Safety Reports Series No. 90

Safety Reassessment for Nuclear Fuel Cycle Facilities in Light of the Accident at the Fukushima Daiichi Nuclear Power Plant

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SAFETY REASSESSMENT FOR NUCLEAR FUEL CYCLE FACILITIES IN LIGHT OF THE ACCIDENT AT THE FUKUSHIMA DAIICHI NUCLEAR POWER PLANT

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SAFETY REASSESSMENT FOR NUCLEAR FUEL CYCLE FACILITIES IN LIGHT OF THE ACCIDENT AT THE FUKUSHIMA DAIICHI NUCLEAR POWER PLANT

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2016

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PO Box 100
1400 Vienna, Austria
fax: +43 1 2600 29302
tel.: +43 1 2600 22417
email: sales.publications@iaea.org
http://www.iaea.org/books

Printed by the IAEA in Austria
July 2016
STI/PUB/1726

IAEA Library Cataloguing in Publication Data

Names: International Atomic Energy Agency.
TTitle: Safety reassessment for nuclear fuel cycle facilities in light of the accident at the Fukushima Daiichi nuclear power plant / International Atomic Energy Agency.
Description: Vienna : International Atomic Energy Agency, 2016. | Series: IAEA safety reports series, ISSN 1020–6450 ; no. 90 | Includes bibliographical references.
Identifiers: IAEAL 16-01045 | ISBN 978–92–0–101916–5 (paperback : alk. paper)
Subjects: LCSH: Nuclear facilities. | Nuclear reactors — Safety measures. | Nuclear reactors — Design and construction. | Nuclear power plants — Accidents — Prevention.
Classification: UDC 621.039.516.4 | STI/PUB/1726

FOREWORD

This publication aims to provide practical information for performing safety reassessment of nuclear fuel cycle facilities. The information provided is relevant for safety reassessment for all types of nuclear fuel cycle facilities in light of the accident at the Fukushima Daiichi nuclear power plant in Japan in March 2011, which followed a severe offshore earthquake and subsequent tsunami. Loss of off-site power, flooding of the nuclear power plant and severe damage to equipment due to the tsunami resulted in an extended station blackout, loss of core cooling and ultimate heat sink, and to fuel melting and hydrogen explosions. The radioactive material released to the surrounding region resulted in significant contamination of the environment. The available experience from this accident is crucial for defining and implementing measures to prevent major accidents at nuclear fuel cycle facilities, and to limit the consequences of such accidents if they do occur.

This publication provides information relevant for all steps in performing such safety reassessments for nuclear fuel cycle facilities. Although it primarily focuses on operational nuclear fuel cycle facilities, the approaches and methods provided in this publication also apply to facilities that are in the design or construction phases, or in a shutdown condition.

The information provided by this publication is not intended to replace or supersede any of the requirements or guidance provided by the relevant IAEA safety standards, and is, moreover, to be used in close conjunction with them. Security topics connected with extreme external events and emergency plans are beyond the scope of this publication.

The IAEA wishes to thank all contributors to this publication as well as the participants of the Technical Meeting on the Implications of the Fukushima Daiichi Accident on the Safety of Nuclear Fuel Cycle Facilities, held 1–5 July 2013 in Vienna, for the review of the first draft of this publication. The IAEA officers responsible for this publication were A.M. Shokr, P.J. Müskens and V.M. Carr of the Department of Nuclear Safety and Security.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

The accident at the Fukushima Daiichi nuclear power plant in Japan occurred following a severe offshore earthquake and subsequent tsunami on 11 March 2011. Flooding of the plant and damage to equipment resulted in an extended station blackout, loss of core cooling, fuel melting, hydrogen explosions and releases of radioactive material to the surrounding region leading to contamination of the environment with potential long term consequences. The lessons learned from this accident will be crucial for defining and implementing measures for preventing accidents at nuclear fuel cycle facilities worldwide and for limiting the consequences of such accidents if they do occur.

The inventories of radioactive material, and consequently the potential hazard associated with nuclear fuel cycle facilities, cover a wide range from front end natural uranium facilities to facilities that can be comparable with nuclear power plants (e.g. pools at spent fuel facilities or highly active concentrated fission product solutions). In addition, for some facilities, the potential for the accumulation and detonation of hydrogen or exothermic chemical reactions following an extreme event could compromise the containment and increase the spread of contamination.

The majority of nuclear fuel cycle facilities worldwide were designed decades ago, according to the IAEA Integrated Nuclear Fuel Cycle Information System [1], and their construction would not now fully conform with the current IAEA Safety Standards publication NS-R-5 (Rev. 1), Safety of Nuclear Fuel Cycle Facilities [2]. Additionally, in nuclear fuel cycle facilities there is a higher potential, compared to other nuclear installations, for an accidental criticality. Many nuclear fuel cycle facilities rely on a combination of static and dynamic containment for confinement that inherently provides potential pathways to the environment under abnormal operating or accident conditions. This is particularly so for extreme external events which also have the potential to damage these barriers directly. In some cases, the characteristics of the facility site and its vicinity may have changed since the construction of the facility, which may affect the potential for external events or accidents and their potential effects and/or public consequences.

Many of the above issues are not fully reflected in the safety analysis for some facilities. A number of the initial lessons learned in the light of feedback from the accident at the Fukushima Daiichi nuclear power plant are also applicable to nuclear fuel cycle facilities. Where these factors have not previously been considered, a revision of the safety analysis for nuclear fuel cycle facilities through carrying out a safety reassessment is justified. The priority for carrying out safety reassessments needs to be decided in accordance with the potential hazard associated with each facility.

On the basis of available feedback from the Fukushima Daiichi accident, the topics that need to be considered for inclusion in the scope of the safety reassessment of nuclear fuel cycle facilities include, but are not limited to, the following:

— The safety requirements adopted for the facility;
— Changes to regulations and international good practice;
— The continued validity, in the light of current knowledge, of the safety criteria adopted for the design of the facility, including its seismic design;
— The design of the facility against flooding (resulting from a tsunami or another cause);
— Delayed or diminished capability of emergency response from external sources, owing to the widespread effects of some natural disasters;
— Physical damage (resulting from a tsunami, wind or another cause);
— Total loss of electrical power supply (including for an extended period);
— Loss of ultimate heat sink;
— Hydrogen (radiolysis) and exothermic chemical reactions;
— Emergency arrangements, accident management and communication of information.

Since these topics are relevant to the reassessment of the safety of nuclear fuel cycle facilities when subjected to extreme external events, exclusion from the safety reassessment of a particular hazard for a particular nuclear fuel cycle facility needs to be justified and such a justification needs to be documented.

1.2. OBJECTIVE

The objective of this publication is to provide suggestions and methods, based on IAEA safety standards and current international experience, for carrying out safety reassessments for nuclear fuel cycle facilities taking into account the available feedback from the Fukushima Daiichi accident. Information is also provided on the use of relevant IAEA safety standards in performing such a safety reassessment. This publication is intended for use by operating organizations, regulatory bodies, design organizations and other authorities involved in the safety of nuclear fuel cycle facilities.

1.3. SCOPE

This publication covers all the steps in the conduct of safety reassessments for nuclear fuel cycle facilities, in light of the experience acquired from the Fukushima Daiichi accident. Although the primary focus is on operational nuclear fuel cycle facilities, the information provided by this publication also applies to facilities that are in the phases of planning, design or construction, or in long term shutdown. The information provided by this publication does not replace but supplements the requirements and guidance provided by the relevant IAEA safety standards, including those on safety analysis, evaluation of external hazards, and emergency preparedness and response for nuclear fuel cycle facilities.

The scope of the safety reassessment, as described in this publication, includes review of the design basis accidents and accident conditions for the nuclear fuel cycle facility and its site (including challenges presented by multi-facility sites) as well as the reassessment of arrangements for preparedness for and response to an emergency resulting from such accidents.

This publication applies to all nuclear fuel cycle facilities within the scope of Ref. [2]. However, facilities that have been shown to have a low hazard potential (e.g. those handling natural uranium where the potential event impact is dominated by uranium chemo-toxicity, or research and development (R&D) facilities with very low radioactive inventories and low criticality risk) may use a graded version of the comprehensive safety reassessment outlined here, where the grading is commensurate with the potential hazard the facility poses to the site and its environs. A graded approach is not used to provide relief from meeting individual safety requirements. It can be applied, for example, by considering — using sound engineering judgement — the safety and operational importance of the topic, and the maturity and complexity of the area involved. The use of a graded approach in the application of the safety requirements for nuclear fuel cycle facilities is required by Ref. [2]. The present publication also provides information on the application of a graded approach and suggests processes for the implementation of the findings of the safety reassessment.

1.4. STRUCTURE

Section 2 discusses regulatory aspects relating to carrying out safety reassessments for nuclear fuel cycle facilities in light of the feedback from the Fukushima Daiichi accident. Sections 3, 4 and 5 discuss the approaches and methodology for performing such reassessments: Section 3 focuses on the review of the design basis and design extension conditions of the nuclear fuel cycle facility; Section 4 focuses on the reassessment of site safety; and Section 5 addresses the reassessment of emergency preparedness and response. Section 6 describes the procedure for the application of a graded approach and contains a discussion of its use in safety reassessment, with a focus on organizational aspects. Section 7 suggests and describes a process for implementing the findings of a safety reassessment. The Annex provides a list of selected postulated initiating events for nuclear fuel cycle facilities.

