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Optimization of Research Reactor Availability and Reliability: Recommended Practices

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OPTIMIZATION OF RESEARCH REACTOR AVAILABILITY AND RELIABILITY: RECOMMENDED PRACTICES

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OPTIMIZATION OF RESEARCH REACTOR AVAILABILITY AND RELIABILITY: RECOMMENDED PRACTICES

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FOREWORD

For a select (and growing) population of research reactor organizations, an unplanned, forced, or otherwise inadvertent reactor shutdown or power reduction is a significant event — so significant that these organizations are willing to proactively invest resources to reduce these occurrences to a minimum. This report focuses on operation and maintenance programmes and best practices that have led to demonstrated performance improvements. The effort to develop the material relied on inputs from representatives of operating organizations with heavily utilized research reactors involved in activities that are highly sensitive to inadvertent automatic shutdowns, reductions in power, forced outages or unplanned outage extensions. The content of this report reflects efforts to achieve operational excellence.

The relevance and importance of related safety and security programmes were repeatedly emphasized throughout the development of this report. The unanimous agreement from all involved is that fully developed and well implemented safety and security programmes, with all the relevant attributes including a well established safety culture and integral management system, among others, are an absolute prerequisite to optimize availability and reliability. Details about such programmes may be found in specifically referenced documents, as well as general references included in a bibliography. Other than these references, it is not the objective of this report to provide any recommendations, guidelines or practices aimed solely at improving facility safety.

This report was developed over the course of two meetings in September 2006 and April 2007. Participants included operation and maintenance managers representing heavily utilized facilities with demonstrated operation and maintenance performance excellence. In these meetings a general outline was developed and then expanded to cover a range of programmes and activities that the participants identified as significant to availability and reliability.

The IAEA wishes to thank all meeting participants and contributors. Furthermore, the IAEA wishes to express its gratitude to Atomic Energy of Canada Limited for hosting the second meeting on this topic. The IAEA officer responsible for this publication was E. Bradley of the Division of Nuclear Fuel Cycle and Waste Management.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

An unplanned, forced, or otherwise inadvertent reactor shutdown or power reduction is a significant event for a nuclear power plant or research reactor. So significant is such an event that nuclear reactor organizations are willing to proactively invest resources to reduce these occurrences to a minimum. To assist these organizations in this endeavour, the IAEA has initiated activities focusing on the optimization of operation and maintenance programmes and the development of best practices leading to demonstrated performance improvements. These efforts have relied on inputs from operating organizations with heavily utilized research reactors involved in activities that are highly sensitive to inadvertent automatic shutdowns, reductions in power, forced outages or unplanned outage extensions. The main aim of these activities has been to promote operational excellence.

1.2. OBJECTIVE

The objective of this report and related efforts is to identify management system attributes and good practices supporting optimal research reactor availability and reliability. The practices of interest are generally within the direct control of the research reactor operation and maintenance organization. A supporting aim has been to initiate a discussion about availability and reliability issues involving key international stakeholders representing organizations committed to improving research reactor operational performance.

1.3. SCOPE

The scope of this report involves activities and management systems generally within the direct responsibility of the reactor organization. It examines the attributes of different management systems, and related practices and activities that have proven their value through demonstrated performance excellence.

2. CUSTOMER/USER EXPECTATIONS

Although there are different types of research facilities, each typically exists to serve its specific customers and their unique needs. While one facility might be dedicated to producing radioisotopes for medical or industrial applications, other facilities are fully devoted to scientific and technical research, education and training, while others offer multiple services.

A detailed awareness of customer and user expectations can improve availability and reliability by allowing the organization to refine its operational planning to suit the customer or user needs. Such an awareness may also enable a facility to better manage unplanned shutdowns by working with customers to ensure that their interests are served in the midst of unforeseen plant events affecting operation (i.e. reducing unplanned losses that tend to impact reliability).

2.1. IDENTIFICATION OF THE CUSTOMER BASE

A customer base must be established in consideration of the facility's mission — typically reflected in a strategic plan as developed, for example, following the guidance given in Ref. [1]. All customers have needs and requirements which must be taken into account for the operation of the facility. The following need to be considered in identifying customer needs:

- What is the composition of the experiment or what material will be irradiated?
- How can the experiment or irradiation be performed?
- When can the irradiation or experiment be performed?
- Are there special conditions for execution of the irradiation or experiment?
- Is there a follow-up expected in the future?

The information derived from these questions serves as input for facility long term operational and maintenance planning. If needed in case of conflict of interest, prioritization is made on the basis of the facility's mission and on financial constraints in consideration of the strategic plan.

2.2. FACILITY NEEDS

The following are examples of documents typically needed by the facility to process customer requests:

- Customer proposals;
- Preliminary feasibility review of the proposal by the facility;
- Contractual agreement (including legal issues, customs issue, etc.);
- Experiment or irradiation safety case (design and safety report);
- Facility review of the safety case;
- Quality assurance/quality control documents;
- Special handling conditions;
- Special (safety/access) training.

