with FMI mitigation and evaluation.

5.6.2.5. Construction and commissioning organisations

As discussed in Sections 3.3, Construction Organisation is the organisation that is in charge of all the activities that are being performed and it performs or oversees tasks that are unique, first-time, large and/or complex, and typically, with extensive and numerous FM hazards and FM targets during the construction phase (noting that, as aforementioned, the refurbishment and major modification project organisation could also be considered as construction organisation).

The construction activities are mostly conducted in a widespread area by multiple disciplines, interfacing and interacting with other simultaneous work. Therefore, the construction organisation would be managing and controlling significant amount and variety of FM which would be associated with more FM hazards and higher FMI incident risks (mostly necessitating special/unique prevention and protection strategies and means).

More importantly, FMI events during the construction are critical since their consequences may not be realised until the commissioning even until the operation where the efficiency and performance, and potentially safe operation, of NPP are adversely and significantly impacted.

For these reasons, generally, the Construction Organisation is the owner of the FMMP during the construction phase and even during commissioning phase since there maybe overlapping activities. As discussed in Sections 3.3. and 3.4, such overlap put the plant and the associated SSCs in a complex situation from the FMM perspective, as final adjustments are made during the construction of some systems while other systems are being tested. In such cases, Commissioning Organisation may become the owner of FMMP.

5.6.2.6. Training organisation

As discussed in Section 4.6, training is an essential part of the FMMP implementation to ensure the understanding of FM, FMM and the relevant planning and performance of tasks accordingly. Training Organisation is, therefore, one of the core entities for establishing and maintaining the information for, and knowledge of, workers, managers or contractors on the elements of FMM and the requirements and expectations of FMMP implementation.

As such, the Training Organisation is responsible for educating the relevant personnel on the awareness of FM, FM hazards, risks and the causes and consequences FMI event, individually and collectively. The training organisation fundamentally contributes to the recognition of FM, prevention of FM generation and FMI events by the provision of initial, continuing and special training. In coordination with the FMMP owner organisation and applying SAT and training techniques, the Training Organisation identify the training needs and associated type, material and environment, ranging from a general FMM awareness and expectations training to all site personnel, to detailed and in-depth training modules for particular disciplines. Using a graded approach, the organisation will set training sessions on particular applications of FMM elements, methods and tools to their specific tasks (e.g. maintenance activities, fuel handling evolutions, chemistry sampling) and will evaluate the results for the continuous improvement of the training.

5.6.2.7. Technical support organisation

The Technical Support (e.g. Engineering) Organisation carries direct and indirect responsibilities for FMM and FMMP in every stage of the lifecycle of an NPP (see Section 3.2 and Section 3.5.2). The proactive and direct organisational responsibilities include designing and engineering FMM features that are built (or to be built) into the SSCs, such as devices, materials, chemicals, etc., as well as the considering concepts, designs and arrangements of some temporary protective/preventive devices and tools.

The system cleanliness, material compatibility criteria and requirements and associated verifications, as well as the predictive models for ingress and transportation paths to prevent FMI events during activities, also require engineering organisation input and review.

In reactive (mitigation) manner, i.e. in case of an FMI event, the engineering organisation may carry responsibilities for:

— Supporting search, detection and removal of FM by designing, proposing or assessing methods, tools and techniques that are discussed in Section 6;
— Performing evaluations and assessments to support the decision to accept/reject the intruding FM as part of a system or component, i.e. redefining the material as ‘non-foreign’ and ‘a new part of the SSC’ in integrated design and overall operation of the SSCs, as discussed in Section 7.

Consequently, they may be responsible for tracking the type, amount and location of FM detected, recovered or left in the SSCs, as well as their impacts on overall plant SSCs. Also, similar to the good practice discussed in Section 3.2.1, the design engineering organisation would establish and update FMT&PDs taking into account the operability and maintainability experience to maintain the mapping of FMs that are evaluated and left in the SSCs, as well as in other design output diagrams and schematics, e.g. process flow, P&ID, maintenance and repair, pneumatic and hydraulic system diagrams, which are discussed in Section 7.

5.6.2.8. Radiation protection organisation

This organisation frequently enters FMCAs to perform surveys or contamination control activities, and therefore, has to follow and adhere to FMM requirements relating to that work area. Radiation Protection Organisation would also assist with ALARA assessments in task planning of a performance, as well as with FM mitigation and recovery assessment and planning relating to intrusions in or around radioactive systems.

5.6.2.9. Chemistry organisation

Routine chemical sampling supports the detection of FM in the SSCs, such as fuel and core, in a timely manner. Therefore, Chemistry Organisation carries responsibilities for FMM in plant systems. The organisation may be directly responsible for control and assessment of any soluble FM and FMI in the plant fluid system. Furthermore, reviews and approvals of chemicals for compatibility with SSCs also reside with Chemistry Organisation, and hence, they are requested to review and approve proposed FMC devices for system compatibility issues, as well.

5.6.2.10. Quality assurance/quality control organisation

In every stage of the lifecycle of an NPP, the QA/QC Organisation carries responsibility for overseeing and inspecting the quality of work, SSCs and materials to ensure adherence to quality standards as well as the expectations of owner/operating organisation. As the QA/QC requirements are (can be) part of the activities by all organisations, the QA/QC Organisation provides support to the activity specific organisations, including the FMMP owner organisation, on the determination and communication of requirements and compliance.

Specifically, in the FMMP implementation and compliance, the QA/QC organisation provides regular inspections of activities, areas and stored equipment and material and reports the non-compliance. In the task level, depending on the nature of the task, the organisation may also have inspections and monitoring roles in area/activity QC checkpoints, close out inspections, among other QA/QC aspects.

Additionally. in following up on FMI event evaluation, root cause determination and corrective action implementation, QA/QC organisation carry responsibilities.

The organisation may also oversee onsite or offsite manufacturing and installation controls and acceptance inspections and conduct independent audits/assessments to ensure the compliance with FMMP requirements and FMM practices, as applicable.

5.6.2.11. Procurement and warehouse organisations

Procurement and Warehouse Organisations are responsible for ensuring the supplies are manufactured, acquired, transported, received and stored free of foreign material.

Procurement personnel ensures this through identifying, describing and communicating specifications, requirements, expectations through purchase order and contract clauses for FMCs (and FMI terms and conditions for contract services) for the activities, components and services (such as for manufacturing, transport, factory and receipt inspections, storage). They also communicate with the FMM Programme Coordinator for FMC tools specifications, selections, stocks and availabilities.

The warehouse personnel ensure that the supplies are delivered free of FM and remain so during the storage (i.e. from the time when items are delivered to the warehouse to the time they are prepared for use in the installation). As such, they perform FM receipt inspections, described in Section 5.5.5.6, when the supplies are received for acceptance and storage. They move the items to storage and ensure the prevention and protection of components, equipment, materials or parts that are in the warehouse inventory from the FM ingress and generation in or on them during the storage. They also deliver and stage equipment, parts and material to the activity areas and ensure that the activity receives (and when applicable, unpacks) them free of foreign material.

5.6.2.12. Security organisation

Security Organisation is a very important contributor to FMMP implementation and improvement due to their proximity to the plant SSCs, as aforementioned several times in this publication. Their direct interference with the plant facility, equipment and material, such as the security inspections of equipment and materials entering and exiting the NPP site which makes them responsible for FMM and, in some cases, FMI. For example, based on the cases from industry experience:

> "FMC devices that were removed to facilitate security inspection were not restored to their pre-inspection or they were damaged during the inspection and left at those conditions after the inspection, resulting in FM incident".

Thus, security personnel need to know that their inspections may potentially result in an FMM issue, and therefore, gaining and maintaining FMM information and knowledge is essential.

Also, owing to their direct interface with the plant as a part of their core security roles and responsibilities, such as their routine patrols of plant facilities, security personnel can participate in the awareness and recognition FM and FM hazards. As long as it does not interfere with their primary responsibilities, Security Organisation, therefore, can support and enhance the FMMP with their observations and reporting of FM and FMM issues/challenges during their routine patrols of plant facilities and report any FMM observations and concerns.

Therefore, for Security Organisation need to know and protect integrity of FMM, for example protection of FMC barriers, during their routine and frequent security inspections. Consequently, the plant owner/operating organisation provides the security personnel with targeted FM training to allow them to recognise, observe and report issues and challenges, particularly on:

— Overall housekeeping conditions;
— Physical FMM controls, such as physical barriers, devices, postings/signs;
— Potential FM, such as dirt or debris near sensitive areas and components.

5.6.2.13. External organisations

There are many various entities that are external to owner/operating organisation and have roles and responsibilities for establishment, coordination and implementation of plant's/project's FMM and FMMPs. These organisations include: technology and equipment vendors; designers; manufacturers; regulatory bodies; and industry associations, such as WANO, INPO, EPRI; technology owner groups and nongovernmental agencies like IAEA, OECD/NEA.

In addition to their contributions to OPEX collection and dissemination, which were discussed in Section 5.5.10.5, they carry (or could be assigned to) other plant/project specific roles and responsibilities, some of which can be as follows:

— **Vendors/Contractors/Suppliers:** Each onsite or offsite entity involved in the activities in support of the owner/operating organisation, such as those design, manufacture, ship, construct, conduct refurbishment and maintenance activities, is to be aware, responsible and accountable of the potential consequences of its activity with respect to FMM, as well as the possible cross effects from other interfacing organisations. This can be accomplished by:

  - Agreeing and adhering to the FMM policy, requirements, expectations, controls and goals anchored and communicated by the owner/operating organisation, as well as activity planning, supervision and oversight by the work control organisation(s);
  - If superior to that of owner/operating organisation (based on their better understanding and experience of the activity), establishing and utilising own FMM programme policy, requirements, expectations, controls and goals after aligning, agreeing and confirming with the owner/operating organisation;
  - Continuously maintaining communication of changes and issues (both in policy and infield activities) by open and prompt exchange of information with the operating organisation and other interfacing organisations and by maintaining and providing records;
  - Contributing to owner/operating organisation continuous improvement of the FMMP based on own experience, information and knowledge of FMM elements and aspects;
  - Committing to exceptional FMM performance in all activities, overriding, if necessary, the demands of production or project schedules.
    Contracts and applications for approved vendor status are some of the most effective instruments for articulating and agreeing upon the obligations of a plant operator, of a plant supplier and of their subcontractors. It is useful to include FMM requirements and expectations in each bidding, tendering and contract document with a vendor or supplier. In the own or common management system documents, each involved entity needs to describe the ways it contributes to FMC and FMM, towards the owner/operating organisation's *foreign material free operation* and *no-*

adverse effect of foreign material, including how those are to be reviewed, agreed and accepted by own and the owner/operating organisation;

— **Regulatory body:** Regulatory body is involved with the FMMP with respect to establishing, and overseeing compliance with, the requirements that ensure the safety related SSCs are, and remain, capable of performing their intended safety functions. They are aware of the fact that when FM is not properly managed, FMI to safety related SSCs (or non-safety related SSCs supporting those) may negatively impact the safe operation by potentially degrading the safety margin. Thus, the rulemaking, oversight and verification of compliance by the regulatory body related to FMM is identified as a role of regulatory bodies. The responsibilities of a regulatory body in terms of FMM and FMMPs may include:

- Establishing requirements and guidance that can be explicitly FMM specific, such as housekeeping, shipping, storage, cleanliness, or that are implicit or incorporated in other requirements, such as QA/QC requirements in construction, commissioning, operation, maintenance, equipment reliability;
- Assuring that the owner/operating organisation establishes, maintains and follows adequate programmes, processes and procedures to ensure that the safety related SSCs and/or the SSCs supporting safety related SSCs are free of FM that could damage or adversely affect intended safety function or significantly degrade safety margins;
- Observing that the owner/operating organisation has an anchored a safety culture that demonstrates awareness, responsibility and behaviour of no tolerance for events challenging nuclear safety, including FMI events, with potential safety consequences in mind;
- Observing that the organisation has an effective condition recognition, identification, reporting and resolution processes that ensure anticipation, prevention, protection, detection and, if necessary, mitigation of FM that could damage, or adversely affect function, integrity and reliability of safety related SSCs, or SSCs supporting them;
- Verifying the effectiveness of corrective action process in preventing recurrence of significant conditions adverse to quality that is caused by FMI;

— **Industry associations:** Aspects of FMM/FME[17] have been a focus area of the industry associations and several organisations involved in the nuclear power industry, including IAEA, WANO, INPO, EPRI (see Section 1.1), FME Industry Working Group (FME IWG), among others. These organisations, associations and groups contribute to the improvement of FMM practices and FMMPs in NPPs in various manners, including the activities of:

- Publishing skilful industry guideline documents to assist sites with FMMP development, implementation and improvement [9–11];
- Distributing FMM related OPEX routinely, as well as promptly, to share learnings;
- Organising/participating joint meetings, workshops of national, regional and international industry working groups, to establish consensus on assistance to the industry focusing on continuous improvement of FMM and FMMP by

[17] Industry initiated standards, guidance and expectations refer to Foreign Material Exclusion (FME) Programme, which is similar to FMMP, mention herein.

development and sharing industry good practices, reviewing OPEX and benchmarking;

- Conducting periodic workshops and training opportunities, such as EPRI's FME coordinator training, IAEA's regional and national workshops, to share knowledge and experience on industry practices FMM workshops are being held, which in turn allows participants to learn and improve;
- Participating peer review and benchmarking visits.

Beyond the nuclear industry, industrial, governmental and non-governmental organisations that are directly and strongly impacted by foreign material/object/body also provide assistance to FMM and FMMPs. Although the process and procedures are specific to their line of work[18], their programme elements and fundamentals are common with nuclear industry and their standards, guidance, procedures, practices, alerts, newsletters [23−37], etc., may contribute to the improvement of FMMPs in nuclear industry. A few examples of those non-nuclear industry efforts include:

- Societies/associations of automotive, aerospace, aviation, food, pharmaceutical, chemical industries and experts;
- Governments' health, transportation, agriculture, aviation ministries/organisations;
- World Health Organisation (WHO).

[18] As well as the terminology used, such as 'foreign object damage/foreign object debris', 'foreign body exclusion' or 'foreign matter management', which are similarly used in nuclear, aviation, medical, pharmaceutical, food industries [23–37].

6. MITIGATION AND REMEDIATION OF FOREIGN MATERIAL INTRUSION

In spite of the anticipation, prevention, protection and exclusion measures that are defined and described in the FMMP, FMs could enter the SSCs or FM paths and can reach/enter the target SSC during the performance of activities, mainly caused by:

— An unknown, unrecognised or unanticipated FM, FM target or FM path;
— Flawed controls or hidden precursors causing failed (or inadequate) FM prevention and protection measures, controls and barriers.

In another words, FMIs typically occur as a result of the lack, deficiency or immaturity/imperfection of the FMM practices and FMMP (here, it is prudent to distinguish a deficient FMMP from an immature/imperfect FMMP to clarify the difference and/or alikeness between: an 'immature FMMP' — which is a continuously improving programme as more information and knowledge is being gained and incorporated towards perfection — is not a 'deficient FMMP', if its shortcoming is due to a previously unknown FM or FMI mechanism. In fact, an event caused by totally new FMM information or knowledge could not be classified or counted as 'deficiency', providing that the FMMP is ensured to improve from this new learning).

Moreover, even a plant/project has a reasonably mature and robust FMMP and FMM practices in terms of FM awareness and FMC, FMs may also exist in the SSCs owing to the historical issues/deficiencies, i.e. a FM entered the SSCs in the earlier activities (e.g. in the previous lifecycle phase of the plant/project or at a time when there was no, basic or defective FMMP existed). Some examples and impacts of such FMs that have gone unknown, unnoticed and/or unrecovered since past phases of the NPP lifecycle were discussed in Section 1.1.3, Section 3.3 and Section 3.4.

As aforementioned in Section 3.3, a large majority of the FM associated events during the operation can be traced back to pre-operational phases of the plant/project, particularly construction phase. In addition to these 'historical FMs and FMIs', there have been numerous cases of latent FMs and FMIs from the earlier days of operations and even from more recent (i.e. 'not so distant historical') activities.

These FMI events primarily involve items left over in the SSCs[19] owing to the several common factors regarding the lack of FMM controls and barriers, including:

— Lack or deficiency of FMMP during construction, manufacturing, commissioning and/or the early phase of operation;
— Lack of FMM, housekeeping and cleanliness concepts and awareness by construction workers (some of which had the competency and skills for their tasks from other construction projects, but could not understand or acknowledge the importance of FMM, housekeeping and cleanliness in nuclear industry — as it was their first nuclear plant construction);

[19] As noted in Ref. [19], in four out of 10 these cases involved I&C and electrical components while valves and pipes each made up 10% of the cases and welds had been 14% of the cases as the top of list of the most affected by construction, manufacturing or commissioning FMM deficiencies.

— Lack of FMM, housekeeping and cleanliness culture and behaviours in the owner/operating organisation;
— Concealment of self-caused FMIs due to fear of punishment or loss of rewards (e.g. loss of bonus, loss of salary).

Such unreported, unrecorded, dismissed or unrealised FMI events resulted in nuclear power plants operating with latent FMs in their SSCs for a long time (according to the survey discussed in Ref. [19], in average, a detection time of about eight years after the initial startup to discover the latent FM).