2. REGULATORY ASPECTS

The requirements on the responsibilities and functions of the regulatory body in respect of nuclear installations, including nuclear fuel cycle facilities, are established in IAEA safety standards [2, 3]. These functions and responsibilities apply to the regulatory supervision of any review of the implications of the Fukushima Daiichi accident for nuclear fuel cycle facilities including the conduct and implementation of safety reassessments.

This publication provides an approach and some methodologies for performing safety reassessment for nuclear fuel cycle facilities, on the basis of the feedback acquired from the Fukushima Daiichi accident. However, other approaches and methodologies, as required by national regulatory bodies, may also be used provided that these result in an equivalent level of safety and take into consideration the use of a graded approach in the application of the safety requirements, according to the potential hazards of the nuclear fuel cycle facility.

Some Member States have already established regulatory requirements regarding safety reassessments and related acceptance criteria in consultation with operating organizations of nuclear fuel cycle facilities. Clarity and transparency as well as effectiveness in communication (including formal and informal communication) between the regulatory body and the operating organization need to be ensured, including the reporting of the results of the safety reassessment to the public, if this is required by national regulations.

In performing its review and assessment function, the regulatory body may require the operating organization to establish a plan for the implementation of actions identified by the safety reassessment (which could be either short term or long term actions) in accordance with the facility management system. This plan and the subsequent report of the results of the reassessment would then be submitted to the regulatory body. The actions identified by the reassessment could include:

- Updating the design and operating documentation including that related to maintenance, periodic testing and inspection programmes, and updating the operating procedures;
- Revising the training and qualification programme for facility operating personnel;
- Updating the facility safety documents (safety analysis report, operational limits and conditions, and emergency plan and associated procedures);
- Proposing R&D activities to address any identified gaps in knowledge;
- Conducting or participating in training, drills and exercises on the performance of critical emergency response functions, particularly for accident conditions and relating to the transition from emergency operating procedures to severe accident management guidelines.

Maintenance, periodic testing and inspection have a common objective: to ensure that structures, systems and components (SSCs) function in accordance with design intents and requirements and in compliance with the safety analysis and operational limits and conditions. Maintenance, periodic testing and inspection may be included in a single programme and performed by the same operating personnel. Guidance on the preparation and periodic review of operating procedures and on the training and qualification of operating personnel is provided in Refs [4–6].

The regulatory body also needs to consider and perform, as necessary, specific inspections aimed at verifying the robustness of SSCs important to safety, operating programmes and procedures (including maintenance, periodic testing and inspection programmes and procedures) and emergency arrangements currently in place. Items important to safety are defined (in Ref. [7]) as items that are part of a safety group and/or whose malfunction or failure could lead to radiation exposure of the site personnel or members of the public. Items important to safety include SSCs whose malfunction or failure could lead to undue radiation exposure to site personnel or members of the public, SSCs that prevent anticipated operational occurrences from leading to accident conditions, and features that are provided to mitigate the consequences of malfunction or failure of other SSCs.

As was recognized in the early stages of the Fukushima Daiichi accident, the effective involvement of the regulatory body is essential not only during normal operating conditions but also in accident conditions. Therefore, appropriate attention needs to be given to the regulatory body’s ability to perform safety reviews and assessments in the case of extreme events. In this regard, as feedback from the accident, the actions to be taken by the regulatory body could include:

- Reassessing the availability and adequacy of the human and financial resources necessary to perform existing, expanded or new regulatory functions during an extreme event;
- Reviewing the existing regulatory activities to determine whether they are adequate to verify compliance by the operating organization with new safety requirements;
- Developing and establishing processes for improved dissemination and use of operating experience (including from emergency exercises, safety reassessment and periodic safety assessments);
- Ensuring that regulatory roles and responsibilities, and communication pathways and expectations for data gathering, use and retention during and after an emergency are clearly specified;
- Encouraging, requiring, commissioning or directing R&D in areas relevant to extreme events and ensuring that the regulatory body has access to advice on the state of the art in these areas.

Owing to generally smaller radioactive inventories and less energetic failure modes for nuclear fuel cycle facilities, the operator may not require severe accident management guidance documents (usually included in emergency instructions). Nevertheless, where there is a potential for a significant release of radioactive or toxic material and the emergency response may change from preventive (e.g. maintaining containment and keeping releases below prescribed limits) to mitigatory, guidance for both on- and off-site response organizations needs to be in place. These organizations also need to be subject to exercises as part of emergency response preparedness.

It is expected that regulatory bodies will analyse the lessons learned from the Fukushima Daiichi accident and will proceed with the revision of existing regulations or the development of new national regulations accordingly.

3. REASSESSMENT OF THE FACILITY

3.1. GENERAL APPROACH TO THE SAFETY REASSESSMENT

This section provides information on developing an approach to carrying out a safety reassessment of a nuclear fuel cycle facility in light of feedback from the Fukushima Daiichi accident. This reassessment needs to be based on the approved safety analysis report. The main objective of this reassessment is to evaluate the robustness of the existing facility protection, in terms of design features and procedures, against the impact of extreme events, with an emphasis on the fulfilment of the main safety functions. The main safety functions of nuclear fuel cycle facilities [2] are:

— Prevention of criticality;
— Protection against external exposure;
— Confinement of radioactive material in order to prevent or mitigate its unplanned release to the environment;
— Removal of decay heat and the dilution of radiolysis gases, where applicable.

The safety reassessment consists of a review of the design basis of the nuclear fuel cycle facility (as described in the safety analysis report) and an assessment of design extension conditions. Design extension conditions are postulated accident conditions that are not considered in the definition of the design basis accident, but that are considered in the design process of the facility in accordance with best estimate methodology, and for which releases of radioactive material are kept within acceptable limits. Accident conditions include design basis and design extension conditions and accidents. An assessment of the impact of accident conditions more severe than the design basis accidents or that involve additional failure is carried out. This may include assessment of any consequential loss of the main safety functions, any cliff-edge failures of SSCs and the relevance of the mitigatory actions to be taken, in order to identify the need for safety improvements in both technical and organizational aspects, thus enhancing the resilience of the facility. In some States, adoption of the safety reassessment (the 'stress test' concept) necessitates calculation of cliff-edge values.

The approach to be used in the safety reassessment has to be essentially deterministic. However, depending upon national licensing regulations, a mixed deterministic and probabilistic assessment of extreme external events may be performed [2, 8, 9].

The safety reassessment, in accordance with a graded approach, has to:

— Refer to the current status of the nuclear fuel cycle facility as built and as operated, including all operational states of the facility, in order to encompass existing and planned operational campaigns and modifications to the facility.
— Refer to the facility as designed and as built.

— Use the most unfavourable facility conditions that are permitted by the operational limits and conditions in terms of, for example, radioactive material inventory and physical configuration, spent fuel throughput, enrichment and burnup, and the concentration, acidity and temperature of spent fuel, uranium, plutonium or fission product solutions and chemical reagents.
— Consider the degradation of the SSCs important to safety due to ageing effects — see Ref. [10] for further guidance for ageing management in nuclear fuel cycle facilities.
— Use the most up-to-date external event information and site characteristics for population and human activity.
— Take into account the possible impact of failure of or damage to SSCs that are not important to safety on SSCs that are important to safety. This may necessitate a detailed walkdown of the facility.
— Take into account accumulated modifications or upgrades made to the SSCs.
— Take into account simultaneous occurrences of more than one external event, as well as sequential and dependent events.
— Use verified and validated models and computer codes, with recognition of their limitations.

3.2. REVIEW OF THE DESIGN BASIS OF THE NUCLEAR FUEL CYCLE FACILITY

The requirements for performing safety analyses for nuclear fuel cycle facilities are established in IAEA safety standards [2, 8]. Additional guidance and examples of safety analysis methodology for a variety of nuclear fuel cycle facility types and sizes can be found in Refs [4–6, 11] and two further publications on this topic are in preparation. The process described in this section is outlined schematically in Fig. 1.

The first phase of a safety reassessment is to ensure that the design basis and the underlying data and assumptions remain valid and that they are consistent with the current conditions of the nuclear fuel cycle facility and its site. In the reassessment the following are reviewed:

— Postulated initiating events (PIEs) as well as the methodology used in the original safety analysis and its continuing validity, including the continuing validity of regulations, design codes, and data (e.g. frequency of PIEs or