The information supplied and the outcome of the review procedures serve as input for facility short term operational and maintenance planning.

2.3. REACTOR SCHEDULING

On the basis of the information retrieved above, a long term (annual) operation and maintenance plan and short term (cycle) plan can typically be established. The final long term plan can then be submitted to customers and to facility staff as soon as it becomes available. The long term plans of the individual facilities can be used, for example, to optimize the availability of irradiation capacity for medical isotopes. The short term plan should be discussed at an early stage (varying from one week to a month) with the customers before the execution of the irradiation or experiment.

The following points ensure efficient and timely scheduling of customer experiments or irradiation:

- Customer/user needs are taken into account regarding scheduling; date/time of commencement of irradiation, duration, cooling requirements and delivery schedule;
- Logistics regarding supply routes, transport mechanisms, and packaging and handling are elaborated with the consent of customers/users;
- Availability of a backup/alternate reactor (based on existing partnerships or collaborations) is ensured.

2.4. COMMUNICATION WITH THE CUSTOMER

To establish good customer relations it is essential to provide a continuous flow of information. Typical examples of useful information to the customer include:

— Expected irradiation conditions such as temperatures, fluxes, fluences, etc.;
— Actual start and end of cycle;
— Actual start of irradiation or experiment;
— Failure of the irradiation or experiment to meet the required conditions;
— Unforeseen shutdowns with or without immediate restart;
— Restart after shutdown;
— Extensions of the cycle duration.

To establish and maintain continuous improvement of facility operation, customer feedback is essential. Typical examples of useful information to the facility operator include:

— Did the irradiation or experiment meet expectations? Possible items to be addressed include:
  - Measured specific activities;
  - Transport schedules;
  - On-time deliveries;
  - Scientific purpose;
  - Instrument performance;
  - Staff assistance.
— Was the experiment or irradiation performed in an efficient and timely manner?
— Did the provided training fulfil its need?
— Were the customer–facility interface requirements, including administrative forms, contacts, communication, etc., clear and concise?
— Have papers or reports been written using relevant test results?
— Were potential abilities of the reactor to meet specific, future needs identified?

3. FUEL CYCLE AND CORE MANAGEMENT

In the case of fuel cycle and core management, three areas should be considered:

- Front end;
- Utilization;
- Back end.

The need for sufficient inventories of fresh fuel (i.e. fuel elements and control assemblies) to ensure continuous reactor operation (or operation as required for reactors with lower utilization factors) is essential for the availability and reliability of a facility. In particular, the reliability of supply, if externally sourced, and the need for alternative or backup supply from qualified fuel manufacturers must be addressed within the context of current and long term strategic plans.

The financial efficiency gains from stable contractual agreements supporting all aspects of the fuel cycle within the facility should be taken into consideration by the operating organization.

The operating organization's ability to handle assemblies as applicable at the end of fuel element and control rod life is important. In particular, the interim storage capacity of the facility's spent fuel pool; the options for the transfer of the fuel to a local storage facility (e.g. underground dry storage) and the options for final disposal or fuel take-back programmes should be considered. Additional information can be found in Ref. [4].

3.1. FRONT END

By considering and adequately addressing the items given below the operating organization reduces the risk of receiving fuel that fails to satisfy the design specifications and/or delays in fuel delivery. Considerations to be taken into account for the front end provisions include:

Administrative agreements. Prior to ordering, the operating organization must determine the technical aspects of the fuel elements, such as:

- Fuel type;
- Cladding design/materials;
- Operating design limits;
- Burnable poison (if required);
- Enrichment requirement;
- Technical requirements (specifications, drawings, etc.);
- Manufacturing qualification;
- Consideration of alternative suppliers.

The technical aspects listed below are incorporated into the subsequent contractual agreements:

- Quantities;
- Schedules;
- Liability (e.g. guaranteed burnup limits);
- Insurances;
- Acceptance inspection.

Delivery/storage. The following technical aspects will increase the probability of successful fuel delivery and storage prior to utilization:

- Safeguards;
- Export/import licenses;
- Container licensing;
- Transport requirements (routes, border restrictions);
- Receipt inspection;
- Storage (safe and secured).

3.2. UTILIZATION

By considering and adequately addressing the items given below the operating organization improves availability and reliability and reduces operational (and back end) waste. Considerations to be taken into account for the utilization of the fuel elements and other core components provisions are:

Planning aspects. The planning aspects listed below should improve customer satisfaction regarding availability and reliability:

- Customer requirements (commercial, technical, scientific);
- Annual operating programme;
- Core configuration.

Operational aspects. By addressing the items listed below the acceptable operation of the research reactor can be verified through trend analysis and comparisons against predicted values:

- Critical control rod settings;
- Power distribution measurements;

- Reactivity requirements;
- Flux profiles;
- Burnup limits;
- Backup core policy.