More importantly, more than three out of four latent FMs were discovered by luck or coincidence. Similarly, the assessments of the discoveries also showed that it was primarily luck or coincidence that the operation of the impacted SSCs was fortunately not needed/demanded (some of those SSCs were safety related, and if they had been needed during accident conditions, they would not have been able to fulfil their safety functions, as discussed in Section 1.1.1).

Therefore, although any FMI event needs to be mitigated, the mitigation process might have some differences based on when the event occurred and when the FM was discovered. Consequently, it may be first necessary to provide the definitions used for classifying FMs based on the time aspect, which would make a difference in the response and mitigation that are discussed hereafter. For the purpose of this publication, a discovered/encountered FM is classified based on the time elapsed between the event occurrence and its discovery as follows:

— *Latent foreign material*: The FMs that have been hidden (i.e. dormant, latent) in a plant SSC owing to an FMI during previous activities are considered as 'latent foreign material';
— *Current foreign material:* Any FM that is not latent, such as the FMs that enter the SSCs during current activities, are termed as 'current foreign material'.

Also, to be consistent with the descriptions provided in current industry guidance [9–11], in this publication, a subset of latent foreign materials is defined as 'legacy foreign material'. As such:

— *Legacy foreign material:* A latent foreign material that intruded into the SSC before: (a) the implementation of current FMMP (including the earlier revisions); or (b) the first opening and working on SSCs during the operation phase, whichever came first is defined as a 'legacy foreign material' or 'legacy-latent foreign material'.

To clarify these definitions, Appendix IV illustrates a sample process of classifying a FM as current, latent or latent-legacy and, based on these definitions. Accordingly. the mitigation process for 'current foreign material' is specifically discussed in Section 6.1, while the mitigation of 'latent foreign material' is discussed in Section 6.2.

6.1. MITIGATION PROCESSES

As defined in Section 2.5.6, mitigation is the retrieval of the FM if an FMI event occurs/occurred, as well as the elimination/relinquishment of its adverse (or potential adverse) impacts and consequences. The mitigation process, therefore, is a plant/project evolution with an aim that is in twofold:

— The FM is removed from the SSC and the SSC is restored to original design and operation conditions, i.e. *no FM left behind*;
— The adverse effects on the fit, form and function of impacted SSC (both FM target and path) — and any other SSCs that have just become (or discovered to be) targets or potential targets upon FMI —, are removed, reversed and/or remediated, i.e. *no adverse FM impact left behind*.

Therefore, the mitigation of an FMI event consists of the detection, notification, recovery, retrieval and analysis aspects, which are described in Sections 6.1 and Section 6.2, for current and latent FMs, respectively. Also, mitigation activities for each aspect are conducted in an orderly and structured manner by following specific processes which, for the purpose of this publication, are defined as:

— Foreign object search and retrieval (FOSAR) process, which consists of:

- Foreign object search and detection (FOSAD) process; and
- Foreign object reach and recovery (FORAR) process;

— Foreign object review and assessment (FORAA) process, which consist of:

- Foreign object technical analysis and assessment (FOTAA); and
- Foreign object programmatic analysis and assessment (FOPAA).

Additionally, based on the classification of FM and FMI (i.e. current FM, latent FM), the application and performance of these processes will vary. Appendix IV also includes a process flow to decide which process may be applicable, required or necessary.

Accordingly, the administrative controls, requirements and expectations for the FMI event mitigation that includes all these aspects (i.e. detection, notification, recovery, retrieval and analysis) and processes (i.e. FOSAR and FORAA), as well as the associated actions in the event of an FMI or loss of FMC, need to be described in the FMMP governing procedures.

Noting that FOSAR and FORAA activities are, by their nature, infrequent and, in most (if not all cases), first time and special plant evolutions, it might also be a good practice to have a separate dedicated working level procedure for such processes for FM mitigation or including the specific tasks of mitigation in the procedures of applicable organisations and refer to them. For example, the technical assessment part of the mitigation (as well as the evaluation for not recovering or accepting the FM as a part of the SSC design) is almost always performed by the technical support (engineering) organisation and can be made a part of engineering procedures or can be covered by the design/configuration control process and procedure. Again, such structure depends on the strength and flow of work processes of the plant/project programmes and the trade-off with an all-inclusive, extensive but large FMMP governing procedure, considering the frequency of such evaluations.

Regardless of how and where the mitigation aspects and instruction are defined or described, it should be again emphasised that upon the occurrence or discovery of an FMI, the following actions are required in this order:

(1) Activity work is immediately stopped, and equipment is placed in safe state.
(2) Prompt notifications are made.
(3) Activity area is secured in order to preserve the event scene and further intrusion of FM.
(4) An appropriate mitigation process is initiated.
(5) The FMI is reported and be entered to the CAP process.

6.2. MITIGATION OF A CURRENT FOREIGN MATERIAL

6.2.1. Notification

The first step after an FMI event is the immediate notification of all involved or relevant plant/project people (from the line managers to the control room personnel) to initiate a prompt review and assessment that include, among others, an assessment of potential mitigation. In general, mitigation is not allowed to be attempted without notifications to applicable groups, and a collective agreement to proceed has been obtained, to ensure the event does not progress further, e.g. by intrusion of another FM or by moving the FM further into the system where the recovery gets harder or impossible, while taking mitigative actions.

As discussed in Section 5.5.10.4, the FMMP administrative procedure needs to provide instructions and directions as to required event response actions, including any specific immediate and other notifications/communication requirements, in the event of an FMI. These instructions would include clear definition and description of necessary information to be presented in the notification(s) to support the decision on how to proceed with mitigation (e.g. conditions and prerequisites for prompt recovery in the immediate notification, known status of the FM in subsequent notifications, etc.), including the appropriate review, approval, supervision and oversight, to ensure that the mitigation proceeds in a timely manner.

6.2.2. Immediate actions

Upon the immediate notification, a prompt mitigation and recovery assessment is performed to determine the adversity of the situation and the immediate actions to be taken, including the necessity of a quick recovery and retrieval or the need for a mitigation plan, based on the information provided in the immediate notification.

In some cases, immediate actions for mitigation of and recovery from an FMI event may be needed or possible, for example:

— A prompt FM retrieval decision and its implementation may be vital, if/when the probability of further FMI and SSC degradation is high, presenting a risk (or potential for risk) for nuclear, radiological or industrial safety, and protective measures cannot be put in place on time due to certain or unusual circumstances;
— A prompt FM retrieval may be feasible and acceptable under special auspices if/when:
  - the FM is readily detected; position and potential movement of the FM is well known;
  - the FM is easily reachable; and
  - its immediate retrieval presents no further risk and hazard, allowing the mitigation process to proceed for prompt removal of the FM.

In other cases, the immediate notification may not be sufficient to make a decision on prompt mitigative actions and more detailed investigation, evaluation and planning of mitigation is needed.

6.2.3. Detection

Before any plans, actions and efforts taken or put into place, the situation surrounding the FMI need to be properly known, understood and interpreted. This requires first a visual search and detection of the FM (i.e. an acute detection) and, if its location is not easily visible (and/or its condition cannot be absolutely known[20]), then a more detailed FOSAD process (i.e. a planned detection). Whether it is acute or planned, the detection process aims, as a minimum:

— Identification of FM that initially intruded and any other FMs that are generated during the FMI from the impact of that FM;
— Determination of shape, condition, location and position of FM(s);
— Determination of equipment damage from the FM(s) and by the sequence of events during FMI.

The detection of FM(s) can be initiated by directly observed/witnessed FMI or by an indication of a potential FMI, for example:

— Acute observation of FM entering the SSC, witnessed by the workers, observers, monitors, inspectors, etc., during the activity performance;
— Reporting/notification by individual(s) of a missing or lost item (or part of an item);
— Individual or work group encountering physical damage/defect while opening the SSC (e.g. gasket material is crumbling);
— Discovery of failed or damaged internal barriers or external covers that are found to be degraded or missing (for example, while the area has been left unattended);
— Materials, tools, parts, items which cannot be accounted for during FMM Log reconciliation (i.e. unresolved log keeping issues, such as the item still in the log, but not in the area or described/identified differently);
— Parts/materials that are found to be missing, damaged or defective during disassembly or reassembly of components;
— Measured anomalies in SSC operating parameters (temperature, flow, pressure, vibration, etc.) or unexpected sensory indications coming from the SSCs (e.g. unusual/unexpected colour, odour, noise, smoke, leak), particularly when they are started, or have been running for a period, following the activity that was performed on them;
— Findings of analyses and assessment that are conducted for the characterisation of a FM and FMI event.

In addition to naked eyes, FOSAD can include various methods and tools (and associated qualification and skills), including:

[20] Absolute knowledge includes not only the knowledge of FM but also of any FM that might have been generated during the event. For example, it might be a dropped adjustable wrench which has a possibility of some small parts coming apart as a result of impact from the fall.

— Simple direct visual tools, such as mirrors, magnifiers, telescopes;
— Special confirmatory tools and analysis for internal detections, such as:

- Borescopes;
- Remotely operated video cameras;
- Radiography;
- Ultrasonic testing;
- Infrared thermography;
- Ferrography;
- Fibreoptic technology;

— Monitoring and detection systems (e.g. leak detection, vibration monitoring).

Before the FOSAD activity is implemented, a planning of the work may be necessary and a **FOSAD Plan** need to be prepared in accordance with the guidance, requirements and expectations provided in the FMMP administrative procedure (or by applicable implementation procedures). In some cases, such as the FM is visible and it can be confirmed that is it intact and that there is no possibility of further movement or any further impact on SSCs (which also requires an independently review and confirmation), a FOSAD Plan may not be necessary. In such cases, even the whole FOSAD process may be skipped and the FORAR process can be considered and started with appropriate review and approval.

The preparation and implementation of FOSAD Plan and its implementation are based on:

— Weighted scale of the graded approach;
— What the known and potential FMs are, including their types, materials, potential locations and forms;
— Sensitivity of the FM and its location to the movements during detection activities;
— Necessary and applicable detection methods and tools;
— Risks to components or personnel associated with detection type, process, tools and methods;
— Operability and maintainability of detection activities, such as accessibility, confined spaces, etc.

Accordingly, the specific contents of a typical FOSAD Plan include (noting that graded approach will determine its contents and scope, as well as the reviews and approvals of the plan, which are defined by the FMMP and other plant/project programmes):

— Description of the FM that is going to be searched for, including type, material, quantity, anticipated quantity, condition, shape and location of FM;
— Description of the FMI sequences, as available
— Existing equipment damage that is known or anticipated;
— Identification and description of, and options for (including options' ranking based on, among others, safety, ALARA, schedule, resources, risks, hazards, retrievability of FM):

- Detection methods and tools to be used, including the location and type of conduct, e.g. infield/remote, intrusive/non-intrusive, continuous/intermittent;
- Detection activity areas, SSCs, and pathway, including systems to be opened, paths to be used, locations for system entry/intrusion, e.g. manholes, drains, vents, and starting with the systems and flow paths/locations with the high possibility or probability of finding the FM;

— Entry conditions and prerequisites for FOSAD procedure/process/activity implementation;
— Anticipated/known hazards, risks and consequences associated with detection methods, tools and activities regarding:

  - Industrial, radiological and nuclear safety;
  - Equipment reliability;
  - Creation of new and additional FM;
  - Existing equipment damage and creation of further damages;

— Measures to eliminate or minimise FM risks and hazards during the activity, for example, for preventing:

  - Further spread or transport of FM during recovery activities;
  - Further FM risk and hazards, as well as new targets and paths, during detection activities;
  - Detection tools from becoming FM themselves (as there are several OPEX on broken or stuck tools, for example lost camera lens in a steam generator header, as one plant representative indicated);

— The necessary activities for locating FM(s) including all the measures to be taken for other programmatic and technical requirements, expectations and actions, such as:

  - Temporary SSC and equipment modifications (opening, disassembly, etc.) for accessibility needs, including the FMM/FMC measures around those SSCs and equipment;
  - Operability, availability, functionality of SSCs that will be modified/worked on for the implementation of FOSAD activities, including tagout;
  - Radiological protection and ALARA assessment;
  - Environmental and confined space conditions assessment;
  - Normal and emergency ingress/egress/movement paths for personnel and equipment;
  - Power and other sources needed and their configuration;

— The schedule and resources to be utilised for the search and detection, including:

  - Qualifications, knowledge, skills and competencies needed for the activity;
  - Training needs (including mock-ups) of personnel performing the retrieval;

— Methods for the monitoring and, if necessary, maintenance of detection equipment and their status during the retrieval efforts;
— Exit conditions from FOSAD and entry to FORAR process and activities, including hold points to wait for needed parallel assessments, such as the analysis, characterisation and confirmation of detected materials (i.e. confirmation of FM type, material, quantity, anticipated quantity, condition, shape and location);
— Possible ‘Plan B’ and readiness to act on it.

It is also important (and a good practice) to collect as much information and knowledge about the FM and FOSAD evolution during the conduct of the FOSAD activities, as such information could be utilised in parallel or subsequent analyses to support FORAR, FORAA and event investigations. More importantly, the collected information and knowledge during FOSAD will support future activities and the improvement of FMM and FMMP. This information and knowledge can be obtained, collected and preserved by various methods and tools including photographs, videos.

6.2.4. Recovery and retrieval

Once the FM is detected and identified and appropriate notifications are made, considerations and planning for the second part of FOSAR, which the process for recovery and retrieval of FM(s) and remediation of the SSC, i.e. the FORAR process, starts for the ultimate retrieval and recovery of the FM(s). The FORAR process follows a defined and established set of requirements and guidance to ensure compliance with nuclear, radiological and industrial safety requirements during the FORAR activities.

Therefore, requirements and expectations for FORAR process as to its planning and implementation need to be defined and described by the FMMP governing procedure (or by applicable implementation procedures) with the acceptable and reasonable criteria, threshold and boundaries, based on a graded approach in determining, planning and performing the FORAR activities. Again, this graded approach would be based on risks and impacts of consequences of retrieval activities, as well as their severity and complexity, as described in Section 4.5.

6.2.4.1. Planning of foreign object reach and recovery

Before the activity is implemented, it is generally required to prepare and implement a **FORAR Plan** following the guidance, requirements and expectations provided in the FMMP administrative procedure (or by applicable implementation procedures). Similar to FOSAD, the FORAR Plan and its implementation are typically based on:

— Weighted scale and categories of the graded approach;
— What the FM is, including its current state, location and form (as determined by the detection process),
— Sensitivity of the FM and its location to further movement (if known or anticipated);
— Available and obtainable retrieval methods to be used;
— Risks to components or personnel associated with retrieval process;
— Operability and maintainability of retrieval activities, for example, accessibility, confined space entry.

Additionally, the FORAR Plan will also consider the results and progress of ongoing analyses and assessment that are being conducted for the characterisation of a FM and FMI event.

The elements described and discussed in any typical FORAR Plan include (noting that graded approach will determine its contents and scope, as well as the reviews and approvals of the plan which are defined by the FMMP and other plant/project programmes):

— Description of FM, source, quantity, condition, shape and location of FM (if any of these is uncertain, the list, method, resource and schedule of any additional analyses that are need needed and/or being conducted);
— Equipment damage that has already been sustained;
— Identification and description of, and options for:

- Retrieval methods and tools (including the compatibility and vulnerabilities of the equipment to be used), e.g. hand, grapple-, disk- or cone-equipped snakes, tapes/adhesives, magnets, reach rods, vacuum systems, flushing systems, temporary screens and strainers;
- Recovery pathway, including systems to be opened, flow paths to be used, locations for system entry/intrusion (e.g. manholes, drains, vents), and their ranking based on, among others, safety, ALARA, schedule, resources, risks, hazards, retrievability of FM;

— Entry conditions and prerequisites for FORAR procedure/process/activity implementation;

— Hazards, risks and consequences associated with retrieval process for:

- Industrial, radiological and nuclear safety;
- Equipment reliability;
- Creation of new and additional FM;
- Existing equipment damage and creation of further damages;

— Measures to eliminate or minimise FM risks and hazards during the activity, e.g. for:

- Further spread or transport of FM during recovery activities;
- Prevent further FM risk and hazards, as well as new targets and paths, during recovery activities;
- Prevent recovery and retrieval tools from becoming FM themselves (as there are several OPEX on broken or stuck tools);

— The necessary activities for locating and removing FM(s) including all the measures to be taken for other requirements, expectations and associated requirements and actions, such as:

- Temporary SSC and equipment modifications (opening, disassembly etc.) for accessibility needs, including the FMM/FMC measures around those SSCs and equipment;
- Operability, availability, functionality of SSCs that will be modified/worked on for the implementation of FORAR activities, including tagout;
- Radiological protection and ALARA assessment;
- Environmental and confined space conditions assessment and associated requirements and actions;
- Normal and emergency ingress/egress paths for personnel and equipment;
- Power and other sources needed and their configuration;

— The schedule and resources to be utilised for the recovery and retrieval, including:

- Qualifications, knowledge, skills and competencies needed for the activity;
- Training needs (including mock-ups) of personnel performing the retrieval;

— Methods for the monitoring of FM, retrieval equipment and their status during the retrieval efforts;

— Inspection and monitoring requirements, methods, tools and timings;

— Exit conditions from FOSAR and entry back to system close-out of the original activity that cause FMI, including hold points to wait for parallel assessments, for example:

- Analysis of recovered materials;
- Commissioning test and operation results after the FORAR;
- Close out to ensure that the SSCs are FM free from the FMI incident;
- Operation (or construction) department’s clearance;

— Follow up surveillance requirements and methods;
— Possible ‘Plan B’ and readiness to act on it.