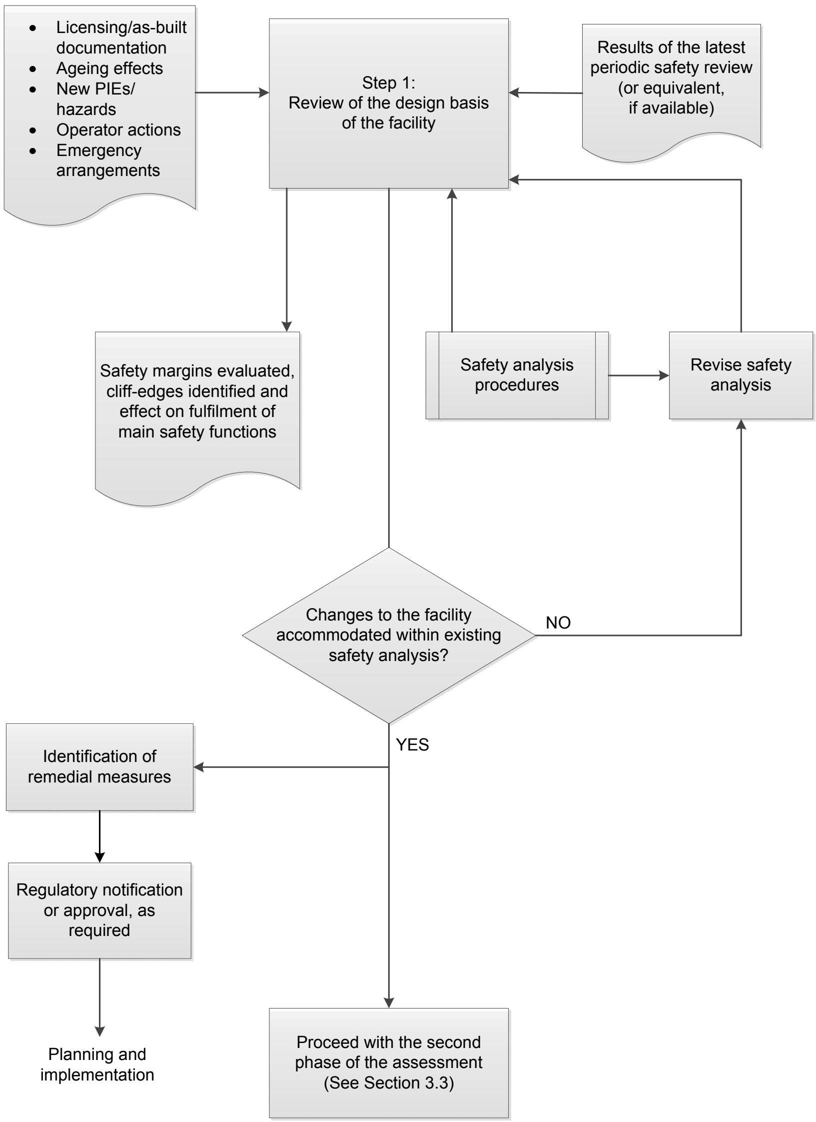

FIG. 1. Flow chart for the review of the design basis of a nuclear fuel cycle facility.

the severity of internal or external events) used at the time of the original assessment;
- Design and administrative provisions, including provisions for maintenance, periodic testing and inspection programmes;
- Adequacy of the emergency arrangements for response to accidents (see Section 5);
- Human resources and organizational factors, selection, training and exercise programmes, operator's qualification and permits or licence updates, programmes for improved human performance and error reduction, etc.

If a periodic safety review (or an equivalent process) has recently been carried out, this may reduce the need for a full safety reassessment. In that case, it has to be verified that the review used the same basis as the safety reassessment, and any difference or gaps need to be assessed, particularly with respect to extreme external event conditions.

If the assumptions used for the original (or existing) safety analysis or design basis have changed, including any new PIEs or hazards that were not previously addressed, the review needs to verify that these changes are accommodated by the existing safety analysis or that the analysis needs to be revised to address them. Consequently, the effects on the safety margins of the SSCs important to safety (i.e. the reserve capacity of SSCs beyond the conditions of which they are designed, in relation to their assigned safety functions) need to be evaluated, any cliff-edge effects identified, and the associated impacts on fulfilment of a main safety function need to be assessed. Corrective actions and compensatory measures need to be planned as necessary.

The next step of the safety reassessment is to proceed with an assessment related to the impact of conditions more severe than the design basis accidents and which involve additional failures.

3.3. ASSESSMENT OF THE IMPACT OF CONDITIONS THAT ARE MORE SEVERE THAN DESIGN BASIS ACCIDENTS OR THAT INVOLVE ADDITIONAL FAILURES

The second phase of the safety reassessment is an assessment of the response of the nuclear fuel cycle facility to conditions more severe than the design basis accidents or accidents that involve additional failures. This requires the identification of a set of design extension conditions followed by an analysis of their effects. The main objective of this analysis is to provide assurance that the design of the facility prevents accident conditions beyond those considered in the design basis, or mitigates their consequences as far as reasonably practicable.

This may require additional safety features or extension of the capability of safety systems to maintain the main safety functions, especially the confinement function. These additional safety features, or this extension of the capability of safety systems, would be sufficient to manage accident conditions in which there is a significant amount of radioactive material confined in the facility. Therefore, this stage of the reassessment is expected to focus on the facility from the perspective of the defence in depth concept and to identify facility specific vulnerabilities. From these, the necessary safety improvements to the facility (the addition of SSCs important to safety) and mitigatory actions can be identified. The process described in this section is outlined in Fig. 2.

The methodology described is based on the assumption that the design basis and the underlying data and assumptions are appropriate to the current status of the nuclear fuel cycle facility, and that the site and the facility are in compliance with their design basis to provide a firm basis for the safety reassessment.

This part of the safety reassessment has to cover:

— Events more severe than the design basis events that originate from extreme events and credible combinations of extreme events that could cause damage to SSCs important to safety and challenge the fulfilment of the main safety functions, including the evaluation of safety margins and identification of any cliff-edge effect;
— Progressions of events that could lead to significant loss of containment (or means of confinement) and/or to criticality combined with failures of SSCs important to safety;
— Adequacy of the emergency arrangements for response to accident conditions (see Section 5);
— Interactions between the facility and other facilities on the site, assuming that the extreme external event has affected all of these facilities simultaneously (see Section 4).

Examples of combinations and consequential events include a tsunami accompanying an earthquake; severe hail with heavy rain or heavy rain after snow (with consequential blockage of drainage channels); and extreme wind with internal or external fire. Minimal combinations of SSCs and human actions that are needed to protect the facility against (or mitigate the consequences of) extreme events have to be identified and documented, as well as any necessary physical improvements to the facility and procedural actions implemented, as appropriate. Physical modifications and altered operational limits and conditions may need regulatory approval. Section 7 provides information on a proposed process for the implementation of such modifications.

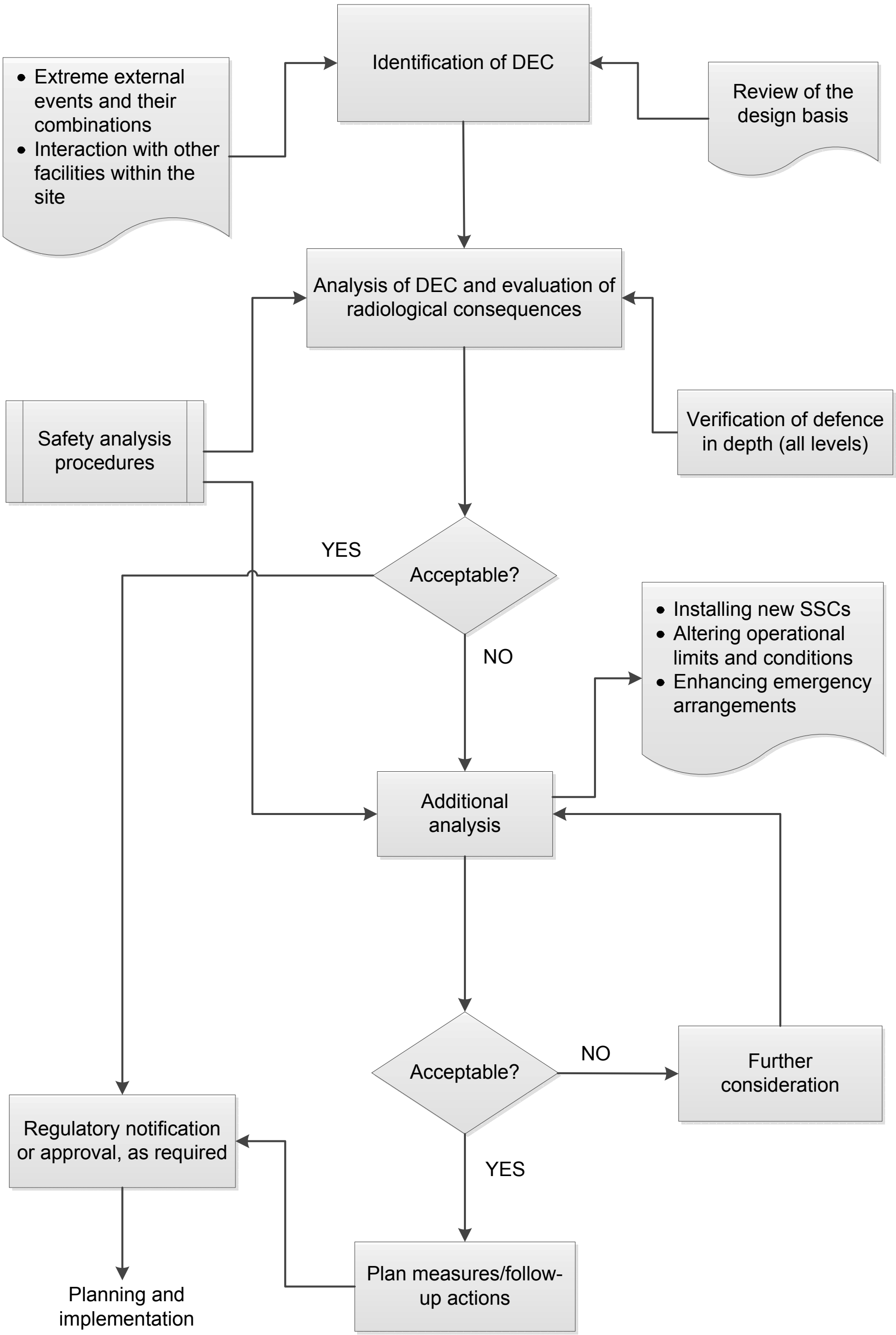

FIG. 2. Flow chart for the assessment of the impact of conditions more severe than design basis accidents, or that involve additional failures.

The SSCs necessary to maintain the main safety functions during different extreme events need to be identified, qualified for their specific operating regime, and documented in the safety analysis report on the facility. Those SSCs that are needed to maintain all or some of the main safety functions during conditions more severe than the design basis accidents also need to be identified.

The safety reassessment has to focus on a comprehensive verification of the effective application of all levels of the defence in depth concept, in accordance with the use of a graded approach, following extreme internal and external events. This needs to include assessing the effectiveness of preventive and accident management measures, the availability of safety instrumentation and control systems, and the access to and the operability and habitability of the emergency control centre. In the context of nuclear fuel cycle facilities, accident management is the taking of a set of actions during the evolution of an accident to prevent escalation to more severe conditions, to mitigate the consequences of such an accident and to achieve a long term safe and stable state of the facility [2].

The list of PIEs, provided in the Annex, has to be reviewed in order to include those that are relevant to the facility, with emphasis on extreme and coincident internal and external events. Consideration needs to be given to combinations of these events and their consequences that are credible for the nuclear fuel cycle facility or its site. If any PIEs are considered irrelevant, this argument needs to be documented and justified.

The analysis has to determine the status of the SSCs important to safety (i.e. whether they will continue to perform the intended function or will fail) that support fulfilment of the relevant main safety functions during the course of accident conditions (including simultaneous or consequential events). The operating organization needs to prepare a list of SSCs important to safety, based upon the existing approved safety analysis report, and needs to obtain agreement on the list from the regulatory body. After this list is established, the contribution of each component to fulfilling one or more main safety functions needs to be determined. Subsequently, the operating organization needs to verify the robustness of the facility or identify the missing information on SSCs important to safety. The results of this verification can be tabulated in a matrix form, as illustrated in Fig. 3.

The next step in the analysis is to evaluate the radiological consequences of loss of the relevant safety functions owing to failures of the SSCs. These consequences need to be evaluated in terms of radiation doses to on-site personnel and the public, as well as the effect of radioactive releases on the environment.

SSCs important to safety	Main safety function affected[a]					Result of verification of robustness						
	Criticality prevention	Containment/ Confinement			External exposure prevention	Earthquake	Flooding/ Tsunami	Fire	Tornado/ Hurricane	Sand blast	Heavy snow	Other (see Annex)
		1[b]	2[b]	3[b]								
Facility protection and shutdown systems												
Cooling systems												
Emergency cooling system												
Building and structures												
Containment or confinement:												
Ventilation												
Filtration system												
Electrical system:												
Uninterrupted power supply												
Diesel generators												
Barrier integrity												

FIG. 3. Example of a blank pro forma that could be used to record the verification of robustness of SSCs following internal and external events or combinations of both. Ticks are entered to record the verification of the individual items and n.a. is entered where an item is not applicable. Notes: a — For some types of nuclear fuel cycle facilities, additional or alternative column heading(s) may be needed. b — (1) Barriers (static and dynamic); (2) Cooling; (3) Prevention of hydrogen (radiolysis) and accumulation of other explosive or flammable materials.

The results obtained can then be used to identify the conditions that are more severe than design basis accidents or that involve additional failures that necessitate further investigation. The evaluation needs to be carried out if:

— The concept of defence in depth is not fully applied in the nuclear fuel cycle facility or site and as a result events may lead to unacceptable radiological consequences.
— Failures of the main safety functions could lead to unacceptable radiological consequences.
— Potential human error (or a feasible combination of errors) could result in the failure of a main safety function and could lead to unacceptable radiological consequences.

Conditions that meet these criteria, for which additional safety measures may be needed, may include:

— Accidental criticality, leading to an early release of radioactive material;
— Melting of spent fuel or vitrified radioactive waste;
— Uncovering spent fuel or thorium/uranium breeder elements in a spent fuel storage pool;
— Extended blackout of a large reprocessing facility;
— Boiling of highly active liquid radioactive waste, for example, in nuclear fuel reprocessing facilities;
— Rupture of a pressurized UF_6 storage or process vessel (> ~60 Celsius);
— Major disruption of a plant handling powders containing plutonium or ^{233}U.

The next step is to identify, on the basis of the results of the safety reassessment, possible preventive measures to be applied and mitigatory actions to be taken. Implementation of these measures and actions needs to be justified by analyses, where appropriate, of the:

— Balance of risks and costs;
— Prioritization of safety improvements across a site;
— Remaining operational life of the facility;
— Feasibility of the modifications and measures.

Indicative examples of possible measures and actions are as follows:

— Acceptance of a failure to fulfil the main safety functions because the radiological consequences are either:
  • Within acceptable limits;

- Manageable with the emergency arrangements currently in place (e.g. realistic evacuation of buildings within the site of the nuclear fuel cycle facility);
- Bounded by the consequences of an event with a scenario that has been previously analysed in the safety analysis report and meets the acceptance criteria (e.g. the analysis may already cover a prolonged loss of power sufficient to envelop the effect of a newly postulated severe weather event on the off-site electrical grid).

— Performance of additional analyses to determine the consequences of the event in order to either:
- Determine the time frame of the event sequence and the associated safety margin (e.g. the flooding level at which inundation of the nuclear fuel cycle facility would result in the loss of a main safety function or the time needed to prevent this loss);
- Identify the need to strengthen the mitigatory actions by enhancing emergency response capabilities, revising existing plans and procedures, providing alternative supplies, tools, equipment and training, and performing drills and exercises for both off-site response organizations and on-site response personnel to test these arrangements.

— Enhancement of preventive measures through installation of new (or modification or upgrade of existing) SSCs resistant to external hazards, such as:
- Upgrades to emergency electrical power supplies, by redundant connections to the off-site power grid, supplementary emergency power generators and/or improved backup batteries, diverse types and locations, and common hook-up configurations;
- Installation of seismic detectors connected to the nuclear fuel cycle facility protection systems and instrumentation that are qualified to operate under extreme conditions;
- Provision of a diverse shutdown system, such as one based on the injection of neutron absorber solution to avoid or terminate a criticality event, or diverse cooling systems to control a chemical reaction;
- Modifications to improve the emergency ventilation system and, where necessary, the associated filtration system;
- Provisions for recycling coolant from delay tanks[1] or lagoons to the key cooling systems;

[1] Delay tanks are used in nuclear fuel cycle facilities to provide for appropriate detection and diversion of potentially contaminated cooling water.

- Installation of passive components in the cooling systems, as applicable to the type of nuclear fuel cycle facility;
- Strengthening of various SSCs, especially those necessary to prevent containment damage, key cooling systems damage or potential hydrogen accumulation in an extreme event.

— Incorporation of provisions for extreme event protected backup equipment (e.g. mobile diesel generators, air compressors and pump trucks) to maintain the main safety functions, and associated revision of the emergency operating procedures (see Section 5). The safety reassessment method also has to be applied for all facilities associated with the nuclear fuel cycle facility, with particular care taken that equipment and resources are sufficient to respond effectively to site-wide events.

3.4. FACILITY TYPE SPECIFIC CONSIDERATIONS FOR SAFETY REASSESSMENT

The safety reassessment of nuclear fuel cycle facilities has to consider the inventory and form of the radioactive material and the associated potential consequences of accidents, which are related to the specific processes, materials and physical status of each facility. The IAEA safety standards specify the main safety functions on which the facility design is based:

> "The facility shall be designed to prevent a criticality accident and the accidental release of hazardous materials. The design shall keep radiation exposures from normal operations as low as reasonably achievable" (para. I.1, Ref. [2]).

All safety reassessments begin with a re-evaluation of the adequacy of the existing design basis, and consider the specific design features of different types of nuclear fuel cycle facilities. This section summarizes those specific differences and has to be read in conjunction with Sections 3.1–3. Detailed lists of safety functions for various types of nuclear fuel cycle facility are provided in Refs [4–6, 11].

3.4.1. Manufacture of nuclear fuel material and fuels

The manufacture of fuel material and fuels includes conversion and uranium enrichment, uranium fuel fabrication and uranium and plutonium mixed oxide fuel (MOX) fabrication facilities, including uranium refining facilities. The safety reassessment of these facilities has to consider the inventory of radioactive material and potential consequences. These are related to the chemical processes used and handling steps involved. For these types of facilities, the main safety functions are the prevention of criticality, confinement for the prevention of releases that might lead to internal exposure and for the prevention of chemical releases, and protection against external exposure.

The safety reassessment of these facilities needs to include:

(a) A review of the facility design basis, including:
   (i) Re-evaluation of the adequacy of ventilation, filtration and monitoring systems to monitor and control radiological and chemical releases;
   (ii) Re-evaluation of the adequacy of fire and explosion prevention and mitigation systems and strategies.
(b) The assessment of the impact of conditions more severe than design basis accidents, including prevention and mitigation of accident progression. A number of issues need to be considered including:
   (i) Criticality control:
      — Failures of SSCs that lead to a potential accumulation of fissile material in the most unfavourable conditions;
      — Introduction of moderating materials resulting from the failure of SSCs.
   (ii) Confinement:
      — Loss of confinement of UF_6, UO_2 or PuO_2 that leads to radiological or chemical consequences.
   (iii) For MOX and ^{233}U fuel fabrication facilities only:
      — Loss of ventilation that may lead to criticality or loss of confinement;
      — Maintaining confinement of highly dispersible powders;
      — Cooling.