It should be noted that, in cases that are noted in Section 6.2.2, immediate actions for mitigation of and recovery from an FMI event may be needed owing to the potential for further decrease in nuclear, radiological or industrial safety. In such cases, where the preparation of a detailed FORAR Plan is proven to be detrimental, the FORAR Plan may be accommodated by a prompt FORAR decision and impromptu strategy/tactic that could be implemented immediately with appropriate review, approval, supervision and oversight. By doing so, it is ensured that appropriate FM is promptly recovered, and the SSC is restored in a safer and more timely manner to prevent further degradation of the SSCs and protect people, equipment or environment.

As a good practice, the FORAR Plan may include a ‘do nothing’ option to provide the decision makers with an input on the impact/value of not retrieving the FM, i.e. consequences, resources needed for evaluation (which is discussed in Section 7). A ‘do nothing’ option can be particularly considered in cases that removal/recovery/retrieval efforts of the material are proven to carry unacceptable or intolerable safety risks than justifying the FM as a part of the plant design and configuration. However, this preview of a possible evaluation process may require comprehensive investigations and assessment of all aspects in integrated design and overall operation of the SSCs, utilising the original/existing design basis information and knowledge with solid scientific and engineering justification that would override the original design.

6.2.4.2. Conduct of foreign object reach and recovery

Once the FORAR Plan is reviewed and approved by all relevant and concerned parties, a **FORAR Working Procedure** (i.e. FORAR Work Instructions) can be prepared to describe how the FORAR will be performed. Depending on the weighted scale of the graded approach, the details of these instructions could vary from task to task. Therefore, the requirements, expectations and criteria for the preparation of FORAR Working Procedure/Instruction as to its type, scope and content, as well as the review and approval requirements, need to be defined by the FMMP (and/or other plant/project programmes).

Whether it is performed in accordance with strategy that is thoroughly evaluated and determined (i.e. by a comprehensive FORAR Plan and a detailed FORAR Working Procedure) or an impromptu strategy/tactic that is implemented under abstract work instructions (providing that the supervision and oversight are similar to those for the formal FORAR plan and procedure), the conduct of the FORAR activities need to be aware of and uphold the following key aspects, as a minimum:

— Nuclear, radiological and industrial safety requirements, which are always the utmost importance, and ALARA principles;
— Risk of relocation or repositioning of FM during recovery to create risk to SSC at hand and other SSCs (for example, risk of recovery efforts/tools causing its migration further into the SSC or getting into more unsafe or complex position to retrieve);

— Introduction and intrusion of new/additional FM into the SSC at hand and other SSCs, causing additional FM problems, from/by:

- Breakup or damage to the equipment or tools (or any parts of those) utilised for the recovery and retrieval;
- New or additional structural damage to SSC caused by the movement of the equipment or tools.

Again, it is a good practice to collect as much information and knowledge about the FM and FORAR evolution during the conduct of the FORAR activities to be utilised in analysis or disposition and closure of the task. As for FOSAD, collected evidence and information will also support subsequent assessments/analysis, incident investigation, future FOSAR activities and the improvement of FMMP. Methods and tools to obtain, collect and preserve information and knowledge during a FOSAR is the same as those that are used for FOSAD.

It is also a good practice to collect as much information as possible before removing the FM which can help in the reconstruction of FMI, including the transport and stoppage of FM during its movement.

Similarly, the entire FORAR activity needs to be reviewed and examined after the activity is completed as there will be lessons learned for the FMI event and from the detection and recovery processes.

6.2.5. Review, analysis, diagnosis, and assessment

Foreign object review and assessment, or FORAA, process primarily aims to identify, characterise and understand the FM as to its type, material, quantity, condition, shape and location. The FORAA process is also conducted to examine or reconstruct the FMI event progress/sequence and to evaluate and assess the course and discoveries of FM detection and retrieval activities, both of which help the event investigation, corrective action determination and programme and process improvement identification. Additionally, the assessment of SSC and FM status and type/location of defects will provide an understanding of potential hazards, risks and prevention and protection measures. As such, FORAA is performed in nearly all stages of the mitigation and remediation process; however, the reasons for, and objectives and scope of, its conduct may differ in each phase, as discussed in the following sections.

6.2.5.1. Analysis and assessment before and during search and detection

As discussed in Section 6.2.3, the objective of a FOSAD process is to identify the FM (and any other FMs that are generated as the FMI progressed) and to determine type, shape, condition, location and position of FM(s).

Inherently, prior to FOSAD, a FORAA is performed mainly to decide and determine what to look for and how and where to look. Such FORAA would also assess known or anticipated conditions of the SSCs which FOSAD will interfere and interface, such as potential or known damages to SSCs that might be caused by the FM and the FMI, as well as the FOSAD itself, including the additional FMs were (or could be) generated.

The results of this preliminary assessment will then support the planning and effective execution of FOSAD in terms of, for example, the determination and selection of: tools and methods that could be applicable; optimal access locations and routes; best timing and sequence of, and resources for, a safe, efficient and effective detection.

Moreover, during the conduct of FOSAD, additional FORAA may be needed as more information and knowledge become available or as a result of an unanticipated condition, unplanned circumstance or an unexpected discovery regarding the FMs or SSCs. In such cases, FORAA would support the decisions on what is the best way to proceed and how to proceed.

6.2.5.2. Analysis and assessment before and during recovery and retrieval

At the end of FOSAD, the resulting findings/observations from the search and detection activities need to be analysed and assessed to provide input to FORAR plans and activities towards adequate preparation and optimal implementation.

Performing a FORAA before FORAR will aim at a better characterisation of the FM and the FMI, i.e. type, shape, condition, location and position of FM(s), and damage to the equipment and SSCs, in support of the decisions on recovery efforts. Again, a FORAA performed before the planning and execution of FORAR will help to determine the most appropriate, useful and efficient tools and methods to retrieve FM(s) — without aggravating or causing further FM(s) and damage to the equipment and SSCs — and the optimal use of resources and time.

Also, FORAA could be needed during the evolution of FORAR activities when unanticipated condition, unplanned circumstance or an unexpected discovery regarding the FMs or SSCs or the FORAR efforts.

6.2.5.3. Analysis and assessment after recovery and retrieval

Once the FM is retrieved, it will be analysed and assessed together with the as-found and as-left conditions of all SSC, equipment and material involved and used in the detection and retrieval efforts. This post-FOSAR process, firstly aims to determine and understand the FM and its interaction with the SSCs by evaluating, including:

— *Wholeness of FM(s)*: The assessment of the wholeness of FM is to confirm that all the pieces of the original FM are accounted for. The results of this assessment will confirm the success of FOSAR activity or will determine the necessity and focus areas (e.g. where and what to look for) of another round of FOSAR for the detection and recovery of pieces still remaining in the SSCs;

— *Form and shape of FM(s)*: The examination of the form and shape of FM(s) would reveal the potential sources of the FM, as well as the indications of SSCs being knocked, collided, bumped, lacerated, smashed, etc. by the FM. Even in some cases, the residues and traces on the FM might give suggestions as to which SSC or equipment might be affected;

— *Source of FM(s)*: The analysis to determine the source of recovered FM provides information and knowledge on several aspects. Firstly, it determines where the FM came from (for example in cases when the FMI was not directly observed, or the FM is a fragmentation of something other the original FM). Secondly, it provides manifestation about where the FM had been (i.e. previous locations and paths). Furthermore, it might be extrapolated on the other plant SSCs and material in similar nature and may reveal the existence or possibility/potential for other same or similar FMs from those SSCs and materials and their anticipated locations.

The FORAA of FM(s) may be accomplished by several methods and tools, including:

— Visual and physical examination by relevant experts;
— Review by experienced, knowledgeable and familiar plant personnel and external counterparts (it is a good practice to distribute photos/videos of the FM to as broad group as necessary for recognition and identification);
— Metallurgical and material analysis;
— Chemical analysis;
— Isotopic analysis (if/when the FM is suspected or known to be subject to radiation) which from the activation of the material in the core) may be able to link the FM to an approximate date that a specific activity or event took place and provide additional information regarding the source. If the FM was recovered from the reactor coolant or primary heat transport systems (RCS or PHT) or an attached system;
— Engineering review of drawings, P&IDs, FMM ingress, transportation and target maps.

After the examination, analysis and assessment of FM(s), FORAA of the impact on the SSCs is performed. This FORAA may include a reconstruction of the FMI event and will deduce any existing and potential future impacts on the form, fit and function of plant SSCs and support the conclusions that the adequate level of 'foreign material free operation' and 'no adverse effect of foreign material on safe, reliable and efficient operation' of the plant is reinstated and assured.

Finally, the FORAA will provide event analysis and assessment in support of the event investigation that is being conducted under the CAP for the determination of corrective actions.

Furthermore, the lessons learned (the 'Act' stage of PDCA cycle) and the information and knowledge gained (the 'Core'/'Know' part of the PDCA cycle) from FORAA will support future activities and be used in the improvement of FMMP and other programmes and processes.

6.3. MITIGATION OF A LATENT FOREIGN MATERIAL

With the exception of detection — which inherently is the initiator of mitigation activities instead of a directly witnessed (or suspected) current FMI incident — and the assessment aspect — which may be more challenging as to reconstruction of a historical event(s) —, the mitigation of a past FMI is the same as that of a current FM. Thus, the following sections discuss the same aspects of mitigation that were presented in Section 6.2 in a different order and with particular emphasis on the differences for, and more details on, the detection and assessment of latent FM processes for the mitigation of past FMI(s).

Another additional importance of the mitigation of past FMIs to note is that once a latent FM is detected (i.e. discovered) and subsequently assessed, the mitigation of an unnoticed/unknown past FMI event provide valuable lessons learned towards the improvement of current FMMP. For example, the consideration of following questions and reflecting their answers into the current programme and processes and FMM practices would be beneficial:

— Why and how long has the FM gone unnoticed?

  - When was it introduced into the SSCs?
  - Were there any opportunities to discover the FM?
  - Was there a failure/inadequacy in the current/recent FMMP concerning detection?

- Was there a defect in design for monitoring the impacts and signs of the FM in the SSC?

— Why did the FM intrude into the SSC?

- What is the apparent cause?
- What were the conditions of work area, people, plant/project, organisation, FMMP?
- Could the FMI have still occurred, under the similar conditions, since the implementation of the existing FMMP (for example, could/would the revealed incidents of construction/personal items being left in the work area or systems during early stages of construction have been prevented by the current FMMP and/or the FMMPs that came into effect since)?

6.3.1. Detection

The detection of a latent FM (especially in case of searching for 'unknown unknown' as discussed later in Section 6.3.3.2) necessitates different (or additional) approaches and processes than of those for a current FM, which were discussed in Section 6.2.3.

As aforementioned, more than 75 per cent of latent FMs were discovered by luck or coincidence. Unless a structured proactive detection (and retrieval) effort, i.e. a special FOSAR (FOSAD and FORAR) project, is conducted for searching latent FMs in targeted SSCs (or all SSCs which are physically and safely searchable); luck, coincident or self-indication continues to be the primary manner of detection.

6.3.1.1. Coincidental and self-revealing detection

Unlike an FMI event which is directly or indirectly observed to happen during a current activity, there is no observed, reported or recorded FMI for the latent FMs. The chance and opportunity for their detection come from an unrelated plant/project evolution or activity, such as:

— Discovery/encounter of FM in the SSC by the workers, observers, monitors, inspectors during an activity performance that is not part of or relevant to FM detection process;
— Parts, materials are found missing, damaged or defective during disassembly or reassembly of components;
— Absence of any reporting or recording of such issue from the last time (or earlier times) when such SSCs were worked on;
— No known or explained reason for such loss, damage or defect to the subject SSC;
— Unusual and sudden change in the trend or indication of monitored SSC operating parameters (temperature, flow, pressure, vibration, etc.) and sensory indications (e.g. unusual colour, odour, noise, smoke, leak) from the SSCs;
— Physical damage to a plant SSC for unknown reasons.

6.3.1.2. Programmatic search and detection

Some owner/operating organisations may choose to establish and conduct comprehensive and programmatic searches in and around plant SSCs with an intent and objective to detect/discover possible latent and legacy-latent FMs. Such latent FM search and recovery efforts are typically triggered due to the recognition of challenges to the plant safety and performance by, for example:

- An event caused by a latent FM, particularly, investigation of which indicates a possibility for existence of similar FMs in the plant SSCs;
- Chronic vintage FMs and past FMM and FMMP defects and deficiencies;
- Series of coincidental discoveries dating back to a specific phase or activity of the project/plant lifetime.

As a result, in accordance with the corporate commitment and policy of a *foreign material free operation* (or, in some cases, by requests from the regulatory body), the owner/operating organisations decide to undertake a detailed, systematic and structured search, detection and assessment process. This undertaking, which can be termed as *comprehensive foreign object search and retrieval (CFOSAR),* could be a one-time special project or a permanent and continuous plant/project programme or process.

The CFOSAR projects/programmes require substantial and dedicated efforts and resources (both human and financial) to look for latent FMs in the plant SSCs (that may have resulted from any or all of the factors that resulted in the lack or deficiency of FMM controls and barriers and at any time in the project's/plant's past) which, at times, may look like looking for a needle in the haystack. Therefore, in order to make a decision to start a CFOSAR, the boundaries need to be defined to inform the decision makers about the extent of efforts and resources (as well as the schedule) to achieve an adequate level of '*foreign material free operation'* and '*no adverse effect of foreign material on safe, reliable and efficient operation*' of the plant.

The matter of the utmost importance for effective and efficient use of efforts and resources and getting expected level of achievement is **where to look**, which may depend on **what to look for**. Therefore, for the success and sustainability of CFOSAR efforts, the scope, plans and schedules need to be carefully set based on a graded and/or targeted approach. If such graded and targeted approach is not properly considered and consistently implemented, the CFOSAR initiatives and efforts, even those with a good start, would face increasing burden and strain on the human and financial resources. As a result, the scope and/or goals and expectations of CFOSAR are gradually relaxed or eliminated, which eventually lead to the ineffectiveness, or even abandonment, of the project/programme (as it can be seen in many OPEX with projects/programmes that are initiated with good intentions to improve but are cancelled on the basis of large and increasing scale of efforts compounded by the perception of lacking immediate visible and tangible benefits).

Therefore, it is essential for an effective CFOSAR that the activities, processes and/or SSCs for search and detection are scoped based on a graded approach and associated weighting scale, that is primarily driven by the corporate character and strategy that will determine and apply a value, importance and significance to each activity, process and SSC reflecting, for example (see also Section 4.5):

- Nuclear, industrial and radiological safety impacts and importance;
- Safety, quality and reliability designations, requirements, expectations and effects;
- Plant performance goals and expectations;
- Severity of consequences of potential dormant FM regarding safety, health, economic and financial aspects.

Similarly, the CFOSAR project/programme may target specific SSCs, activities, time or periods in the plant history. For example, it may target any or all of the following:

- All plant SSCs;
- Items related to safety, items supporting the safety and safety support features;
- Safety Class 1 and 2 SSCs;
- SSCs that are similar to the one found with a latent FM;
- SSCs that were worked on during a certain period where many FMI discovered to occur (e.g. certain multiple activity periods, such as construction, refurbishment, maintenance outage, major plant modification and maintenance);
- SSCs that has never (or recently) been opened or worked on or entered;
- SSCs that has higher probability of, or potential for, leftover and with idle or static points/areas, such as tanks, vents, traps;
- Activities that resemble the activity that assessed to be the cause of specific historical FMI, (including those that are legacy or were abandoned after certain time in operation);
- Activities that were performed under a FMMP that is known to be defective;
- Activities that were performed without a FMMP.

Also, some SSCs can also be eliminated/excluded from the scope, such as those that:

- Have been operated with no unusual trends or indications;
- Have been tested, surveyed, monitored;
- Recently opened, worked on or entered.

However, such elimination of SSCs to be carefully elaborated and well justified based on the design and configuration aspects, as OPEX has shown that:

A latent FMs may exist in SSCs that have shown no unusual indications or trends and/or have been tested, surveyed many times. For example, in case of the discovery of a latent FM in a plant's containment spray system, it was possible to meet the test acceptance criteria, and the blockage of FM has gone unnoticed, since the system might have redundant paths (or paths with least resistance in the tests that are conducted with air flow). Therefore, passing the test may not mean that there is no latent FM in the SSC.

Regardless of the scope, extent and schedule of search and discover efforts, the ultimate goal of CFOSAR is:

- Remove or evaluate (see Section 7) and assess the impacts of the found foreign material;
- Reflect those findings and learnings into the FMMP to establish measures to eliminate or minimise similar FMM issues in the future.

6.3.2. Notification

Same as the notification process presented in Section 6.2.1, in case of the discovery of a latent FM, immediate notification will be made to the line management (i.e. supervisors/team leaders) and to all involved or relevant plant/project personnel, including to the control room, for prompt assessments and mitigative actions.

6.3.3. Immediate actions

Similar to what was described in Section 6.2.2, upon the immediate notification, a prompt assessment is performed to determine the adversity of the detected/discovered/encountered FM and the immediate actions to be taken for mitigation.