3.4.2. Nuclear fuel reprocessing facilities

Nuclear fuel reprocessing facilities vary in design and complexity from small laboratory facilities to large facilities. The main safety functions of all these facilities are the prevention of criticality, the confinement of radioactive materials (including removal of decay heat and dilution of radiolysis gases) and protection against external exposure. The complexity of the facility is an additional factor that needs to be considered in performing safety reassessment.

The safety reassessment of these facilities has to include:

(a) The review of the design basis:
   (i) Re-evaluation of the adequacy of ventilation, filtration and monitoring systems to monitor and control radiological and chemical releases;
   (ii) Re-evaluation of the adequacy of fire prevention and mitigation systems and strategies.
(b) The assessment of the impact of conditions more severe than design basis accidents, including the prevention and mitigation of accident progression. A number of issues need to be considered, including:
   (i) Criticality control;
   (ii) Failures of SSCs that lead to a potential accumulation of fissile material in the most unfavourable conditions;
   (iii) Failures of SSCs that can introduce moderating materials, such as failure of piping and vessels.
(c) The review of provisions for confinement:
   (i) Loss of confinement of hazardous materials that leads to radiological or chemical consequences;
   (ii) Loss of gas flows, leading to a dangerous accumulation of hydrogen from e.g. radiolysis.
(d) Evaluating systems for preventing or mitigating a loss of cooling of vessels or equipment containing material with significant decay heat (e.g. highly active liquid waste) that may lead to releases into the environment.
(e) Appropriate monitoring and surveillance systems to inform timing and prioritization, for example by:
   — Maintaining the dilution against the accumulation of flammable gases;
   — Preventing an increase in the temperature of highly active liquor towards boiling point;
   — Maintaining the confinement of highly dispersible plutonium or ^{233}U material (powders).
(f) A review of the appropriate mitigation strategies in the case of limited monitoring and surveillance capability.

3.4.3. Spent nuclear fuel and dry high level radioactive waste storage facilities

As wet and dry spent fuel storage facilities are significantly different from one another, with different physical structures and safety features, the approaches of the safety reassessment are described below for each type of facility separately.

3.4.3.1. Wet spent fuel storage

The main safety functions of these facilities are the prevention of criticality, the confinement of radioactive materials (particularly the removal of decay heat), protection against external exposure and the maintenance of fuel retrievability.

The safety reassessment of these facilities needs to include:

(a) A review of the design basis;
(b) Assessment of the impact of conditions more severe than the design basis accidents, including prevention and mitigation of accident progression and keeping in view that the main goal is to preserve the fuel cladding integrity (which implies keeping a sufficient level of water in the pool and adequate cooling), the reassessment has to include:
    (i) The timeframe and potential of water level changes (e.g. temperature increase, boiling point, loss of water cover) due to either decay heat effects or acute or chronic leakage;
    (ii) The timeframe within which hydrogen can be prevented from accumulating to unsafe concentrations;
    (iii) Appropriate monitoring and surveillance systems to inform timing and prioritization for e.g. preventing loss of water cover.

3.4.3.2. Dry storage of spent fuel and storage of solid high active wastes

The main safety functions for these facilities are the prevention of criticality, the confinement of radioactive materials (particularly removal of decay heat and dilution of radiolysis gases), protection against external exposure and maintenance of fuel/waste retrievability. The safety reassessment of these storage facilities has to include:

(a) The review of the design basis, which addresses:
    (i) Confinement measures for dry fuel cask storage. The potential for loss of confinement is expected to present localized effects.
    (ii) Confinement measures for fuel cladding storage facilities (particularly in ageing storage silos) where gas dilution systems are required to prevent fires and aerial release of volatile species.
(b) Assessment of the impact of conditions more severe than the design basis accidents. The review needs to include:
    (i) The anticipated time before decay heat associated with dry fuel stored in casks will increase to too high a level (where applicable), leading to containment degradation.

(ii) The anticipated time before decay heat associated with the storage of vitrified highly active waste will increase to too high a level, leading to containment degradation.
(iii) The anticipated time during which inert gas cover will continue to exclude oxygen from the facility. Backup fire mitigation needs to feature prominently within the accident management strategy.
(iv) Appropriate monitoring and surveillance systems for e.g. oxygen concentration, ventilation performance, including passive (cooling) ventilation, and temperature changes.

3.4.4. Facilities for low and intermediate level radioactive wastes

Facilities for low and intermediate level radioactive wastes include radioactive waste processing facilities and facilities for interim radioactive waste storage. These facilities generally contain a limited inventory of radioactive material but may also contain significant quantities of chemicals and flammable material.

The characteristics of different kinds of waste treatment and storage facilities have to be taken into account in the safety reassessment. The safety reassessment of these treatment and storage facilities has to consider:

(a) The kind of waste treatment and storage (from treatment facilities for waste incineration, cementation or compaction to facilities limited to storage of radioactive waste) and its purpose, and the various inventories present in the facilities in practice.
(b) The current status of the facility (including age, size and condition) that might be challenging to confinement.
(c) The waste properties, including the:
    (i) Type of waste, e.g. its physical or chemical form and hazardous properties (chemo-toxicity, radio-toxicity, flammability, etc.);
    (ii) Physical form of the waste and its packaging.

For such facilities, the main safety functions are:

— Prevention of criticality for intermediate level waste;
— Confinement of radioactive materials (including, for some facilities, removal of decay heat and/or dilution of radiolysis gases);
— Protection against external exposure;
— Maintenance of waste retrievability in interim storage.

In many lower level waste facilities, only confinement will be relevant. However, as the definition of ‘low’, ‘intermediate’ and ‘high’ level wastes is subject to national requirements or agreements, care needs to be taken in justifying the exclusion of a safety function from reassessment.

Confinement of the radioactive material is the primary objective of the safety systems of waste treatment and waste storage facilities. Accident conditions may be due to a complete or substantial loss of containment.

The safety reassessment of these facilities has to include:

(a) The review of the design basis accidents:
   (i) A reassessment of whether the existing safety functions to prevent the loss of integrity of the confinement are adequately implemented in safety relevant SSCs, such as:
   — Structures;
   — Ventilation systems;
   — Detection systems for fire and respective suppression systems;
   — Waste package integrity.
(b) The reassessment of the impact of conditions more severe than the design basis accident assessment, which has to include the:
   (i) Evaluation of the possibilities of reducing the release potential of the radioactive material inventory during and following accident conditions;
   (ii) Evaluation of the available response time for accident conditions and their progression, as this would determine the potential means of mitigating the accident, particularly for defining suitable equipment and operator actions.

3.4.5. Nuclear fuel cycle R&D facilities

Nuclear fuel cycle R&D facilities vary considerably among Member States in design, complexity and potential hazards. The safety reassessment of these facilities has to consider the inventory and form of the radioactive material and the associated potential consequences, which are related to the specific processes and materials in use, to the physical status of the facility and materials and to other aspects.

In view of the wide spectrum of hazards encountered at these facilities, an initial review needs to be carried out to eliminate those clearly below the threshold for safety reassessment so that resources can be concentrated on facilities with the hazards that are potentially highest. This, in accordance with the use of a graded approach, does not mean waiving any safety requirements on safety analysis or periodic safety reviews of these facilities.

The main safety functions of the R&D facilities are prevention of criticality, confinement of radioactive material, including removal of decay heat, and protection against external radiation exposure.

The safety reassessment of R&D facilities has to include:

— The review of the design basis, which needs to include the evaluation of whether the existing safety functions preventing criticality and loss of integrity of the confinement are adequately ensured by the relevant SSCs. These include ventilation systems, detection and suppression systems for fire, configuration and control systems for criticality prevention and control, and SSCs that maintain containment integrity and address its possible failure.
— Assessment of the impact of conditions more severe than the design basis accidents, an evaluation of the opportunities for reducing the potential release of the radioactive material inventory, and an evaluation of mitigation measures for criticality accidents.

4. REASSESSMENT OF THE SITE

4.1. REVIEW OF THE SITE CHARACTERISTICS

Requirements, guidance and methodologies for assessing external hazards for nuclear fuel cycle facilities are provided in IAEA safety standards and other publications such as Refs [2, 12–17]. As well as being useful for the initial siting, design and safety evaluation of a new nuclear fuel cycle facility, these publications also need to be used for reassessment of an existing nuclear fuel cycle facility to cope with extreme external events including, if necessary, human-made events. In this section, the site is taken to mean a contiguous area occupied by one or more nuclear fuel cycle facilities. Risks due to any reactors or non-nuclear facilities on the site or in the vicinity are considered external hazards in the following, regardless of whether they were licensed together with the facility. Section 4.2 provides guidance for multi-facility sites (including guidance on non-nuclear hazards on the site of a nuclear fuel cycle facility, such as chemical or fuel stores).

A site-wide review of safety may be coordinated with a review of the security of the site affected by an extreme external event. Methodologies for reviewing the security of the site are beyond the scope of this publication;

further guidance is provided in the publications of the IAEA Nuclear Security Series [18–22].

Changes to the characteristics of the site area and its vicinity can be detrimental to the continued safety of a nuclear fuel cycle facility. The review needs to focus on determining whether any such changes may result in an increase in the magnitude of a potential external hazard or the frequency of occurrence of potential external hazards or in changes to the associated radiological consequences of a postulated event. Information on the reassessment of external hazards for verification of compliance with the nuclear fuel cycle facility design basis is provided in Section 3.

Where nuclear fuel cycle facilities are located at industrial sites with other nuclear or non-nuclear facilities, it is recommended to start the site safety reassessment by examining the area in the vicinity of the facility and determining whether (and to what extent) this needs to be considered in the safety reassessment.