However, in most cases of latent FM, the immediate actions may not be needed and further actions may be deferred to the completion of more detailed investigations and evaluations, unless the prompt operability determination results in the relevant SSC being inoperable and the operability is needed for nuclear, radiological or industrial safety.

There are also some early actions are to be taken when a FM is unexpectedly encountered/discovered, such as determining whether the FM is latent or current by check and verification of (see also Appendix IV for a flowchart for decision making and actions):

— Any ongoing FOSAD activity for a same or similar FM: If there is an ongoing FOSAD, then this discovery would serve as the detection of a ‘current FM’ that is being searched for and the detection of this FM needs to be immediately communicated to the FOSAD team for their FOSAD activities that are in progress. Consequently, further FORAA activities and all evidence need to be turned over to that FOSAR team;

— Any unrecovered FM in similar or same nature: If there is no ongoing FOSAR for the detected/discovered/encountered FM, then it would be necessary to check the maintained lost parts list, typically termed as *unrecovered foreign material list* or *lost parts list*, which has the records of FMs that have been missing, undetected, unrecovered, equivocal[21] or evaluated (see Section 7 for the evaluation process). This check will verify and confirm whether the FM is one of those that were undetected or unrecovered and it could be classified as a current FM, for which the applicable FORAR or FORAA is to be conducted. (It should be noted that even the FM is in the unrecovered FM list as ‘evaluated FM’, it is necessary to ensure that all the analyses, assumptions, justifications and conclusion of evaluation are still valid and correct, particularly the assumptions and conclusions on the transportability of the evaluated FM. For example, the past evaluation might have concluded that the FM would stay in its place or disintegrate/dissolve/decompose without impacting the SSCs for the rest of plant life. This conclusion could be invalid if the FM is found to be moved to somewhere else or still intact, which requires a new FORAA).

If the detected/discovered/encountered FM is determined not to be a current FM by these checks and verifications, then it is classified as a latent FM and it leads to the conduct of both new FOSAR and FORAA processes, as shown in the sample process depicted in Appendix IV. In such cases, since the FM has already been detected, the FOSAD activities may mainly consist of FM characterisation while the FORAR would be a full-blown process following all the methods and tools discussed in Section 6.2.4.

On the other hand, if the detected/discovered/encountered FM is determined to be a current FM, this would add to the review, analysis and assessment that is described in Section 6.2.5 upon further investigation that may discover that current FMMP requirements and expectations have been deficient or were not followed. Such cases could be, for example:

— The FM is listed in the unrecovered FM list but there is no evaluation report (or the existing report is inadequate, particularly as to no evaluation and justification to leave it in the SSCs). In this case, it would be necessary to conduct a detailed assessment of the FMMP itself by a FOPAA (in addition to an investigation under CAP);

[21] During the lifetime of a plant/project, there may be some cases where an FMI event is suspected but there is no evidence of FM or FMI determined. Such cases may also be entered in the unrecovered FM list with annotation that the FM is ‘equivocal’ to be on the conservative side.

— The FM is found in a location that was not considered/anticipated in the previous evaluation, and there was no justification to leave it in the SSCs. Such case would require a detailed assessment of impact by a FOTAA.

As depicted in Appendix IV, depending on the programmatic analysis and assessment, in some cases, the FM can be considered as latent. Such cases may be the missed opportunities (e.g. the current FM has gone unnoticed by activities that worked on the system or tests performed between the intrusion and discovery of this 'current FM') rendering the FM 'latent'.

It should be again emphasised that, upon unexpected detection/discovery/encounter of a FM, before moving/removing the FM to preserve the event scene and further intrusion of FM, it is essential to secure the area and to collect as much information as possible by an event scene recognition for the subsequent analysis and assessment. This scene/area recognition also serves to understand what would involve and entail the assessment and possible further investigation. It also helps to develop a systematic approach to recognising, collecting and recording evidence.

Therefore, the scene/area of the FM, as a whole and parts of potential evidence, needs to be documented by notes, photos (overview, mid-range and close-up), videos and sketches prior to the removal of FM and prior to moving things around and from the scene. It would be also a good practice to pack, tag and log collected items for preservation of FM and other material records, when possible. Such scene investigation that entails the collection and documentation of evidence will help to reconstruct the historical FMI during the analysis and assessment. Only after the documentation of area/scene, the FM can be removed by a FORAR process.

At this stage, it could be also a good practice to consider a preliminary FORAR plan to describe the evidence collection process and identify critical evidence to be collected and preserved.

6.3.4. Recovery and retrieval

Recovery and retrieval process for latent FM is the same process that would be implemented following a current FMI event. As such, the same requirements and expectation of a FORAR effort for a current FM apply and, typically, the similar tools, methods and actions, that are discussed in Section 6.2.4, would be utilised.

6.3.5. Review, analysis, diagnosis and assessment

In addition to those aspects of the FORAA process for a current FM, that are discussed in Section 6.2.5, the objectives and scope of the review, analysis, diagnosis and assessment of a latent FM would include:

— Confirming that the FM, although stayed dormant, has not affected the form, fit and function of any SSC (particularly, confirming that the FM would not have prevented the SSCs from fulfilling their safety related functions, if they had been needed);
— Analysing and assessing the time and conditions of occurrence for FMI which will differ depending on the type of FM (latent FM or latent-legacy FM).

Additionally, since a past FMI is, by its nature, a 'cold case' owing to its conditions and circumstances dating back to a distant past and history, its review, analysis, diagnosis and assessment will have additional challenges, including:

— Impact of time passed on the FM and the surrounding SSCs (physically and conceptually);
— Revised, replaced or ‘new’ programmes, processes, procedures, guidance;
— Changes in the organisation, the work area, and activities;
— Different people than who were there and had the first hand and key knowledge and information about the subject FMI, particularly about ‘how things were done in those days’;
— Change in corporate strategy, culture and knowledge.

Consequently, the FORAR of a latent FM would require extensive field and office/lab examination and investigation, including research and study of historical records, reconstruction and surmise of time and conditions of original FMI occurrence, documentation of conditions. Review internal and external OPEX could also assist in refining and validating the extent of condition and impacts. Also, particularly in those cases that are not too far in the past, the people involved in the activities in ‘those days’ may still be in the organisation with same or different roles. Such cases will add tasks of searching, finding and interviewing those people, as it would be very beneficial to have their recollection to reconstruct the FMI and the surrounding conditions, including the programmatic aspects. It could be even possible that the original FMI incident was reported and evaluated (although it may not be formally investigated or recorded owing to the FMMP and CAP requirements at that time) by the people who are still in the organisation. However, it is important that the analysis, assessment and rereview/reinvestigation need to be conducted by the people who did not conduct the original investigation in order to avoid the potential cognitive bias effects and constricted perspective, e.g. ‘tunnel vision’.

Additionally, FORAA of a latent FM may necessitate the utilisation of new tools and methods in addition to those discussed in Section 6.2.4. Such additional means to collect, review and assess the historical evidence may include new or different forensic technologies and tools, methods, information, knowledge and expertise that are available now; but were not available at the estimated or known time of FMI.

Once a latent FM is discovered/encountered, its enhancing value needs to be determined by asking critical questions (such as the questions listed in Section 6.3 and Appendix IV as to why and how long the FM has gone unnoticed, why the FM intruded into the SSC and/or transported, and so forth), preferably by a multidisciplinary team of experts. Asking questions with a high probing value will better determine the value of potential lessons to be learned for example, regarding:

— Potential for other SSCs that may have exposed to similar work conditions resulting in other latent FMs;
— Determination of what the latent FM caused/impacted (or could have caused/impacted but avoided by coincident or luck);
— The identification and recognition of potential latent impacts on SSCs;
— Indication of an existing issue with SSCs or the FMMP;
— Assessment of potential impact of material not yet accounted for those remains in the system or component;
— Possible prevention measures of recurrence;
— Measures required to prevent further equipment damage or degradation.

Accordingly, FORAA of latent FMs would need more time and resources (e.g. personnel with diverse competencies, skills, experience and experience, state of the art tools and methods) for proper and comprehensive conduct, than a FORAA of a current FM. On the other hand, the analysis and assessment of a latent (or legacy) FM may provide very valuable lessons learned towards the identification of gaps and the improvement of the plant configuration (by the results of FOTAA) and FMMP (by the results of FOPAA). Therefore, these impacts and values of latent FM analysis and investigation need to be assessed and provided to the decision makers in order to commit and dedicate time and resources, which could be very extensive and require organisational and administrative commitment.

In informing the decision makers, as well as in developing a FORAA Plan, it needs to be kept in mind that identifying and applying the resulting programmatic and technical lessons learned and, if any, belatedly implementing [still] applicable corrective actions to the current FMMP and plant activities will improve the plant FMM performance, FMMP and other programmes, processes and procedures and eliminate or minimise future FMIs.

7. EVALUATION

'Existence/intrusion of FM' is the second most common source of configuration management related nuclear power plant issues, just behind the 'inconsistencies in facility documents' [68]. The direct relation between FM and plant configuration originates from the definition of FM Evaluation process, which is, as stated in Section 2.5.7, a technical and scientific (engineering) input to the decision by the decision authority (see Section 5.4.1.1) to declare the material as *'non-foreign'* akin to *'a new plant configuration'*.

Therefore, all possible efforts need to be exhausted to recover all known FM and to avoid leaving them in plant SSCs, as the default setting is 'all FM has to be retrieved'. Accordingly, the FM Evaluation process needs to regarded as the least desirable and practiced part of FMM and FMMP, to be performed extremely rarely and under special circumstances when leaving the FM in SSC is inevitable, such as those when:

— The FOSAR efforts are proven to carry much larger nuclear, industrial and radiological safety risks than evaluating and accepting the FM as a part of plant design and configuration;
— The FM is proven to be physically impossible to detect, reach or retrieve.

Accordingly, the FMMP governing document will define and describe the conditions when to abandon the retrieval of FMs (i.e. when to perform an evaluation). It will also identify the roles and responsibilities for performing an evaluation and refer to the applicable requirements and expectations of design and configuration control programmes to be followed, in a graded approach, to provide input to the executive decision that the system can be returned to service with FM left inside.

The FMMP administrative procedure will also define and describe where and how the temporary/permanent acceptance of FM as a part of the design and configuration will be recorded, tracked and maintained. Conversely, such requirements and expectations can be contained in the design and configuration control governing documents defining and describing exemptions/variations (if any) to a normal design modification process.

7.1. DESIGN ASSESSMENT AND JUSTIFICATION

Incorporating the FM into design and operation as a design intent and/or operational feature makes it a *part of the design* or *a part of normal operational configuration* requires a solid technical decision that will override the original design and modify plant configuration, essentially constituting to a permanent or temporary *'design modification'*. As such, the evaluation towards leaving a FM in the SSC and returning the SSCs to operation requires an integrated assessment of the fit, form and function of SSCs and their design and operational interfaces and interactions with other SSCs *with the FM in them*.

Specifically, the evaluation needs to comprehensively and completely anticipate, identify and investigate and justify the integrity, reliability and operability of SSCs and any known and possible threats to their fit, form and function from the unrecovered (and thus became a part the SSCs) FM, particularly regarding:

- Potential generation of new FM caused by the FM that is being left in the SSC;
- Natural or forced movement possibilities and anticipated transportation paths or mechanisms, as well as the behaviour of the FM through those paths and locations, including at the potential resting places, regarding further and accumulative equipment and component damages and degradations;
- Flow paths of interconnecting systems and the probability of the FM reaching all paths;
- Potential and known current and short and long term impacts on the SSCs design and operational functions, specifications and the nature of characteristics and indications of impacts;
- Prevention and protection feature and compensatory action that could be incorporated in the design and implemented in operation to minimise or eliminate further adverse impacts on SSCs;
- Material compatibility of abandoned FM within the SSC and other interfacing SSCs;
- Anticipated SSC response to the FM during operation;
- Monitoring, surveillance and observation requirements and features.

Since maintaining the very high level of safety and performance expected of a plant requires that any design decision, including the decision to make an unrecovered FM a part of the design or a part of normal operational configuration, is to be made with a full understanding of all aspects including the design criteria and bases and the operational specifications for each system, equipment and component:

- Review, justification and acceptance of the FM as a temporary or permanent part of SSC need to be performed by the design conscience and has to be approved by the design authority (see Ref. [57]);
- The operations organisation needs to review and concur with the assessment and provide their input to the design authority and the decision authority.

Therefore, providing that the FOSAR and FORAA processes have determined the type, source and amount of the material to be left and remain in the plant SSC(s), the technical support (i.e. engineering) personnel will conduct the assessment of plant design and operation with the FM in the SSC(s) and, accordingly, will justify and technically approve the 'plant design and configuration change'.

Performed in accordance with the applicable requirements and activities of design and configuration control programme, processes and procedures, the evaluation ought to sufficiently, adequately and correctly address the issue of FM being left in the SSC, such that:

- With no further design and operational procedure changes, the FM, as-is, can be accepted as a part of design and configuration without compromising the safety, reliability and performance of plant design and operation are not compromised; or
- Require further design and operational procedure changes to compensate the adverse impacts (existing or anticipated) of FM left in the SSCs on the plant design and configuration.

Normally, for the FM evaluation, the technical support organisation would follow a process for that is prescribed for a design modification. However, providing that a graded approach is described within the design modification process, only a subset of design modification process requirements and expectations maybe applicable to a FM evaluation. Such subset of design modification process, which is typically referred as 'simplified prompt design solution', 'fast track design mod' or 'online design change', may not be the same as that of a comprehensive design modification evaluation (e.g. the preparation, content, approval of FM evaluation package could be different from a typical design change package). In this process, the technical support (engineering) personnel determines the type of process to implement using the graded approach, such that the human resources and documentation needs for the modification are optimised and the modification is executed in a timely manner. In any case, it needs to be ensured that the FM evaluation sufficiently, adequately and correctly addresses design requirements and considerations. Thus, the criteria, scaling and thresholds of graded approach for conducting FM evaluations need to be determined and controlled by the design authority and they need to be clearly described either in the FMMP governing procedure or, preferably, in the design control procedure to which the FMMP procedure would refer.

7.2. TRACKING

In order to maintain and control plant configuration and design integrity, a process, method or tool needs to be in place to document and keep the records of FMs that have been left in the system (of course, based on a sound and robust evaluation process). The FMMP needs to also establish (or support) a systematic tracking of FM abandoned in the SSCs.

The tracking process of 'left in system FMs' is necessary because of the following reasons:

— To maintain and control plant configuration;
— To continuously verify and validate the assumptions made in the assessment and justification during the evaluation process regarding the impact on the fit, form and function of SSC;
— To ensure location of item is known with a certain proximity and future recovery efforts are planned and executed as deemed necessary;
— To provide records for identification and assessment of latent or past FM.

Typically, tracking of 'left in system FMs' is accomplished by utilising an *'unrecovered FM list'* or *'lost part list'*. This list would include not only the entry for FM identification but also other known information, such as:

— FMI event report identification, including the activity and system entry point, if known, as well as the FOSAR report, if exists;
— FM evaluation report key points:

  - Type, shape, form, material, source and quantity of FM remaining in the SSCs;
  - Last location and potential future location(s) of FM (noting that the FM needs to be monitored, when possible, particularly during the plant/system evolutions that may cause any location changes for example, during the opening of the adjacent, interfacing or connected SCCs or equipment);
  - Determined existing impact on the plant SSCs;
  - Anticipated impacts on the SSCs and their fit, form, function and operation;
  - Potential fertility for fragments or other FMs;
  - In place monitoring, surveillance and observation tools, equipment and methods;
  - Potential impact on system components or plant operations; including the anticipated sensory indications of impact;

— Plant and system conditions and anticipated FM locations necessary for next retrieval opportunity (e.g. next outage, next plant hot or cold shutdowns) for the work management process to document the need, schedule and resources in the planning process;
— A schematic FM Map that depicts:

- Current known/predicted location;
- The path from the system entry point to the current location;
- Anticipated future paths and locations;
- Paths that have been checked, tests, inspections or work activities have been performed that led to the detection (or confirmation of non-existence) of FM.

The ‘lost parts list’ is to be updated in a timely manner and made easily accessible by the site personnel, preferably electronically, and as applicable, in hardcopies.

It is also a good practice to track the unrecovered FM in updated design output drawings (e.g. P&IDs, process flow, maintenance and repair, pneumatic and hydraulic system diagrams and schematics, as applicable). with depiction of known/anticipated location of FM (similar to the one that is simply illustrated in Figure 19).