Changes within the site area and in its characteristics that need to be reviewed to verify their continued acceptability may include changes in the:

— *Distribution of workers on the site.* In many Member States, people who work in the site area but are designated as non-radiation workers are treated as members of the general public with respect to radiation dose limits. Therefore, the effects of changes in the distribution of workers on the site (including changes in the proportion of workers designated as radiation workers to those designated as non-radiation workers) need to be assessed to verify whether the potential consequences of an event have changed, and whether appropriate protective measures need to be applied.

— *Other facilities within the site area and any changes in their use.* Such changes can have a positive or negative impact on the safety of the nuclear fuel cycle facility by increasing or decreasing potential hazards. For example, the complete decommissioning of another nuclear facility located on the site could significantly reduce the potential hazard.

— *Site infrastructure and support services.* Changes in these aspects can also have positive or negative impacts on the accident prevention measures and/or planned mitigatory actions. For example, the addition or removal of accident prevention and mitigation measures, or improvements to site control and alarm systems (which may have occurred, perhaps more than once, on many older sites) need to have benefits in relation to severe accident management.

Changes in the characteristics of the site’s surroundings need to be reviewed to verify the site’s continued acceptability. They may include changes in the:

— *Surrounding population.* Analysis needs to be performed to verify the effect of any changes in the surrounding population (or its distribution) on the potential consequences of an event. For example, the consequences of an accident at a nuclear fuel cycle facility that was originally located far from any urban area will be different if it is now encroached upon by new residential developments or any buildings especially for the use of members of the public with limited mobility, such as hospitals, schools or health care centres for the elderly.
— *Local land use.* Analysis needs to be performed to verify the effect of any changes in land use that could represent a new or increased hazard to the nuclear fuel cycle facility and the site. For example, new industrial facilities located nearby could represent a new external hazard if they involve the use of large volumes of toxic or explosive gases. Conversely, the removal of a nearby industrial facility may reduce the potential hazard to the nuclear fuel cycle facility and the site.
— *Local transportation routes.* New roads, railways or airports constructed near the nuclear fuel cycle facility may increase or decrease the potential hazards to the nuclear fuel cycle facility and the site installations.
— *Hydrology and topography of the site vicinity.* Changes in hydrology and topography could present a new hazard or remove an existing hazard to the nuclear fuel cycle facility and the installations on the site. For example, if the site is located near a river, construction of a dam upstream or downstream from the nuclear fuel cycle facility may affect the risk of flooding.

4.2. REASSESSMENT OF SITE-WIDE EVENTS (MULTI-FACILITY SITES)

Sites of nuclear fuel cycle facilities often contain multiple facilities that undertake the stage-wise processes of conversion, enrichment, fuel fabrication, spent fuel storage, reprocessing, and waste management. They may also contain other industrial facilities. These sites may also contain significant radioactive waste and spent fuel.

The safety reassessment of multi-facility sites is more than the addition of the safety reassessments of the site’s distinct facilities. In order to assess the impact of extreme external events on the site area and any surrounding supporting facilities, the entire site needs to be considered, so that the potential for simultaneous accidents at different facilities can be assessed, including the assessment of the ability of on-site response personnel and off-site response organizations to respond effectively.

A process to reassess the potential impact of extreme external events across the whole site could involve the following steps:

(a) Identification of possible new hazards to the nuclear fuel cycle facility and its workers that may arise from other facilities on the site. Examples include increases in the size of fissile storage or extensions to the lifetime of radioactive waste storage.
(b) Identification of other on-site facilities for which the external event may result in higher potential consequences than those that would result from the effect of the external event on the nuclear fuel cycle facility and its associated facilities (e.g. an adjacent research reactor).
(c) Determination of the impact of the external event on the site infrastructure and supporting services with respect to both its impact on the:
    (i) On-site facilities (the nuclear fuel cycle facility and its associated facilities) due to consequential and common cause failure;
    (ii) Accident prevention measures to be applied or mitigatory actions to be taken within the nuclear fuel cycle facility and its associated facilities (e.g. flooding impact on standby generators or diesel fuel supplies).
(d) Reassessment of the ability of the on-site response personnel and/or the off-site response organizations to manage effectively events occurring simultaneously within multiple facilities on the site, including the nuclear fuel cycle facility and its associated facilities (see also Section 5). Simultaneous events may be initiated by the same external event and it is necessary to consider the impact of this initiating event on the site infrastructure. Emergency workers could have an excessive workload or conflicting priorities, and some supporting facilities may not be available.

Reassessment of the potential impact of extreme external events on the site vicinity has to include (but is not limited to):

(a) *Their impact on access to the nuclear fuel cycle facility site*. For example, the access of facility operating personnel to the site to replace those on duty needs to be evaluated. Access of the off-site response organizations to the facility site needs to be coordinated properly, between the local competent authorities and site authorities. Alternative access paths to the site need to be investigated in the case of blockage of the normal access path (e.g. owing to an external event).

(b) *The availability of on-site response personnel.* Resourcing different positions relevant to the performance of emergency response functions with on-site response personnel for an emergency initiated by an extreme external event could be challenging particularly because of the possibility of:
   (i) Several facilities being affected simultaneously;
   (ii) The need for a prolonged response;
   (iii) Loss of access to the site (see Section 5).
   (iv) In the case of extreme external events, there may be a natural tendency for on-site response personnel to absent themselves from their workplace in order to assist their families, which may mean that required staff functions are left unfilled, which poses additional difficulties for accident management.

(c) *The availability of the off-site response organizations.* Arrangements for notifying and obtaining responses from off-site organizations need to be verified. These arrangements may be subject to formal agreements between the facility and the off-site response organizations.

(d) *The training and capability of off-site response organizations.* Assuming that access to the nuclear fuel cycle site is ensured, the training and capability of off-site response organizations need to be verified (see also Section 5), particularly in emergency response to accident conditions initiated by an extreme external event(s) affecting several facilities simultaneously. This also includes performing appropriate drills and exercises involving the whole site (see Section 5).

(e) *The siting of the emergency centre.* The location of the emergency centre needs to be evaluated. Placing the emergency centre on the site for directing the on-site emergency response may affect its operability and habitability under the severe conditions of an extreme external event. Wherever the emergency centre is located, its continuous accessibility, protection from external hazards and communication with affected facilities need to be verified.

5. REASSESSMENT OF EMERGENCY PREPAREDNESS AND RESPONSE

This section provides information on the performance of a review of the emergency arrangements in place in order to verify their adequacy in addressing the consequences of accidents.

As a first step, the existing emergency plan and associated procedures and arrangements need to be reviewed to ensure that they are adequate and realistic, particularly for conditions more severe than design basis accidents initiated by an extreme external event affecting several facilities simultaneously. Safety requirements and associated guidance on emergency preparedness and response in relation to nuclear fuel cycle facilities are established in IAEA safety standards [2, 23–25] and form the basis for this review.

In the second step, the following topics have to be reassessed and verified:

— *Assessment of hazard*. The objectives of this reassessment are to verify that all event sequences that may lead to an emergency have been considered and are covered by emergency operating procedures that support the emergency plan. This needs to include consideration of:
  - Characteristics of the nuclides and chemicals that may be released;
  - Information on the timing and consequences of accident conditions and sequences, including events that involve the total loss of all safety measures;
  - Identification of new actions that are facility specific, site-wide, or off-site and that could be taken to mitigate the effects of accident conditions.

— *Chain of command and control*. The objectives of the reassessment are to verify that a clearly defined command and control system that is well understood by all involved is in place to:
  - Effectively manage the response to an emergency;
  - Decide promptly on protective actions and other response actions to be taken.

— *Communication.* The objective of the reassessment is to verify the existence of adequate procedures and means for effective communication during an emergency. Pre-established communication procedures need to be in place to ensure effective communication between on-site response personnel at different locations on the site with off-site response organizations, and effective communication to the public. All the means of communication used need to be redundant and diverse in nature, in order to ensure their operability (considering, for example, possible damage due to the initiating extreme external event) and their availability for an extended period of time, which may be necessitated by the emergency. Communication with the public may not interfere with the prompt implementation of the protective actions and other response actions in an emergency, and needs to be carried out in a coordinated manner so that consistent messages are given to the public.

— *Readiness of the on-site response personnel and off-site response organizations*. The objective of the reassessment is to ensure that arrangements are in place and are implemented to ensure the capability of on-site response personnel and off-site response organizations to respond to accidents. They need the flexibility to respond to the acute local effects of chemicals released with nuclear material and to respond to an extreme external event affecting several facilities simultaneously. The availability of on-site resources, including the number and expertise of personnel to carry out emergency duties for an extended period, needs to be reviewed and revised, as necessary. Emergency drills and exercise programmes also need to be revised to cover the responses to such events.

— *Support of on-site emergency personnel*. The objective of this reassessment is to evaluate whether arrangements have been made to assist families of emergency responders in taking protective actions and to provide for communication of status of family situations (to emergency workers who are involved in the response and are unable to assist their families) during an emergency.

— *Emergency equipment.* The objective of the reassessment is to ensure that equipment necessary for use in response to an emergency (such as radiation survey meters, neutralizing chemicals or meteorological instruments) is continuously available for its intended use under severe conditions and is subject to periodic verification. The availability and suitability of the analysis tools (such as computer codes for the estimation of potential radiological consequences) to be used in an emergency initiated by an extreme external event affecting several facilities simultaneously also need to be covered by the reassessment. The reassessment has to verify that any additional equipment required to maintain the main safety functions is suitable and available for use under severe conditions and is qualified to function correctly under those conditions. The review needs to cover:
  - The availability of power supplies such as mobile diesel generators and batteries, water supplies for critical cooling, and for maintaining the ultimate heat sink where applicable;
  - All accident scenarios which require ‘consumable’ resources (fuel, reagents, protective equipment, inert gas supplies, compressed air for instruments and liquid movements, human resources, etc.) to regain control of and/or maintain the facility in the safest state feasible, to ensure that the resources identified will be available for a sufficient period, in accordance with the anticipated degree of local or national disruption caused by the initiating event.

Interfaces for use of off-site equipment need to be prepared and available. The operating organization needs to have agreements in place to ensure that the emergency equipment is available from off-site sources, and it needs to consider alternative access routes or methods consistent with the expected area and site conditions.

— *Emergency centre*. The objective of this reassessment is to determine whether the emergency centre for directing the on-site and off-site emergency response is adequate to ensure access, habitability and long term operability in accident conditions with consequences more severe than the design basis.
— *Accessibility and logistical support.* The objective of the reassessment is to ensure that alternative means of access for off-site response organizations to the site are in place, and logistical support is available when needed, with due consideration of the possible impact from an extreme external event. It needs to be ensured that those personnel tasked with providing analytical support for decision making can properly validate and verify the results under extreme event conditions, to minimize any potential confusion that may arise from the receipt of conflicting information.
— *Role of the regulatory body*. See Section 2.
— *Training and qualification*. The objective of this reassessment is to review and revise the training and qualification of the operating personnel to cover the operator's response to accident conditions and to ensure that operators are adequately trained to recognize fully the potential for an extreme external event and to provide prompt advice on any chemical and radiation hazards to off-site personnel. The emergency plan and associated procedures have to provide for the implementation of the chain of command and control, including decision making in all phases of the emergency response. Training, drill and exercise programmes need to provide for training and testing in realistic situations, the chain of command and decision making in an emergency response, particularly for conditions initiated by an extreme external event affecting several facilities simultaneously.

6. APPLICATION OF A GRADED APPROACH

Considering the different types and sizes of nuclear fuel cycle facilities and their associated utilization programmes, a graded approach needs to be applied to a safety reassessment and to be commensurate with the potential hazard of the nuclear fuel cycle facility [2, 4–8]. Aspects of the reassessment that may be subject to grading include the scope, extent and details of the analysis, and the required human and financial resources, which may be significantly less for low radioactive inventory nuclear fuel cycle facilities (typically front-end facilities, excluding MOX fuel fabrication) than those required for high inventory (back-end) nuclear fuel cycle facilities. It is also important to note that nuclear security considerations may change the grading of a facility.

Factors affecting the application of a graded approach [2] are those related to the risk and the potential hazard, including, for example:

— The scale of operations undertaken at the facility;
— The inventory of radioactive material, the amount and enrichment of fissile material or the inventory of transuranic elements and the perceived criticality risk;
— The amount, nature and physical and chemical forms of the radioactive materials that are used, processed or stored at the facility;
— The facility design, the complexity of the site and the facility, the inherent safety features in the design and the maturity of the process;
— The presence of high pressure piping or the use of high temperature or pressure processes;
— The quality (robustness) of the means of confinement (containment and ventilation systems, presence of high inventory glovebox suites, etc.);
— The facility utilization programme;
— The stage of the lifetime of the nuclear fuel cycle facility, including ageing of the nuclear fuel cycle facility;
— Any other internal hazards (e.g. hydrogen, chemical and fire hazards);
— Siting (regional characteristics including location of reservoirs, dams and large water bodies, and geological or meteorological conditions);
— Structural concept (above or below ground) and the proximity of other nuclear or non-nuclear industrial sites;
— Proximity of the nuclear fuel cycle facility to populated areas and the availability of off-site support to cope with accidents.

Where applicable, the radioactive inventory of the facilities within the entire site needs to be considered rather than that of individual facilities, unless it is technically justified to consider the facilities individually. Where there are many facilities, it may be necessary to categorize them in order to prioritize effort. Care has to be taken when prioritizing facilities, however, not to make assumptions about the conclusions of the reassessment.

Grading may be applied to the scope and the level of detail of review of design basis events and the assessment of the accident conditions of a nuclear fuel cycle facility. Certain accident scenarios may not apply or may need only limited analysis in low potential hazard (low radioactive inventory) nuclear fuel cycle facilities compared to facilities with high potential hazard. For example, the analysis and management of a loss of cooling event differs significantly depending on the inventory and design of the nuclear fuel cycle facility.

The graded approach may also be applicable to the selection of site related design basis events (and accident conditions to be assessed) to the extent that the examination of events may show that some of them pose a minimal hazard to the nuclear fuel cycle facility in a particular site.

A graded approach may also be used in the application of the safety requirements related to the levels of defence in depth, in the sense that level 5, and sometimes level 4, may be met by the inherent safety characteristics of the nuclear fuel cycle facility instead of through engineered safety features of the design. If the nuclear fuel cycle facility is designed with minimal confinement or containment, for example, this needs to be justified on the basis that there is no potential for release of radioactive or toxic material from the facility under accident conditions that might result in unacceptable off-site consequences.

Grading may be also applicable to the extent of emergency arrangements to be established based on the potential hazard associated with the nuclear fuel cycle facility in accordance with Refs [23, 24]. Grading may also be applied to the number and types of escape routes, based on the layout and size of the nuclear fuel cycle facility. It may also be applied to the necessary emergency equipment and to the scope and frequency of the emergency drills and exercises.

A graded approach can also be applied to the organizational aspects, including human and financial resources, for performing the safety reassessment and to the management of the implementation of the findings of the assessment. Application of the graded approach needs to be based on the potential hazard of the nuclear fuel cycle facility, and needs to take into account the existence of other nuclear installations on the site. It also needs also to be reflected in the regulatory requirement for a safety reassessment.

Nevertheless, certain organizational factors, such as safety culture and human performance, are required to be maintained by the managers at the highest level [26], since weakness in relevant areas could have a significant impact on the effectiveness of emergency responses.

The application of a graded approach can be reviewed as the safety reassessment progresses and a better understanding is obtained of the level of risk arising from the facility or activity. Its scope, extent, level of detail and the effort involved can be adjusted accordingly. For example, as the safety reassessment progresses, it may emerge that the likelihood of significant consequences is greater than originally considered and more effort and/or details may be required to demonstrate compliance with the safety requirements, or vice versa.

7. IMPLEMENTATION OF THE REASSESSMENT FINDINGS

It is important that a process be established for the implementation of the findings of the safety reassessment described in Sections 3, 4 and 5.

The prioritization of facilities requires balanced professional decisions based on analyses, regulatory requirements and engineering judgement. Different types of facilities have differing PIEs and DECs, including extreme external event frequencies and magnitudes. These need to be considered both in the safety reassessment and in the implementation of any changes arising from it. Programmes for improvements need to be prepared by the operating organization and submitted to the regulatory authorities for endorsement, approval or authorization, in accordance with existing national requirements.

The regulatory body needs to analyse the extent to which the lessons learned from the Fukushima Daiichi accident are understood and applied to the site and nuclear fuel cycle facilities (see also Section 2).

Upon completion of the safety reassessment, the operating organization may have identified findings or opportunities for improvement that require follow-up actions:

— Findings, such as a non-compliance with a regulatory requirement, which need corrective actions to ensure that an adequate margin of safety is maintained.
— Opportunities for improvement, such as deviations from best management practices or design requirements that do not currently have a significant impact on safety.

Improvement actions may take one or more of the following forms:

— Improving safety culture, leadership and organizational aspects, including the definition of the roles and functions of groups and individuals within the nuclear fuel cycle operating organization. This definition of roles and functions includes definition of the lines of communication, and incorporation of the emergency management system into the integrated management system. Requirements and guidance on application of the management system for facilities and activities are provided in Refs [26, 27].
— Enhancing training and qualification programmes for nuclear fuel cycle operating personnel and ensuring adequate human resources for the safe operation of the facility.

- Improving management system processes, as needed.
- Improving systems for feedback of operating experience.
- Modifying (or upgrading) the SSCs that are not adequately designed or would not perform as necessary, as well as improving the availability and performance of emergency equipment during accident conditions.
- Revising SSC surveillance, maintenance, calibration, periodic testing and inspection regimes, and programmes for ageing and obsolescence management.
- Modifying procedures for preventive accident management, provision for better conditions for the resources to be used in accident situations (increasing stocks of emergency supplies and equipment, improving housekeeping and testing, and checking frequencies, etc.).
- Strengthening emergency arrangements for dealing with accident conditions initiated by an extreme external event affecting several facilities simultaneously. This includes selection, training and qualification programmes, drills and exercise programmes, emergency plans and procedures, availability and operability of the necessary equipment and facilities etc., and enhancing cooperation with off-site organizations that can assist in an accident situation.

In addition, the results of the evaluation of the design basis and all accident conditions need to be shared with the nuclear fuel cycle facility operating personnel in order to promote a better understanding of the prevention of accidents and mitigation of their consequences and to improve safety culture.

To ensure effective implementation of the findings of the reassessment, the operating organization also needs to establish an action plan that may be submitted to the regulatory body for review. This plan may also be subjected to a peer review. Such an action plan needs to identify those actions for which a temporary shutdown of the facility is required. The operating organization is responsible for ensuring the availability of the human and financial resources necessary for the implementation of the action plan. This plan can include short term and long term actions, depending on the impact of each action on the safety of the facilities. For example, it is expected that actions that will result in direct safety improvements will have a priority over actions that have only a small or uncertain benefit as well as actions that could be implemented quickly and easily (‘quick-fix’ issues) irrespective of the scale of their immediate benefits. A cost–benefit analysis may be applied in the area of operational improvements, including improvements to the facility availability and utilization programme. Opportunities for improvement that are identified may be addressed over a longer period of time within the normal allocation of resources and normal planning for the facility.