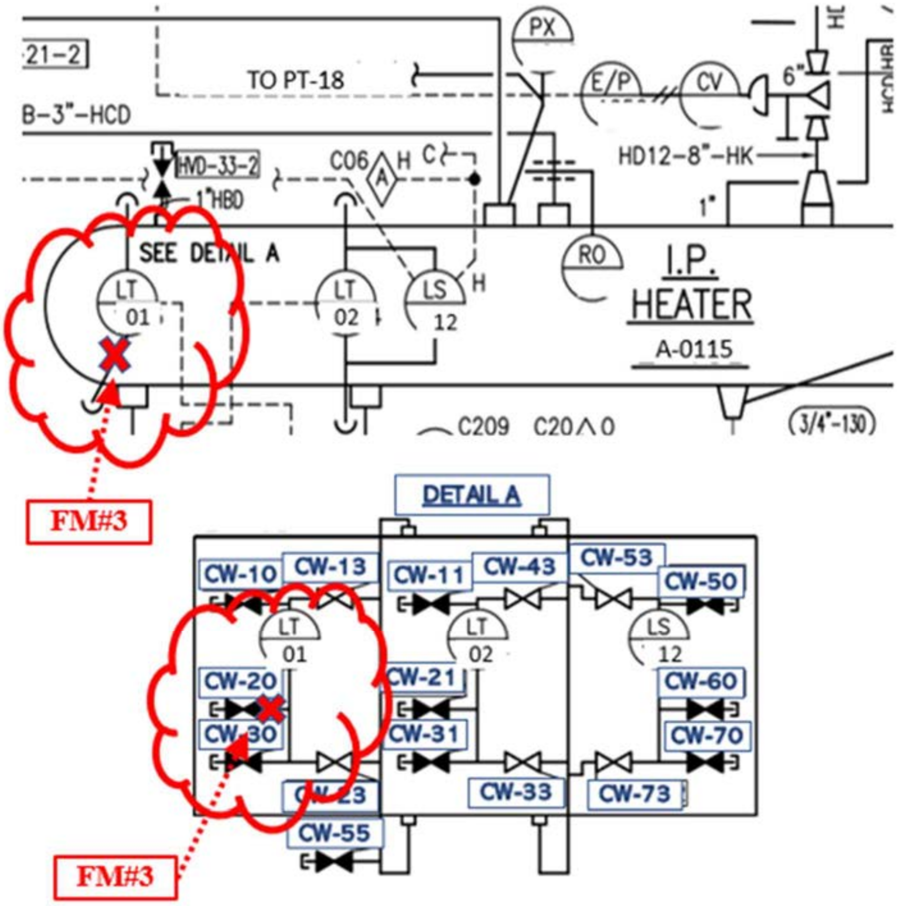


FIG. 19. An example of identifying and incorporating the foreign material (FM) left in system into the design drawings temporarily or permanently (system and component identification numbers, e.g. CW-33, C06, HD12, HK, HCD, LS, IP, LS, LT, PT-18, etc., are for illustration purposes only).

Unrecovered foreign material may also be tied to the plant's system health or project's progress reporting and be a part of performance indicators. For example, some plants have established plant health committees which can be periodically used as an existing mechanism for overall review and recommendations on unrecovered FM to upper management.

As much as is known, the system health report includes the type and source of the material as well as the amount. The report also includes postulated locations in the system(s) where the FM may settle or where it may be transported, along with the anticipated system/component response to the FM. The report needs to also present past and future opportunities to recover FMs and the description and status of FOSAR plans until the FM has been recovered.

Similarly, FMMP status and progress report could include a summary of unrecovered FM and affected systems; approximate known and unknown FM locations and amounts; number of active recovery plans; and any short or long term activities to address 'left in system' FM issues. Lost FM trends and PIs/KPIs which are presented in FMMP status and progress report provide the information and input towards decision making by the FMM Programme Owner/Manager on the FMMP.

The assignment of roles and responsibilities for tracking FM may vary from one plant/project organisation to another, or from one phase of the nuclear plant/project phase to another. For example, typically during the operation phase, the technical support organisation, e.g. system engineering, own the tracking process, while it could be the responsibility of the responsible designer during the construction phase. However, recalling the discussions in Section 5.6, 'what needs to be done' here is the recording and tracking of FMs temporarily or permanently left in the plant SSCs. Therefore, besides the ownership, other responsibilities could be assigned to the best fitting organisations according to their skill, competency and authority (as well as when/how fast/often the list needs to be updated for whom), the tracking can be assigned to a particular discipline, department or individual other than the design engineering or system engineering, e.g. maintenance (engineering), FMMP coordination, work planning, etc., for effective and timely tracking

Regardless of the responsible organisation(s), the FMMP administrative procedure needs to define and control the interfaces to ensure timely and correct tracking of FMs. Such interfaces may even include organisations without direct roles and responsibilities. For example, the licensing or QA/QC organisations, could need to know (or could request) the status and conditions of the FMs in plant SSCs, for reportability or regulatory inspections or quality audits, programme control inspections, respectively.

8. CONCLUSION

The issue of FM impact on the performance and safety at the nuclear power plants has continued since the initial problem identification in early 1990s despite a series of guidance and programmatic expectations established in the 1990s and 2000s towards resolving and managing FM in the plant SSCs. However, despite the extensive industry efforts on the good and effective practices for the exclusion of FM, the FM related events continue to occur and reoccur and, as discussed in this publication, observations and industry experience reviews showed that:

- Occurrence and reoccurrence of FMI events have primarily been attributed to deficient (or lack of effective) establishment, implementation, execution and improvement of the FMMP and its processes and procedures, as well as the weak FMM culture, resulting in acute issues;
- FMMPs mainly focused on fuel reliability, maintenance effectiveness and timely outage implementation aspects, rather than overall corporate strategy and policy to *'foreign material free operation'* in achieving '*no adverse effect of foreign material'* on safe, reliable, effective and efficient operation of the plant;
- Regulatory bodies — in addition to their initial focus on the reliability of nuclear fuel and fuel degradation caused by FM affecting the dose received by workers and further impede on the health and safety of the public — have become also concerned about:

  - FMI events leading to (or potentially result in) nuclear safety consequences due to loss of safety-related functions of SSCs;
  - Effectiveness of quality assurance programmes of the nuclear power plants, as the issues with FMM (or lack of it) were found to be recurring (in the same or different nuclear power plants) have indicated programmatic and/or cultural inadequacies;

- In addition to acute problems occurring during operation phase, the OPEX show that FMI events that occurred during design and construction have resulted in latent potential safety, reliability and performance problems, issues and concerns during operation phase. These events also showed the importance of FMM long before the operation phase and beyond.

Moreover, the lack of clear understanding and acceptance of (as well as insincere commitment to) the main reasons and the ultimate goals of FMM and FMMP (which is, again, to achieve foreign material free operation without adverse effect of foreign material on safety, reliability, effectiveness and efficiency) have led to the weakening of FMM culture and practices in many plants/projects, which were manifested by various conditions, including:

- Reactive attention and focus on FMM (i.e. the FMM has become important only when there is an FMI event that affected safe and efficient operation and electricity generation, and soon after drifted away to 'another non-essential plant programme' status until the next event) which made the maintenance and improvement of FMMP sporadic that is often initiated or reviewed and revised (fixed) by:

  - A 'force' to improve an inadequate (or declining) FMM, which is typically by the emergence of undesirable consequences, recommended by industry peer groups, such as IAEA, INPO, WANO, or enforced by the regulator body. In such cases,

efforts on the programme improvement are conducted by a management directive or dictate and the employees tended to perceive these efforts as compliance with management directives imposed on them by outsiders and responsibility is on the plant/corporate management;
    - Bringing in professional staff external to the groups and/or organisations to 'create' a new programme or 'fix' the existing one with a new (their external) perspective. In such cases the employees incline to believe that the responsibility for FMMP is on those professional staff who are brought in and is delivering the programme improvements;

- Minimisation of dedicated resources and putting the ownership and responsibility of the entire programme on a few people at lower ranks of the organisation (in some cases even only on one person) who do not have authority — rather than the direct ownership and responsibility of high-ranking management —. This 'one-person coordination and administration' mostly led to overwhelmed programme coordinators to a point that, in some plants, nobody wanted to take the role;
- Increased programmatic controls, procedures, instructions (particularly expanding in response to any new event) have made the following of those difficult and ineffective which, in some cases, caused workarounds, relaxations of requirements. This also made the FMMP to be perceived as a burden which to be minimised or eliminated (as mentioned earlier, until the next significant event).

This publication, therefore, has collected and discussed the solution of such issues and challenges and identified several good FMM practices that are common to establish an effective FMMP and its continuous improvement towards *'foreign material free operation'* and '*no adverse effect of foreign material* on safe, reliable, effective and efficient operation of the plant' goals and objectives, including:

- Corporate level commitment and a resolute policy defining philosophy, strategy, values and commitment for allocation of resources with adequate and clear FMM expectations and goals in supporting safe and sound decision making on the management of foreign material;
- Culture of understanding, promoting and demonstrating values and conscience in practices, as well as behaviours, in the management of foreign material;
- Organisation with collective awareness and ownership where roles, responsibilities and interfaces are clearly identified and defined and where everybody pays attention to FMM and recognise FM hazards and risks and understand consequences of their actions on plant safety and performance;
- Systematic implementation of a governing programme for FMM in establishing, developing, coordinating, integrating, assessing, modifying and improving associated processes, procedures and activities proactively:
- Graded approach that is driven by the corporate and organisational culture and characteristics that will assign and apply a corresponding value, importance and significance to a particular arrangement and activity including:

    - Nuclear, industrial, environmental and radiological safety impacts and importance;
    - Quality and reliability designations, requirements, expectations and effects;
    - Plant performance goals and expectations;
    - Degree of probability of FMI event based on the existing/generated FMs, created FM paths and FM targets during the entire activity;

- Severity of consequences of FMI regarding safety, health, economic and financial aspects;
- Rarity/frequency/specialty/complexity of the activity;

— Plant/project procedures that are written, controlled and implemented with the premises that the task performance start at work management planning (or design) stage specifying the FMM requirements, risks and control measures and making them part of the process until final application in the field and subsequent closure and task critiques noting that:

  - In some organisations, FMI events continue to occur when they lack behaviours of a good FMM culture, even though they are following the best industry practices in procedure writing and maintain large number of procedures that cover, in detail, every aspect of FMC and FMI event prevention;
  - Conversely, some organisations which demonstrate habitual (i.e. not necessarily instructed) behaviours of a good FMM culture in the awareness and management of foreign material (e.g. show behaviours of cleanliness, good housekeeping, informal active communications and peer cultivation, risk recognition) have a few or no FMI events and maintain a good FMM with a minimal but sufficient set of instructions/procedures;

— Training for the awareness, knowledge, skills and attitudes for FMM which anchors effective work practices and ensures competency for recognising FM, FM path, FM target and associated risks and undesirable effects and consequences in personal and organisational decision making during activities;
— Effective work practices towards identifying FM issues and requesting or providing information to identify and resolve those correctly, effectively and in a timely manner, which are understood and performed at all levels of the organisation;
— Provision of adequate time and resources for 'critical thinking' on FM aspects of the tasks with sufficiency for core activities and with allowance for discretionary and urgent activities such that opportunities for incorrect/inadequate task performance due to unrecognised, miscommunicated, misunderstood, omitted, rushed actions;
— Implementation and practice of a systematic approach for continuous improvement with effective and prompt problem (or potential problem) identification, corrective action and trending programmes to document and track FM related events, near misses, close calls, potential hazards and observed weaknesses and gaps;
— Application of conclusive and conducive metrics with objectives to assess the overall health of FMMP and to discover areas of improvement;
— Oversight, both continuous and periodic, of the FMMP and associated programmes, processes and procedures through focused observations and feedback of work practices and programme itself;
— Periodic assessments of the FMMP by internal and external organisations, including benchmarking, to identify areas of improvement and implement industry practices (or the practices of other industries in which FMM is strictly practiced), to identify and to develop and implement plans for FMMP optimisation;
— Use of OPEX in an effective and timely manner, including complete review and extraction of applicable lessons learned with timely incorporation in the FMMP elements, processes and procedures to prevent or minimise similar events, deficiencies and/or vulnerabilities.

Overall, there is no 'one-size-fits-all' structure and content for an effective FMM and continuously implemented and improved FMMP. This is because of the fact that the corporate strategy and character, management and frontline approach and modus operandi, tradition and values are different for each organisation. Regardless, for effectively establishing, implementing and applying appropriate and adequate FMM decisions in project/plant task and activities, a systematic approach with well-thought steps is proven to be essential. Accordingly, built on, and supported by, personal and organisational FM and FMM awareness, ownership, commitment and conviction, as a minimum, a good and effective FMMP need to be able to:

— Recognise and express the need, significance, ultimate goals and scope for FMMP for an effective FMM and its implementation;
— Classify the activities and tasks, their importance to FMM and associated risks and consequences for foreseen FM and its impact on the SSC’s form, fit and function;
— Identify the behaviours, competencies and qualifications needed for effective administration and implementation FMMP and overall FMM scope in activities;
— Identify potential sources for FMMP administration and implementation and select/assign organisations and individuals as applicable and needed;
— Communicate the FMMP scope, FMM policy, commitment, requirements and expectations and any relevant information to the organisation for complete and correct execution of the activities;
— When the outcome of the FMMP is provided, understand and know the relevant and accurate aspects and be mindful of the FMMP goals and achievements;
— Gain, retain and preserve, maintain and transfer the FM knowledge and information for the completeness and continuity of FMM behaviours and actions throughout the plant’s lifetime, including those that are collected by FMM and FMMP OPEX in the nuclear and other industries;
— Thoroughly assess good practices of FMM and effective FMMP provision and utilisation observed and recognised in other organisations (within or outside nuclear industry) for adaptability and possibility for implementation to own organisation considering the corporate strategy, organisation la structure and culture.

Such a systematic and structured approach, which is applied continuously throughout the nuclear power plant lifetime for each and every activity concerning and involving FM, will:

— Ensure that correct and timely FMM information is provided for making safe and sound decisions with confidence and comfort in accordance with the FMM policy, programme, strategy and goals of the organisation;
— Provide flexibility, adaptability and effectiveness of FMMP in the best manner that would achieve *‘foreign material free operation’* in achieving ‘*no adverse effect of foreign material’* on safe, reliable, effective and efficient operation of the plant.

APPENDIX I. FOREIGN MATERIAL RISK LEVEL CRITERIA

It is aforementioned in the publication that the current industry practice to categorise/classify FMRLs by a tiered system based on deterministic and/or probabilistic approaches based on safety, reliability, operability, availability, and the economics of plant performance and sustainable, effective and efficient electricity generation, as well as the overall corporate strategies/goals.

As such, some owner/operating organisations may choose to assign a predetermined FMRLs deterministically based on the safety and/or production significance/importance of that particular SSC or component, for example:

- Spent fuel pool;
- Main generator;
- Steam generator;
- Turbine;
- Transformers;
- Check valves;
- Motors;
- Reactor cavity when vessel head is removed;
- Torus or suppression chamber (BWR types);
- Refuelling pool during refuelling;
- Containment sump.

In addition, most owner/operating organisations use graded approach in the determination of FMRLs based on the probability of occurrence and consequences of an FMI incident during a particular activity. It is common in the industry to apply a method consisting of a combination of both in one form and another.

A quick review of graded approach for the determination of FMRLs used by NPPs shows that FMMPs typically use three FMRLs as a minimum, primarily based on the existing industry guidance, such as those provided or referred by Refs [9 – 11], namely, *no risk*, *standard (or Level 1) risk* and *high (or Level 2) risk*, as shown in Figs 20 and 21. In these commonly used FMRL determinations, considerations are also given to mitigation aspects as prevention, protection and exclusion, adding difficulty of mitigation of consequences, such as setting criteria for the possibility and difficulty for foreign material detection and retrieval/recovery after an FMI event and example of which is provided in Table 1.

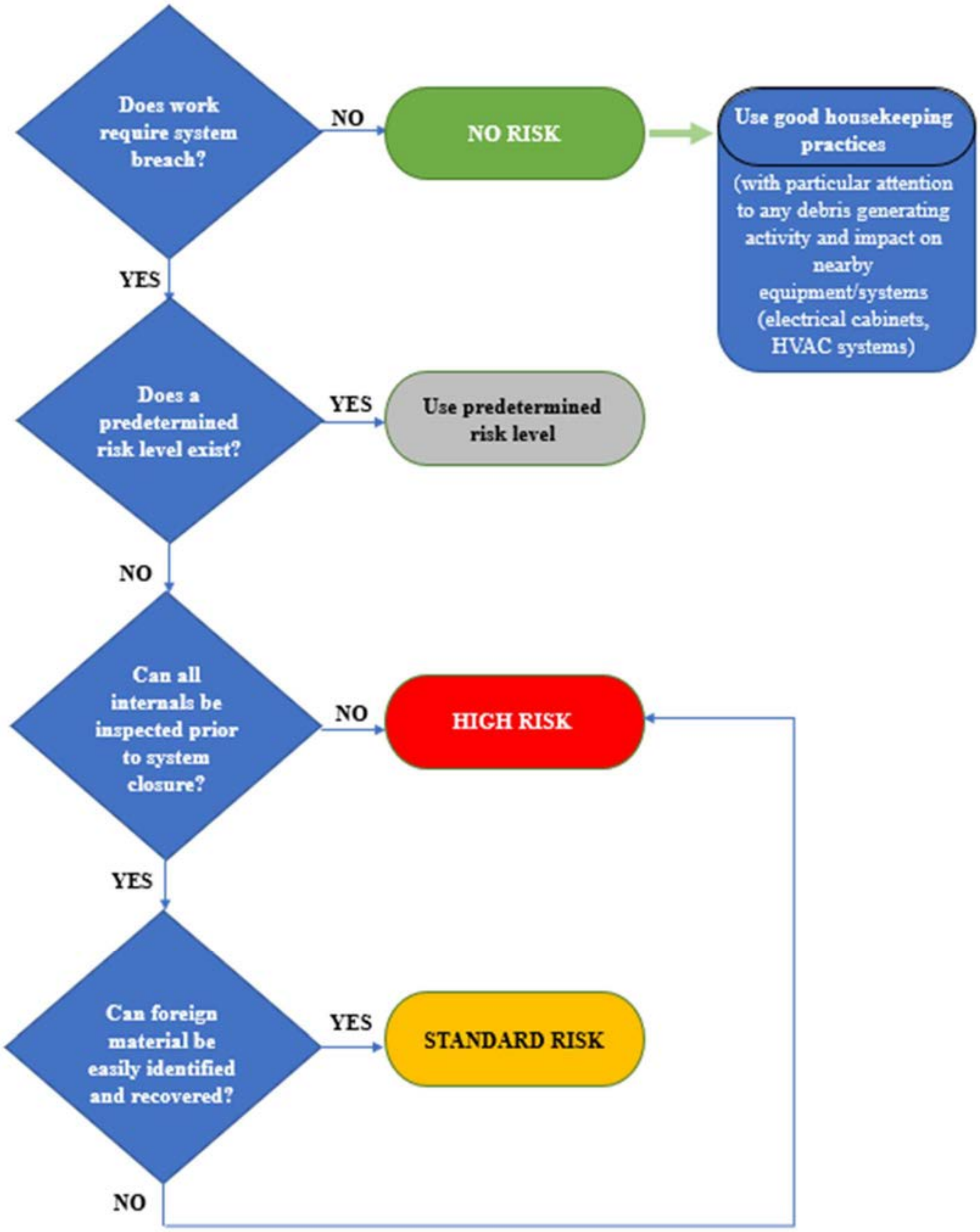


FIG. 20. A sample FMRL determination flowchart (courtesy of R. Lightfoot, Bruce Power). HVAC — heating, ventilation and air conditioning.

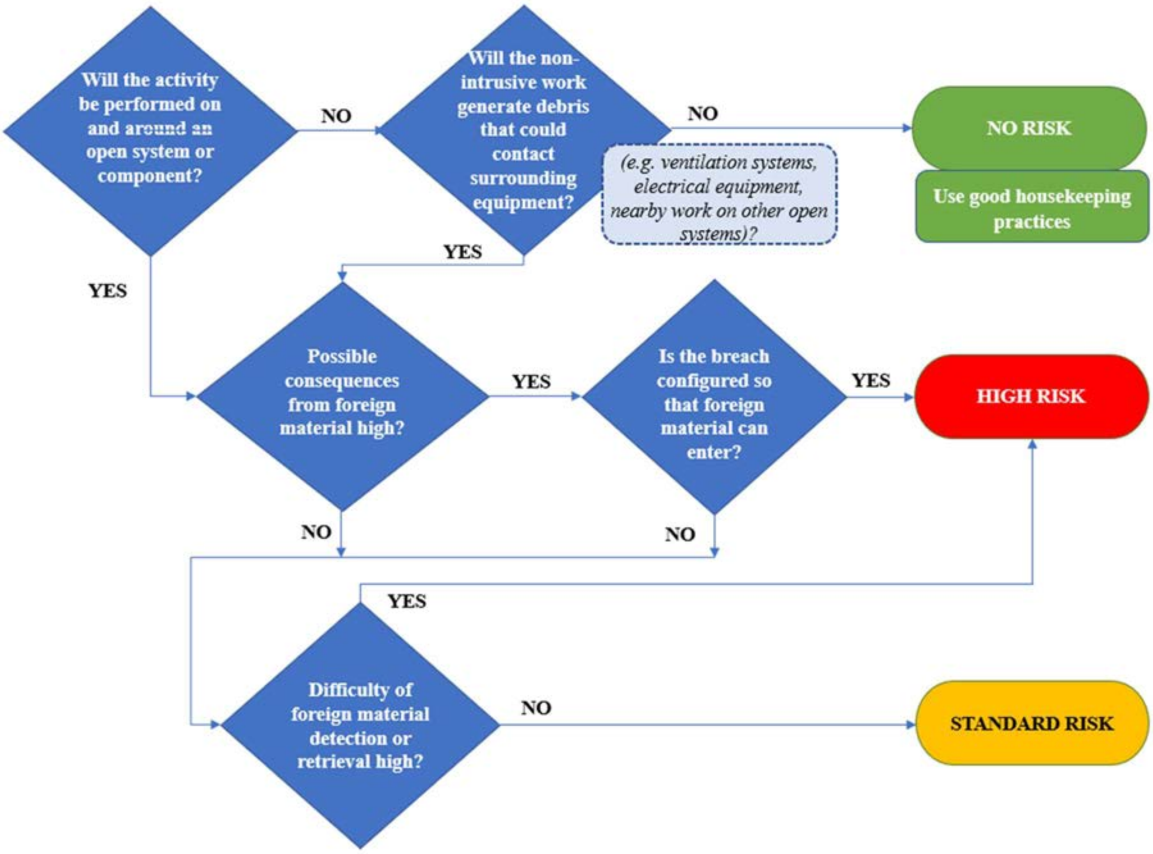


FIG. 21. A sample FMRL determination flowchart (courtesy of D. Ziebell, EPRI).

Table 1. FOREIGN MATERIAL RISK LEVEL CRITERIA BASED ON CONSEQUENCES, PROBABILITY AND MITIGATION

Level	Criteria
	I. Risk level based on the consequences of foreign material intrusion
High	For this activity, the magnitude of the potential consequence associated with the safety, health, environmental, security, quality and economic performance are unacceptable. For example (this is not an all-inclusive list): • Damage to nuclear fuel; • Unavailability of engineered safety feature (ESF) functions; • Damage to fission product barriers, e.g., steam generator tubes; • Degradation of vital production equipment such as turbines, generators, transformers; • Chemical or lubricant contamination leading to any of the above; • Control system inoperability creating the risk of plant transients; • Impact to SSCs vital to the safe operation of the plant.
Standard	For this activity, the magnitude of the potential consequence associated with the safety, health, environmental, security, quality and economic performance is elevated, but acceptable, yet are worth preventing. For example (this is not an all-inclusive list): • Reduced reliability of components; • Entry into disallowed configurations (loss of required redundant equipment); • High rework costs; • Prolonged outages or labour costs associated with search and retrieval activities that could have been avoided.
	II. Risk level based on the probability of foreign material intrusion
High	• Personnel entry or partial entry into a system or component; • Tools or inspection equipment will enter the system or component; • Debris-generating activities; • Critical electrical systems; • Reactor cavity with the head removed; • Torus or suppression chamber hatches and down comers; • Medium to large openings
Standard	• Debris-generating activities; • Potential for foreign material intrusion from uncontrolled areas; • Small openings; • No foreign material generating activities; • Clean work environment;
	III. Risk level based on the difficulty of foreign material detection
High	• Foreign material cannot be easily identified; • Foreign material can migrate to a poorly visible location.
Standard	• All foreign material readily visible
	IV. Risk level based on the difficulty of foreign material recovery
High	• Foreign material cannot be readily recovered • Foreign material retrieval might require breaching of other systems or components • Special recovery tools or techniques nay required • Lost foreign material could require and extend the outage
Standard	• All foreign material is easily accessible

APPENDIX II. FOREIGN MATERIAL CONTROL AREA CRITERIA

Foreign material control area designations are often associated with a particular FMRL. As mentioned in Appendix I, industry typically use three FMRLs: no risk; standard (or Level 1) risk; and high (or Level 2) risk, and as such, the current commonly used designations for FMCAs include[22]:

— High risk, standard risk and good housekeeping areas;
— Level 1, 2 and 3 areas; or
— High, moderate and low risk areas.

An example of FMCA designation and associated requirements/restrictions used by an owner/operating organisation is illustrated in Table 2.

Table 2. REQUIREMENTS FOR DESIGNATED FOREIGN MATERIAL CONTROL AREAS

Area designation	Level 1 / High	Level 2 / Standard	Good housekeeping
Establishment of boundary	Yes	Yes	Task manager's decision
FMM signage	Yes	Yes	Task manager's decision
Personnel access	Restricted	Controlled	Permitted
Training	FMCA requirements refresher	FMCA requirements refresher	No
Pre-job briefing	Yes	Task manager's decision	Task manager's decision
Tool and material reconciliation	Yes	Task manager's decision	No
FMC device reconciliation	Yes	Yes	No
Pre-cleaning of the area	Yes	Yes	As per applicable procedures
Area inspections during and after work	Yes	Yes	Task manager's decision

Furthermore, at each phase of plant lifecycle, some housekeeping and cleanliness standards may apply. For example, in construction phase, the FMCA categorisation could be similar to the housekeeping zone requirements of industry regulations and standards, such as those in Refs [40–43], which define the categorisation of zones based on the restrictions regarding to those listed in Table 3.

[22] As noted in Section 5.5.2 of this publication, another category, special foreign material control area (SFMCA), may also be applied.

Table 3. ZONE DESIGNATION AND RESTRICTIONS ASSOCIATED WITH THE CLEANLINESS REQUIREMENTS FOR HOUSEKEEPING ACTIVITIES DURING THE CONSTRUCTION PHASE OF NUCLEAR POWER PLANTS [42]

ZONE	RESTRICTIONS					
	Clothing change	Clean gloves, shoe and head covers	Filtered air	Tool/material precleaning	Tool/material and personnel reconciliation	Food, drink and tobacco
ZONE I	X	X	X	X	X	X
ZONE II		X		X	X	X
ZONE III					X	X
ZONE IV						X
ZONE V						

More importantly, FMCA designations are strongly connected to plant/project FMM culture. Industry experience indicates that a clear and robust designation system by which personnel determine when the most stringent FMCs need to be applied has a strong connection to FMM awareness, attitudes and values. Another observation is that in most cases, three levels of areas may not cover all expectations for FMCs. Therefore, to build and arrange the FMCAs (and buffer zones) vary depending on the decision making and qualified person in the organisation, as well as independency from actual activity. As such, in some NPPs the responsible discipline's supervisor of the activity decides on the shape, type, extent and ingress/egress locations, etc., with consultation from FMM Coordinators, as necessary, while in some NPPs the designated groups, such as FMM Programme Coordination group or FMCA Monitoring group, may do so with the approval of FMM Programme Coordinator and/or the responsible work groups supervisors/team leaders. The latter one is particularly practiced during the control and work activities performed by non-station personnel.

As such, while setting the areas in accordance with industry guidance and complying the minimum requirements and expectation of area category, each organisation may set the specific requirements in accordance with their corporate culture, experience, competencies and values and attitude. Just as an example, herein, Table 4 illustrates a set of FMCA designations with associated requirements and expectations for a generic organisation as:

- General plant area;
- Foreign material attention area;
- Foreign material control area;
- Foreign material defence area.

Table 4. A SAMPLE FOREIGN MATERIAL CONTROL AREA (FMCA) DESIGNATION SCHEME AND THE ASSOCIATED REQUIREMENTS AND EXPECTATIONS FOR THE CONTROLS

Aspect	Requirements and controls			
FMRL	No risk	Low risk	Standard risk	High risk
Area designation	General plant area	Foreign material attention area	Foreign material control area	Foreign material defence area
Signage and posting	‘KEEP CLEAN’	‘FMM – ATTENTION ZONE’ ‘Restricted entry - Enter with permission from work owner’	‘FMM – CONTROL ZONE’ ‘Controlled entry – Enter through the checkpoint’	‘FMM – DEFENCE ZONE’ ‘Limited entry – Enter with permission by the checkpoint’
Buffer zone	Not applicable	Not required	Not required	Strategically placed outside FMCA
Barriers	In accordance with the plant’s programmes and processes	Visible restrictions of general traffic (e.g. solid or retractable ‘restricted entry’ barriers) around the zone.	Visible restrictions of general traffic (e.g. solid or retractable ‘limited entry’ barriers) outside the zone. Enclosed boundary barriers. Barriers to establish a single entry point donned with instructions and requirements Clean enclosure boundaries.	Visible restrictions of general traffic (e.g. solid or retractable ‘limited entry’ barriers) outside the buffer zone. Enclosed boundary barriers. Barriers to establish a single entry point donned with instructions and requirements Clean enclosure boundaries. Barrier between buffer zone and area.
Personnel access	In accordance with the plant’s programmes and processes	Restricted and generally monitored entry to qualified people assigned to (and supporting) the activity	Controlled entry to qualified people assigned to the activity. Monitored, self-checked and recorded (in the FMM Logs). Self-validation and recording of allowance/permission for access. Accounting and reconciliation of people (at the end or interruption of the activity).	Controlled entry and exit limited to only essential, qualified and approved people. Monitored, peer-checked and recorded (in the FMM Logs). Monitored, peer-validated and recorded allowance for access. Accounting and reconciliation of people (at the end or interruption of the activity) and periodically during the activity.

Table 4. A SAMPLE FOREIGN MATERIAL CONTROL AREA (FMCA) DESIGNATION SCHEME AND THE ASSOCIATED REQUIREMENTS AND EXPECTATIONS FOR THE CONTROLS

Aspect	Requirements and controls			
FMRL	No risk	Low risk	Standard risk	High risk
Area designation	General plant area	Foreign material attention area	Foreign material control area	Foreign material defence area
Training	General employee training for FMM and FMMP.	General employee training for FMM and FMMP. Proficient level FMM training Discipline specific FMM training.	General employee training for FMM and FMMP. Proficient level FMM and FMC training Discipline specific FMM training. Activity specific FMM training.	General employee training for FMM and FMMP. Expert level FMM and FMC training Discipline specific FMM training. In-depth activity specific FMM training, e.g. mock-up, simulator.
Cleanliness	General plant housekeeping and cleaning standards and habits. Usual personnel movement and regular walkdowns with awareness, vigilance, observance and practice for and cleanliness and housekeeping. Smoking, eating and drinking only in permitted areas.	General plant housekeeping and cleaning standards and habits. Usual personnel movement and regular walkdowns with awareness, vigilance, observance and practice for and cleanliness and housekeeping in the work area. Initial area clean-up. Initial and periodic walkdowns and cleanliness checks by the work crew with awareness on housekeeping and cleanliness and corrections when issues identified. 'Clean as you go' practice. Final area clean-up and 'end of job' housekeeping checks. No smoking, eating and drinking in the zone.	General plant housekeeping and cleaning standards and habits. Pre-job walkdown with identification and correction of any housekeeping and cleanliness issues. Initial area clean-up. Periodic walkdowns and cleanliness checks by the work crew with specific attention to housekeeping and cleanliness and corrections when issues identified. 'Clean as you go' practice. Final area clean-up and 'end of job' housekeeping checks. No smoking, eating and drinking in the zone.	General plant housekeeping and cleaning standards and habits. Pre-job walkdown with identification and correction of any housekeeping and cleanliness issues. Initial area clean-up. Initial area clean-up and housekeeping inspection. Periodic and random walkdowns and cleanliness checks by the work crew with special attention and focus to housekeeping and cleanliness and corrections when issues identified. Periodic cleanliness inspections. 'Clean as you go' practice. Final area clean-up and 'end of job' housekeeping checks. Final cleanliness inspections. No smoking, eating and drinking in the area and buffer zones.

Table 4. A SAMPLE FOREIGN MATERIAL CONTROL AREA (FMCA) DESIGNATION SCHEME AND THE ASSOCIATED REQUIREMENTS AND EXPECTATIONS FOR THE CONTROLS

Aspect	Requirements and controls			
FMRL	No risk	Low risk	Standard risk	High risk
Area designation	General plant area	Foreign material attention area	Foreign material control area	Foreign material defence area
Attire and personal Items	Required plant attire, clothing, PPE.	Required activity attire, i.e. clothing, PPE. Secured personal items, e.g. jewellery, eyewear, keys, wallets and badges, with appropriate devices. Permitted and secured carry and use of electronic devices, e.g. phones, pagers, tablets. Tallying and reconciliation of personal items at the final area clean-up.	Required activity attire, clothing, PPE (secured by FMM approved devices). No unnecessary personal items, e.g. jewellery, keys, wallets. Secured (by FMM approved devices) personal items that are necessary for the performer, e.g. eyeglasses, hearing aid, etc. No personal electronic devices. Authorised and secured electronic devices that are required and necessary for the conduct and communication of activity. Self-check, validation and recording (in the FMM Logs) of brought in personal items. Periodic self-check on personal items and attire conditions. Accounting and reconciliation of personal items upon exit of the zone (at the end or interruption of the activity)	Required activity attire, clothing, PPE (secured by FMM approved devices). Necessary outer clothing in the zone, e.g. shoe and head covers, cotton gloves, etc. for protection of SSCs from outside contamination. No unnecessary personal items, e.g. jewellery, keys, wallets. Secured (by FMM approved devices) personal items that are necessary for the performer, e.g. eyeglasses, hearing aid, etc. No personal electronic devices. Authorised and secured electronic devices that are required and necessary for the conduct and communication of activity. Peer-check, validation and recording (in the FMM Logs) of brought in personal items. Periodic walkdowns to check on personal items and attire conditions. Accounting and reconciliation of personal items upon exit of the zone (at the end or interruption of the activity).