The operating organization also needs to review the collective findings of the safety reassessment to determine if the aggregate of potential impacts makes the risk associated with continued operation of the facility greater than the benefit that would be derived from its continued operation.

Despite the fact that nuclear fuel cycle facilities are of different types, sizes and utilization programmes, the results of the safety reassessment, in particular the evaluation of design extension conditions, is likely to reveal common issues and generic lessons to be learned by the whole nuclear fuel cycle facility community. Therefore, the results of the safety reassessment need to be shared, in particular, those related to generic lessons learned. Some operating organizations have already published the results of the safety reassessment ('stress-tests' or 'complementary safety assessment') of their nuclear fuel cycle facilities — see, for example, Ref. [28]. It is also important to note that it is not expected that facilities would report information that could identify security vulnerabilities or commercial information associated with a facility's specific design.

Operating organizations need to consider the independent review of the safety reassessment through, for example, peer review processes, taking into consideration the relevant national regulatory requirements. Peer reviews can also be conducted as a partnered review with the facility personnel or as an independent review of the process and the effectiveness of the facility review. Peer reviews may also be conducted under the auspices of the IAEA.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Integrated Nuclear Fuel Cycle Information System (2012), https://infcis.iaea.org/

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Fuel Cycle Facilities, IAEA Safety Standards Series No. NS-R-5 (Rev. 1), IAEA, Vienna (2014).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Governmental, Legal and Regulatory Framework for Safety, IAEA Safety Standards Series No. GSR Part 1 (Rev. 1), IAEA, Vienna (2016).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Conversion Facilities and Uranium Enrichment Facilities, IAEA Safety Standards Series No. SSG-5, IAEA, Vienna (2010).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Uranium Fuel Fabrication Facilities, IAEA Safety Standards Series No. SSG-6, IAEA, Vienna (2010).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Uranium and Plutonium Mixed Oxide Fuel Fabrication Facilities, IAEA Safety Standards Series No. SSG-7, IAEA, Vienna (2010).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Safety Glossary, Terminology Used in Nuclear Safety and Radiation Protection, 2007 Edition, IAEA, Vienna (2007).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment for Facilities and Activities, IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), IAEA, Vienna (2016).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste, IAEA Safety Standards Series No. GSG-3, IAEA, Vienna (2013).

[10] ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT, OECD NUCLEAR ENERGY AGENCY, Ageing Management of Nuclear Fuel Cycle Facilities, CSNI Technical Opinion Papers No. 15, OECD Publishing, Paris (2012).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Criticality Safety in the Handling of Fissile Material, IAEA Safety Standards Series No. SSG-27, IAEA, Vienna (2014).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. NS-R-3 (Rev. 1), IAEA, Vienna (2016).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Evaluation of Seismic Safety for Existing Nuclear Installations, IAEA Safety Standards Series No. NS-G-2.13, IAEA, Vienna (2009).

[14] INTERNATIONAL ATOMIC ENERGY AGENCY, Seismic Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSG-9, IAEA, Vienna (2010).

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, WORLD METEOROLOGICAL ORGANIZATION, Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSG-18, IAEA, Vienna (2011).

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Volcanic Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSG-21, IAEA, Vienna (2012).
[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Site Survey and Site Selection for Nuclear Installations, IAEA Safety Standards Series No. SSG-35, IAEA, Vienna (2015).
[18] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5), IAEA Nuclear Security Series No. 13, IAEA, Vienna (2011).
[19] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Security Recommendations on Radioactive Material and Associated Facilities, IAEA Nuclear Security Series No. 14, IAEA, Vienna (2011).
[20] EUROPEAN POLICE OFFICE, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL CIVIL AVIATION ORGANIZATION, INTERNATIONAL CRIMINAL POLICE ORGANIZATION–INTERPOL, UNITED NATIONS INTERREGIONAL CRIME AND JUSTICE RESEARCH INSTITUTE, UNITED NATIONS OFFICE ON DRUGS AND CRIME, WORLD CUSTOMS ORGANIZATION, Nuclear Security Recommendations on Nuclear and Other Radioactive Material out of Regulatory Control, IAEA Nuclear Security Series No. 15, IAEA, Vienna (2011).
[21] INTERNATIONAL ATOMIC ENERGY AGENCY, Security of Radioactive Sources, IAEA Nuclear Security Series No. 11, IAEA, Vienna (2009).
[22] INTERNATIONAL ATOMIC ENERGY AGENCY, Identification of Vital Areas at Nuclear Facilities, IAEA Nuclear Security Series No. 16, IAEA, Vienna (2012).
[23] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL CIVIL AVIATION ORGANIZATION, INTERNATIONAL LABOUR ORGANIZATION, INTERNATIONAL MARITIME ORGANIZATION, INTERPOL, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, PREPARATORY COMMISSION FOR THE COMPREHENSIVE NUCLEAR-TEST-BAN TREATY ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, UNITED NATIONS OFFICE FOR THE COORDINATION OF HUMANITARIAN AFFAIRS, WORLD HEALTH ORGANIZATION, WORLD METEOROLOGICAL ORGANIZATION, Preparedness and Response for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GSR Part 7, IAEA, Vienna (2015).
[24] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR OFFICE, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GSG-2, IAEA, Vienna (2011).
[25] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR OFFICE, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS

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[26] INTERNATIONAL ATOMIC ENERGY AGENCY, The Management System for Facilities and Activities, IAEA Safety Standards Series No. GS-R-3, IAEA, Vienna (2006).

[27] INTERNATIONAL ATOMIC ENERGY AGENCY, Application of the Management System for Facilities and Activities, IAEA Safety Standards Series No. GS-G-3.1, IAEA, Vienna (2006).

[28] OFFICE FOR NUCLEAR REGULATION, “Stress Tests” for UK Non-Power Generating Nuclear Facilities – Final Report, ONR Report ONR-UKST-REP-12-001 Revision 1, ONR, Bootle, UK (2012).

Annex

SELECTED POSTULATED INITIATING EVENTS FOR NUCLEAR FUEL CYCLE FACILITIES

The following list of postulated initiating events are reproduced from Annex I of IAEA Safety Standards Series No. NS-R-5 (Rev. 1), Safety of Nuclear Fuel Cycle Facilities[1].

"EXTERNAL POSTULATED INITIATING EVENTS

"Natural phenomena

"Natural phenomena would include:

(a) Extreme weather conditions: precipitation including rain, hail, snow, ice; frazil ice; wind including tornadoes, hurricanes, cyclones, dust storms, sand storms; lightning; extreme high or low temperatures; extreme humidity.
(b) Flooding.
(c) Earthquakes and eruptions of volcanoes.
(d) Natural fires.
(e) Effects of terrestrial and aquatic flora and fauna (leading to blockages of inlets and outlets, and damage to structures).

"Human induced phenomena

"Human induced phenomena would include:

(a) Fires, explosions, or releases of corrosive or hazardous substances (from surrounding industrial or military installations or transport infrastructures);
(b) Aircraft crashes;
(c) Missile strikes (arising from structural and/or mechanical failure in surrounding installations);

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Fuel Cycle Facilities, IAEA Safety Standards Series No. NS-R-5 (Rev. 1), IAEA, Vienna (2014).

(d) Flooding (e.g. failure of a dam, blockage of a river);
(e) Loss of power supply;
(f) Civil strife (leading to infrastructure failure, strikes and blockades).

"INTERNAL POSTULATED INITIATING EVENTS

"Internal events would include:

(a) Loss of energy and fluids (e.g. loss of electrical power supplies, air and compressed air, vacuum, superheated water and steam, coolant, chemical reagents and ventilation);
(b) Failures in use of electricity or chemicals;
(c) Mechanical failure, including drop loads, rupture (of pressure retaining vessels or pipes), leaks (due to corrosion), plugging;
(d) Failures of, and human errors with, instrumentation and control systems;
(e) Internal fires and explosions (due to gas generation and process hazards);
(f) Flooding (e.g. vessel overflows)."

Uranium fuel fabrication facilities

This is a postulated initiating event, the requirements for which are described in greater detail in NS-R-5, appendix I:

- Fires and explosions.

Mixed oxide fuel fabrication facilities

These are postulated initiating events, the requirements for which are described in greater detail in NS-R-5, appendix II:

- Fires and explosions;
- Leaks and spills;
- Loss of decay heat removal;
- Load drops;
- Mechanical failure.

Conversion facilities and uranium enrichment facilities

This is a postulated initiating event, the requirements for which are described in greater detail in NS-R-5, appendix III:

— Internal:
  - Fires and explosions.

Reprocessing facilities

These are postulated initiating events, the requirements for which are described in greater detail in NS-R-5, appendix IV:

— Internal:
  - Fire and explosion;
  - Equipment failure; leaks;
  - Flooding;
  - Loss of support systems;
  - Load drops;
  - Missiles.

— External:
  - Earthquake;
  - Extreme weather conditions.

Fuel cycle research and development facilities

This is a postulated initiating event, the requirements for which are described in greater detail in NS-R-5, appendix V:

— Internal:
  - Fire and explosion.

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ISBN 978–92–0–101916–5
ISSN 1020–6450