Table 4. A SAMPLE FOREIGN MATERIAL CONTROL AREA (FMCA) DESIGNATION SCHEME AND THE ASSOCIATED REQUIREMENTS AND EXPECTATIONS FOR THE CONTROLS

Aspect	Requirements and controls			
FMRL	No risk	Low risk	Standard risk	High risk
Area designation	General plant area	Foreign material attention area	Foreign material control area	Foreign material defence area
FMC devices	Typical plant protection FMC devices for SSCs with normal openings.	Typical plant protection FMC devices for SSCs with normal openings. Pre-job walkdown with identification of need for any additional FMC devices. Installation of additional FMC devices needed for SSCs with normal openings, if FM exposure is increased, and for SSCs with openings created during the activity. Initial and periodic walkdown to ensure all openings are covered properly, adequately and completely with needed FMC devices. Removal of added FMC devices needed for SSCs with normal openings and openings created during the activity. Final walkdown to ensure all additional FMC devices are removed. Tallying and reconciliation of added FMC devices for the activity at the final area clean-up.	Typical plant protection for SSCs with normal openings. Pre-job walkdown with identification of need and types of FMC devices. Self-check, validation and recording (in the FMM Logs) of brought in FMC devices. Installation of required FMC devices for SSC openings created during the activity, and additional FM devices for SSCs with normal openings, if FM exposure is increased Initial and periodic walkdown to ensure all FMC are installed properly, adequately and completely, as required and needed. Removal of required FMC devices for SSC openings created during the activity, and additional FM devices for SSCs with normal openings, if FM exposure is increased, upon the verification of closure requirements. Accounting and reconciliation of FMC devices upon exit of the zone at the end of the activity).	Typical plant protection for SSCs with normal openings. Pre-job walkdown with identification of need and types of FMC devices. Peer-check, validation and recording (in the FMM Logs) of brought in FMC devices. Installation of required FMC devices for SSC openings created during the activity, and additional FM devices for SSCs with normal openings, if FM exposure is increased Initial and periodic walkdown to ensure all FMC are installed properly, adequately and completely, as required and needed. Initial, periodic and final inspection of all FMC devices. Removal of required FMC devices for SSC openings created during the activity, and additional FM devices for SSCs with normal openings, if FM exposure is increased, upon the verification of closure requirements. Accounting and reconciliation of FMC devices upon exit of the zone at the end of the activity).

Table 4. A SAMPLE FOREIGN MATERIAL CONTROL AREA (FMCA) DESIGNATION SCHEME AND THE ASSOCIATED REQUIREMENTS AND EXPECTATIONS FOR THE CONTROLS

Aspect	Requirements and controls			
FMRL	No risk	Low risk	Standard risk	High risk
Area designation	General plant area	Foreign material attention area	Foreign material control area	Foreign material defence area
Tools	Plant requirements and expectations.	Plant requirements and expectations. Only tools needed to perform the activity. Initial tool examination for cleanliness and integrity. Tools are secured with appropriate devices. Final tool examination for integrity. Final walkdown to ensure all tools are removed. Tallying and reconciliation of tools at the final area clean-up.	Plant requirements and expectations. Only tools needed to perform the activity. Initial tool examination for cleanliness and integrity. Tools are secured with approved FMM devices and tool controls. Self-check, validation and recording (in the FMM Logs) of tools brought in, including partials and securing devices. Periodic self-checks and examination to ensure cleanliness and integrity, including the securing devices. Periodic removal of tools that are no longer needed from the zone. Removal of all tools (except those needed for system closure) from the zone, upon the verification of closure requirements. Final self-checks and examination of tools to ensure cleanliness and integrity, including the securing devices. Accounting and reconciliation of tools upon exit of the zone at the end of the activity or when the activity is interrupted.	Plant requirements and expectations. Only tools needed to perform the activity. Initial tool inspections for cleanliness and integrity. Tools are secured with approved FMM devices and tool controls. Peer-check, validation and recording (in the FMM Logs) of tools brought in, including partials and securing devices. Periodic checks and inspection to ensure cleanliness and integrity, including the securing devices. Immediate removal of tools that are no longer needed from the zone. Removal of all tools (except those needed for system closure) from the zone, upon the verification of closure requirements. Final peer-checks and inspection of tools to ensure cleanliness and integrity, including the securing devices. Accounting and reconciliation of tools upon exit of the zone at the end of the activity or when the activity is interrupted.

Table 4. A SAMPLE FOREIGN MATERIAL CONTROL AREA (FMCA) DESIGNATION SCHEME AND THE ASSOCIATED REQUIREMENTS AND EXPECTATIONS FOR THE CONTROLS

Aspect	Requirements and controls			
FMRL	No risk	Low risk	Standard risk	High risk
Area designation	General plant area	Foreign material attention area	Foreign material control area	Foreign material defence area
Consumables	General plant work requirements and practices.	General plant work requirements and practices. Only items and parts needed to accomplish task are brought in. Initial tally and organisation of items and parts, clean containers and bins, away from the system to be opened. Wasted items and parts placed in bins and bags far away and separated from the SSCs being worked on and removed from the zone, as practicable. Final walkdown to ensure all unused and wasted items and parts are removed. General tallying and reconciliation of items and parts at the final area clean-up. Unused items and parts returned to storage and wasted ones are dispositioned after the activity.	General plant work requirements and practices. Only items and parts needed to accomplish task are brought in. Self-check, counting and recording (in the FMM Logs) of items and parts brought in. Initial organisation of items and parts in clean and secure bins and containers away from the system to be opened. Wasted items and parts placed in sealed and secured containers and/or bags far away and separated from the open systems and removed from the zone, periodically. Final walkdown to ensure all unused items and parts are removed (except those needed for system closure) from the zone, upon the verification of closure requirements. Accounting and reconciliation of items and parts upon exit of the zone at the end of the activity or when the activity is interrupted. Unused items and parts returned to storage and wasted ones are dispositioned after the activity outside the zone.	General plant work requirements and practices. Only items and parts needed to accomplish task are brought in. Peer-check, counting and recording (in the FMM Logs) of items and parts brought in. Initial organisation of items and parts in clean and secure bins and containers away from the system to be opened, or in buffer zone. Wasted items and parts placed in sealed and secured containers and/or bags far away and separated from the open systems and removed from the area and buffer zone, periodically. Final inspection to ensure all unused items and parts are removed (except those needed for system closure) from the zone, upon the verification of closure requirements. Accounting and reconciliation of items and parts upon exit of the zone at the end of the activity or when the activity is interrupted. Unused items and parts returned to storage and wasted ones are dispositioned after the activity outside the zone.

Table 4. A SAMPLE FOREIGN MATERIAL CONTROL AREA (FMCA) DESIGNATION SCHEME AND THE ASSOCIATED REQUIREMENTS AND EXPECTATIONS FOR THE CONTROLS

Aspect	Requirements and controls			
FMRL	No risk	Low risk	Standard risk	High risk
Area designation	General plant area	Foreign material attention area	Foreign material control area	Foreign material defence area
Material handling, packaging, shipping	General plant work requirements and practices.	General plant work requirements and practices. Self-check of packed materials delivered and brought in the area, to ensure or FMC devices, storage FMM covers and, as applicable, tamper-proof packing material are intact and FM-free. Erection of FMM barriers and/or FMC devices during movement and storage of items inside area, as needed. Unpackaging material such that it does not produce foreign material.	General plant work requirements and practices. Self-check of packed materials delivered and brought in the area, to ensure or FMC devices, storage FMM covers and, as applicable, tamper-proof packing material are intact and FM-free. Recording (in the FMM Logs) of packed materials (including FMC devices, storage FMM covers and, as applicable, tamper-proof packing material) brought in the area, if any. Erection of FMM barriers and/or FMC devices when movement and storage of items inside area is necessary. Unpackaging material such that it does not produce foreign material. Remove packing material from the zone after unpacking, as practicable. Accounting and reconciliation of packing material (including FMC devices, storage FMM covers) upon exit of the zone at the end of the activity or when the activity is interrupted.	General plant work requirements and practices. Self-check of packed materials delivered and brought in the buffer zone, to ensure or FMC devices, storage FMM covers and, as applicable, tamper-proof packing material are intact and FM-free. Recording (in the FMM Logs) of packed materials (including FMC devices, storage FMM covers and, as applicable, tamper-proof packing material) brought in the area, if any. Erection of FMM barriers and/or FMC devices when movement and storage of items inside area or in buffer zone is necessary. Unpackaging material in buffer zone, if possible, and in a manner that it does not produce foreign material. Remove packing material from the buffer zone after unpacking, as practicable. Accounting and reconciliation of packing material (including FMC devices, storage FMM covers) upon exit of the zone at the end of the activity or when the activity is interrupted.

APPENDIX III. EXAMPLES OF METRICS FOR PROGRAMME REVIEW

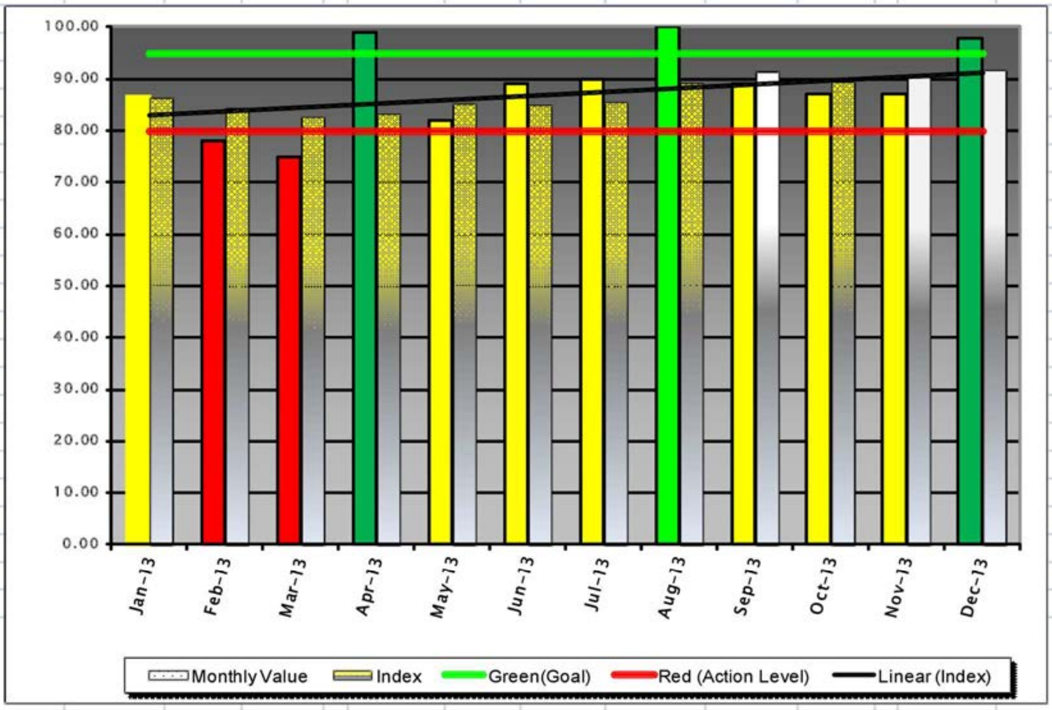
The plant/project management needs to proactively check, identify and correct weaknesses and the strengths in FMM and associated programmes, processes, practices and procedures that could impact safe and reliable operation and efficient and effective performance of the plant. This requires management's (and relevant plant staff's) active support for routinely trending and assessing to monitor whether the activities relating to FM and FMM are deteriorating or are being maintained or improving. This monitoring will aim to identify and correct/improve any areas for improvement, as well as issues relating to declining performance or effectiveness. Accordingly, the associated measures (e.g. indicators/metrics) will be selected and tailored towards identification of the underlying causes and precursors of any defect and deficiency in FMMP and associated process and procedures.

The performance indicators also serve to ensure that decision and programme authorities become and remain aware of actual practices and values in the field, including those for the performance of external organisations at the owner/operating organisation's site and facilities site or at their offsite facilities. Moreover, metrics also provide the avenue to set and communicate performance goals, as well as identifying any gaps, to station/plant/site personnel. As discussed in Section 5.5.11 of this publication, in an effective FMMP, the purpose of the measurement process and efforts is not about the counting events/errors/failures, and certainly, not establishing criterion for rewarding or punishing individuals or organisations. It is rather a part of the learning and informing culture towards continuous improvement and sincere organisational commitment to the safe and efficient operation.

The performance indicators are, therefore, selected and used to measure the significant portion of overall FMMP health status and trend based on the corporate strategy, safety and performance goals and FMM commitment and policy as to why something needs to measure and what needs to be measured for that purpose. Figure 22 illustrates an example of such effort in establishing performance indicators and their assessment for a hypothetical nuclear power plant for which the performance indicators are defined and monitored based on:

— Meaning of (i.e. what it is measuring) and reason (i.e. why it is measuring) of indicator;
— Grading scale and associated criteria/threshold/rule;
— Weighting and the basis of weighting;
— Analysis and assessment methods and tools.

FME Performance Indicator **As of 31Dec2013**



The index reflects the 6 month rolling average .

Date	Significant Event	Threat	Condition	Monthly Value	Index	Date	Significant Event	Threat	Condition	Monthly Value	Index
Jan-13	0	1	3	87.00	86.33	Jul-13	0	1	0	90.00	85.50
Feb-13	0	2	2	78.00	84.33	Aug-13	0	0	0	100.00	89.17
Mar-13	0	2	5	75.00	82.83	Sep-13	0	1	1	89.00	91.50
Apr-13	0	0	1	99.00	83.17	Oct-13	0	1	3	87.00	89.50
May-13	0	1	8	82.00	85.17	Nov-13	0	1	3	87.00	90.33
Jun-13	0	1	1	89.00	85.00	Dec-13	0	0	2	98.00	91.83

Definitions of events

Significant Event (21 pts)- An FME event involving shortfalls in FME control practices that has resulted in any one of the following: Regulator recordable personnel injury, Fuel damage, Significant plant equipment damage, Loss of generation, Reportable radioactive release, Entered into, extended or exceeded a limiting condition for operation, Unplanned radiation exposure of >.5 REM, Reportable environmental release.

Threat (10 Pts) -An error in FME implementation that if not detected would result in any one of the following: Personnel injury, fuel damage, Generation loss, Significant plant equipment damage. In addition, the following are also threats: FMI into a safety related or critiical system requiring recovery plan to retreive, Event that causes minor plant equipment damage, unplanned inoperability of equipment, FMI resulting in evaluation in lieu of retreival, Material in FMEA not logged or unaccounted for material in FMEA log.Human error in FM exclusion practices which if not detected could pose a risk of personnel Injury, plant equipment damage, fuel failure, or loss of generation and is the result of inappropriate human behavior during the conduct of a work activity. Events requiring an evaluation in lieu of retrieval will also be considered FME Threats.

Condition (1 pts) - A minor or administrative error involving FME practices that can range from incomplete paperwork to material introduction. No effects to a system or component has resulted. Low threshold FME related issues, incorrect behaviours, poor housekeeping and programmatic errors.

Goals

Green 100-95	White <95-90	Yellow <90-80	Red <80

The index is calculated based on the following formula: 100 - n ((21 * # Significant Event) + (10 * # Threats) + (1 * # condition))
n=1 for single unit site, n=.5 for two unit site, n=.33 for 3 unit site, n=.25 for 4 unit site

FIG. 22. A Sample performance indicator monitoring and analysis (courtesy of R. Lightfoot, Bruce Power, with permission).

APPENDIX IV. DETERMINATION OF LEGACY AND LATENT FOREIGN MATERIAL AND ASSOCIATED ACTIONS

The FMs that have been hidden (i.e. dormant, latent) are considered as *'latent foreign material'* and specifically discussed in Section 6.2, while any FM that is not latent, such as the FMs that enter the SSCs during current activities, are termed as '*current foreign material*' for the purpose of this publication and is discussed in Section 6.1. To be consistent with the descriptions provided in current industry guidance [9−11], a subset of latent foreign materials can be defined as '*legacy foreign material'* meaning that the FM intruded into the SSC before the implementation of current FMMP (including the earlier revisions) or the first opening and working on SSCs during the operation phase, whichever came first.

Figure 23 and Figure 24 depicts a sample process for classifying a discovered FM as current or latent first, and then latent or legacy which would make a difference in the response to and mitigation of an FMI event as discussed in Section 6.1 and Section 6.2 of this publication.

According to the classification of FM and FMI (e.g. current or latent), the application and performance of mitigation processes will vary. As shown in Fig. 23 and Fig. 24 initial process to be followed upon latent and latent-legacy FMs, is the foreign object review and assessment (FORAA) process, which includes foreign object technical analysis and assessment (FOTAA) and foreign object programmatic analysis and assessment (FOPAA).

Once the review and assessment completed, foreign object search and retrieval (FOSAR) process, which, in the case of latent and legacy items that are discovered by an unrelated activity, would mainly consist of a foreign object reach and recovery (FORAR) process.

Figure 23 and Figure 24 also illustrate the determination flow in deciding which process may be applicable, required or necessary.

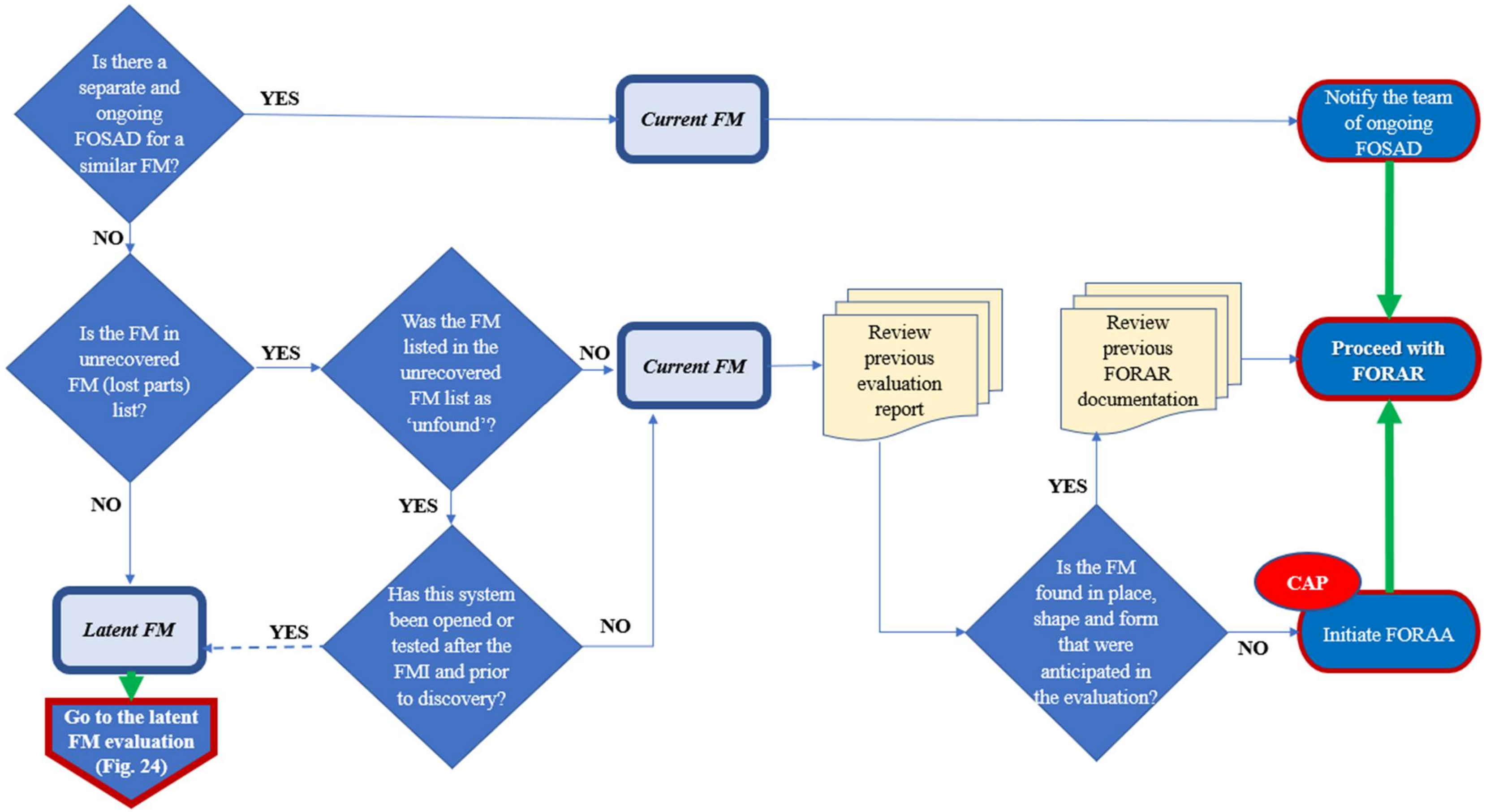
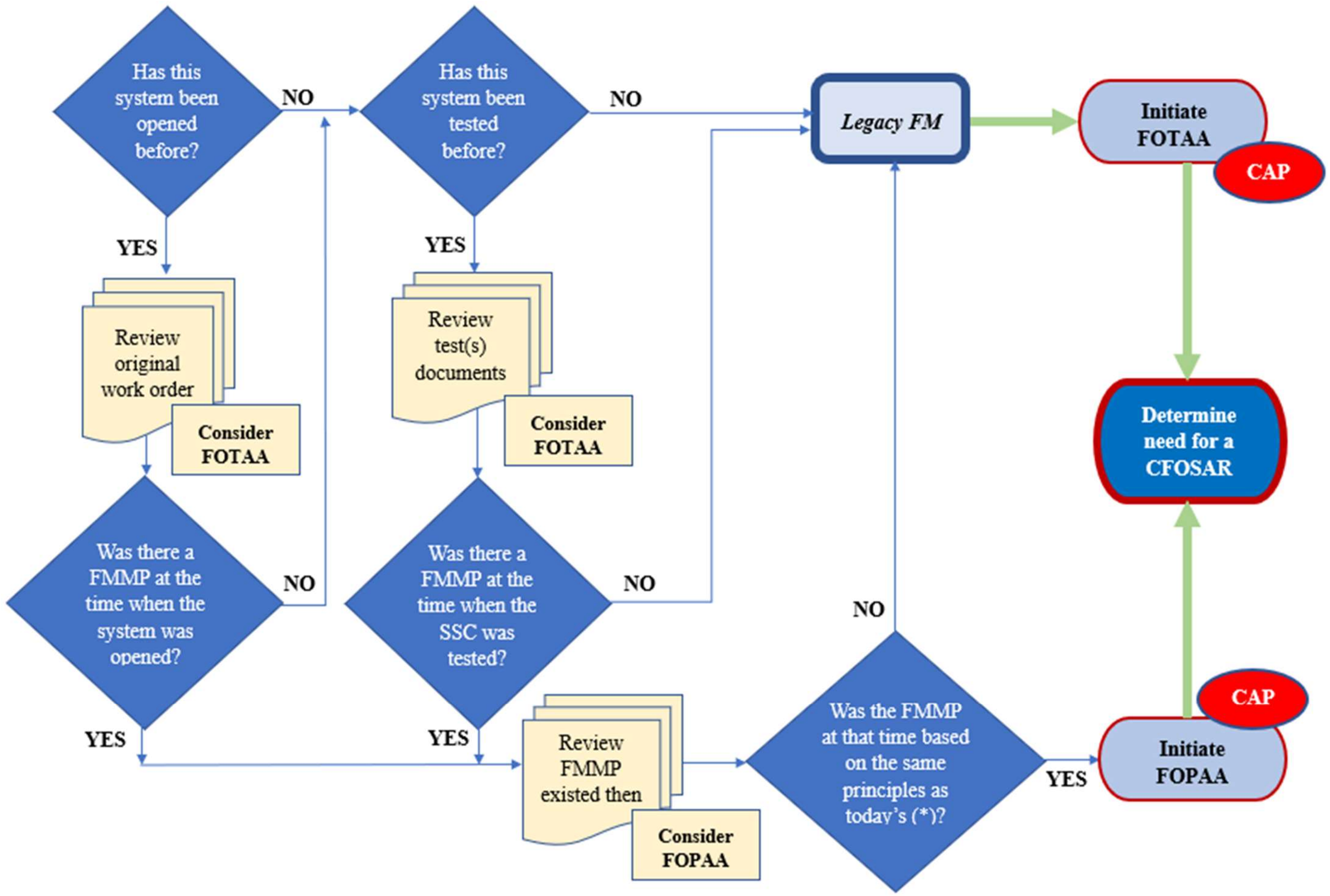


FIG. 23. A sample flowchart to determine whether a discovered foreign material is current or latent. CAP —corrective action programme, FM —foreign material, FORAA —foreign object analysis and assessment, FORAR —foreign object reach and recovery, FOSAD —foreign object search and detection.



(*) The principles for the industry were established circa 1997 by IAEA, INPO, EPRI. The IAEA has evaluated the practices according to the principles in the OSART missions since circa 2000.

FIG. 24. A sample flowchart to determine whether a latent foreign material is a legacy foreign material. CAP —corrective action programme, CFOSAR — comprehensive foreign object search and retrieval, FM —foreign material, FMMP —foreign material management programme, FOPAA —foreign object programmatic analysis and assessment, FOSAR —foreign object search and retrieval, FOTAA —foreign object technical analysis and assessment, SSC — system, structure and component.

APPENDIX V. EXAMPLES OF AWARENESS COMMUNICATION FROM AVIATION INDUSTRY

One of the very first steps in the implementation of a robust and effective FMMP is to ensure that all relevant staff (internal or external personnel) is aware of the programme's existence and fundamentals. All elements of a plant's/project's system of FMM, particularly identification, prevention and removal/solution of FM and FM hazards, have to be in sight and on mind of every function of the plant/project organisation. This necessitates the communication of those elements to each and every employee performing those functions, onsite or offsite, by effective verbal, written and visual methods. such as workshops, seminars, newsletters, news bulletins, lessons learned notifications (by briefings and/or printed materials).

The concept of awareness communication and associated methods and tools are not unique to nuclear industry, and examples can be found and be adopted from other industries. For example, the following is an excerpt from the aviation industry, taken from the Advisory Circular issued by the US Department of Transportation's Federal Aviation Administration on airport foreign object debris (FOD) management programmes, regarding the communication of programme existence and status towards awareness (Section 3.1. of Ref. [25], Awareness):

> "A first step in implementing a successful FOD management program is making sure that applicable personnel are aware of the program's existence. An airport's FOD management system should be visible in all aspects of the airport operation. Improvements in FOD safety will occur most efficiently if all airport personnel are actively encouraged to identify potential FOD hazards, act to remove observed FOD, and propose solutions to mitigate those hazards. Some examples of organisational communication are:
>
> (a) FOD seminars;
> (b) FOD letters, notices and bulletins;
> (c) FOD lessons-learned;
> (d) FOD bulletin boards, safety reporting drop boxes, and electronic reporting through web sites or email; and
> (e) A method to exchange safety-related information with other airport operators through regional offices or professional organisations.
> (f) Airport FOD program promotional materials, such as t-shirts, stickers, FOD disposal cans, and smaller give-away items.
> (g) FOD discussion at employee staff meetings".

Similarly, another FOD manual prepared for the aviation industry stresses the communication of 'good' stories (titled 'FOD Fighter' [26]) sharing highlights of exceptional techniques used for prevention and protection of FOD at the subject facility. There, it is suggested to share such stories in a brief form on the quarterly basis, including to highlight successes to vendors/customers. Reference [26] also recommends recognition and reward programmes to reinforce the attitudes and behaviours that are desired to be preserved and perpetuated. Some ideas suggested in Ref. [26] include:

> "[…] Ideas -
>
> — Award a monthly "traveling" trophy to the employee with the most significant FOD finding of that month.

— Recognise the employee(s) who go 5 business days without any pre/post shift finds in their housekeeping zone.

— Recognise employees for coming forward when a tool is missing.

— Recognise crew with zero finds by Quality – the award gets better the more consecutive inspections with zero finds – you start all over once Quality finds something.

— Request test pilots visit the floor to thank the employees for care in preventing FOD" [26].

The very same manual [26], also suggest involving the families of employees in FOD awareness campaigns and activities. For example, a FOD poster contest, which the staff and family members can participate, could be held to raise attention to the awareness, prevention and compliance aspects of FOD management. As suggested, the FOD Employee Council (which is, by the roles and responsibilities, similar to the FMM Committee that is discussed in Section 5.6.1.6 of this publication) is to judge the entries and the results are to be shared with all personnel at the facility. An excerpt from the flyer of such a contest was provided in Ref. 26, as follows:

"The purpose of this contest is to increase awareness of the potential damage to aircraft and support equipment and the danger to personnel caused by foreign objects.

— FOD can come in many different forms and produce disastrous effects if not identified and corrected. In severe cases, FOD can directly threaten safety of flight crews and integrity of the aircraft.

— Examples of FOD include a tool left behind on the aircraft, ball bearings left inside a hydraulic tube, adhesive tape left on a detail part, a cleaning rag left behind in the cabin.

— FOD prevention is an essential element in all activities and is the responsibility of every employee.

The posters should address themes around Awareness, Prevention, and Compliance.

The top 6 posters in the 13+ age group will be displayed at all facilities on a rotational basis during the next six months. Prizes will be awarded to the top 3 entrants in the 12 and underage group" [26].

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GLOSSARY

buffer zone. An area established immediately adjacent to critical or sensitive foreign material control area as appropriate or practicable. This zone is maintained free from material having a potential of being tracked, blown or falling into the foreign material control area.

current foreign material. Any FM that is not latent (see latent foreign material), such as the FMs that enter the SSCs during current activities.

foreign material. Any material that is not part of the system or component as per design.

foreign material control area. The activity area/region (i.e. confines, sectors or subsectors) that determine the appropriate and adequate level of FM awareness, behaviours, instructions, skills, qualifications, as well as the degree, arrangement and specialty of prevention, protection and exclusion measures and controls (also referred as ‘foreign material exclusion area’ or ‘foreign material exclusion zone’).

foreign material exclusion. The processes for preventing foreign material intrusion into SSCs.

foreign material close call. A potential FMI occurrence or harm that was avoided owing to timely observation, interpretation and intervention. These are the incidents of acts, conditions or circumstances by which an FMI event could have occurred or would cause harm to safety and performance; but they were fended off by application of systematic awareness.

foreign material event. An unintended FMI occurrence the consequences or potential consequences of which are not negligible from the point of view of protection, safety and performance, i.e. these are the FMI incidents that occur due to an act or condition and cause harm to safety or performance

foreign material intrusion. Introduction of foreign material into a system or component.

foreign material near miss. A potential FMI event that could have occurred as the consequence of a sequence of actual occurrences but did not occur or cased harm owing to the conditions prevailing at the time. In other words, these are the FMI incidents that: occurred but did not cause harm to safety and performance; or could have occurred, under the time, conditions or circumstances by chance; however, they would occur or cause harm in different times, conditions or circumstances.

foreign material path. The route, ambient, medium that will transport, carry or bring foreign material to the foreign material target.

foreign material target. A body of substance, system, component or environment functions and conditions of which would be adversely affected when it contains or is introduced to foreign material.

latent foreign material. The foreign materials that have existed in the SSCs owing to the historical issues/deficiencies and have been hidden (i.e. dormant, latent), i.e. a FM entered the SSCs in the earlier activities (e.g. in the previous lifecycle phase of the plant/project or at a time when there was no, basic or defective FMMP existed).

legacy foreign material. The foreign material intruded into the SSC before the implementation of current FMMP (including the earlier revisions) or the first opening and working on SSCs during the operation phase, whichever came first.

normal operations. Operation of nuclear power plants within specified OLCs.

nuclear steam supply system. The reactor and the reactor coolant pumps (and steam generators for a pressurised water reactor) and associated piping in a nuclear power plant used to generate the steam needed to drive the turbine generator unit.

nuclear power plant owner/operating organisation. The company or organisation that is the operator of a nuclear power plant. This organisation has the primary responsibility for the safe operation of the plant and will have to satisfy the requirements of the nuclear regulatory body in the country.

safety case. A collection of arguments and evidence in support of the safety of a facility or activity. Normally includes the findings of a safety assessment and a statement of confidence in these findings.

special foreign material control area. A specific area for which predetermined foreign material controls apply.

technical support. An activity (or part of an activity) to assist decision makers with technical and scientific input in decisions on the achievement of design and performance objectives.

technical support organisation. Any organisation (or individual or group) that provides technical and scientific support to decision makers for decisions on preparation for a nuclear power plant project and afterwards, for the design, licensing, construction, commissioning, operation, maintenance and decommissioning of plant.

utility/electric utility. An entity that owns assets and operates facilities for the generation, transmission or distribution of electricity/energy for commercial sale to the individual and/or industrial consumers.

ABBREVIATIONS

ALARA	as low as reasonably achievable
CAP	corrective action programme
CBT	computer based training
CFOSAR	comprehensive foreign object search and retrieval
CCC	construction coordination centre
DLA	dynamic learning activity
ECCS	emergency core cooling system
EC/JRC	European Commission’s Joint Research Centre
EPRI	Electric Power Research Institute
ESF	engineered safety feature
FM	foreign material
FMC	foreign material control
FME	foreign material exclusion
FMI	foreign material intrusion
FMM	foreign material management
FMCA	foreign material control area
FMRL	foreign material risk level
FMMP	foreign material management programme
FMT&PD	foreign material target and path diagram
FOD	foreign object damage/foreign object debris
FOPAA	foreign object programmatic analysis and assessment
FORAA	foreign object review and assessment
FORAR	foreign object reach and recovery
FOSAD	foreign object search and detection
FOSAR	foreign object search and retrieval
FOTAA	foreign object technical analysis and assessment
GET	general employee training
HACCP	hazard analysis and critical control points
HVAC	heating, ventilation and air conditioning
INPO	Institute of Nuclear Power Operators
INSAG	International Nuclear Safety Advisory Group
IRS	International Reporting System for Operating Experience
KPI	key performance indicator
NDE	non-destructive examination
NPP	nuclear power plant
O&M	operation and maintenance
OCC	outage control centre
OECD/NEA	Nuclear Energy Agency of the Organisation for Economic Cooperation and Development

OPEX	operating experience
OSART	Operational Safety Review Team
PDCA	plan-do-check-act (Deming’s) cycle
PPE	personal protective equipment
PRIS	Power Reactor Information System
P&ID	piping and instrumentation diagram
QA	quality assurance
QAP	quality assurance programme
QC	quality control
QA/QC	quality assurance/quality control
R&D	research and development
RFID	radio frequency identification
SAT	systematic approach to training
SFMCA	special foreign material control area
SSC	system, structure and component
TNA	training needs analysis
WANO	World Association of Nuclear Operators
WHO	World Health Organization

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