Fuel integrity control. The risk of fuel failure and subsequent unscheduled shutdowns can be reduced through proper fuel integrity control. It includes, but is not limited to, the following items:

- Careful handling;
- Visual inspection;
- Fission product monitoring;
- Coolant gap measurements;
- Sipping of suspected elements.

Records and administrative controls. The following records and administrative controls will ensure that the proper records are kept as required for inventory, storage and disposal:

- Burnup inventory;
- Fuel element history;
- Inventory (fission products, U, Pu, burnable poison, nuclides);
- Reactivity monitoring;
- Safeguards;
- Core management systems.

These can vary from simplistic (spread sheet type) calculations regarding fuel locations in the core to complex multimode and dimensional core physics calculations to determine optimal fuel and flux efficiencies and core loading patterns.

3.3. BACK END

In some Member States research reactors are not permitted to operate without a proper back end solution. Furthermore, thorough consideration of the back end strengthens reliability and availability and reduces the risk of undue operational constraints, particularly in the longer term. Considerations to be taken into account for back end provisions include:

- Safeguards;
- Physical protection;
- Back end policy;
- Contracts (transport and disposal);
- Storage (intermediate and long term);
- Integrity monitoring;
- Inventory (fission products, U, Pu, burnable poison, nuclides);
- Transport (on-site and off-site).

3.4. NON-URANIUM BEARING STRATEGIC MATERIALS

The importance of ensuring the availability of other strategic materials required for facility operation through systematic supply chain planning should be taken into consideration as stated above for fuels. In particular, those components regarded as critical for ongoing operation or the supply of products or services should be accounted for, for example, fissile target plates for ^{99}Mo production, in-core components such as beryllium reflectors, and aluminium and lead filler elements.

4. MAINTENANCE

Maintaining a high level of availability and reliability depends greatly on an adequately funded, risk informed, plant maintenance programme (also called an operational maintenance plan) that is recognized as a priority by plant management. Both the availability and reliability of a facility are usually directly related to the quality of the maintenance programme. An effective preventive/predictive maintenance programme minimizes the occurrence of corrective and breakdown maintenance. Typically, maintenance programmes are integrated with overarching plant life management assessments and programmes. An effective work control programme provides the way to manage all maintenance activities while satisfying related configuration management and configuration control requirements [5].

The following sections describe areas that have a strong influence on facility availability and reliability. Annex I includes examples of in-service inspections and a typical maintenance schedule for a low power research reactor as an additional, more specific, reference to some of the items that follow.

4.1. PREVENTIVE/PREDICTIVE MAINTENANCE

Reactor equipment from system to component levels should be included in this programme in proportion to the extent that failures would have an effect on reactor availability and reliability. Additionally, the requirements for preventive/predictive maintenance of experimental devices should be considered if experiment failure would directly reduce reactor availability and reliability. Such a risk informed approach allows the prioritization of maintenance tasks as well as the efficient allocation of resources.

Preventive and predictive maintenance have been combined here as they are both proactive approaches that aim to avoid structure, system or component (SSC) failures and/or at least mitigate the effects of such failures. Preventive and predictive tasks can normally be scheduled well in advance. This scheduling can provide the opportunity to acquire the correct personnel, tools, specialized equipment, procedures, work permits and facilities to complete the work. This may be of particular interest if a portion of the work has to be completed away from the facility.

4.2. INSPECTION, TEST AND SURVEILLANCE

As part of any preventive or predictive maintenance activities, as well as some corrective maintenance programmes, SSC inspection, testing and surveillance provide information about equipment performance as well as valuable feedback regarding maintenance programme effectiveness.

Periodic inspection of reactor equipment and instrumentation is necessary to provide specific qualitative performance data to identify the need for, and extent of, maintenance. It is important to develop and implement risk informed inspection, testing and surveillance schedules.

Scheduled tests and surveillances on reactor equipment and instrumentation provide measured acceptance criteria on performance and opportunities for operability assessments. The outcome of such tests is usually fail or pass. Related data can be trended for input into a predictive or preventive maintenance programme.

4.3. CORRECTIVE MAINTENANCE

Corrective maintenance involves the restoration of SSC operation following a failure or when performance deviates beyond an established limit. Certain SSCs may be placed in a corrective maintenance programme if their overall risk to availability and reliability is low. Such a deliberate approach is also known as 'run-to-failure'. Typically, facility operation can easily withstand the failure of SSCs placed into corrective maintenance programmes due to equipment redundancy, low operational relevance, simple restoration, etc. Inclusion into a corrective maintenance programme should follow some type of maintenance assessment.

The occurrence of corrective maintenance activities cannot, in general, be accurately predicted. However, such work can be optimized if replacement components necessary for the corrective task are readily available. This is particularly true for priority equipment with long delivery lead times. Additionally, qualified personnel must be available for the corrective task to ensure that the work is implemented in accordance with any related assumptions or expectations. Personnel training is an integral part of any maintenance programme, but has particular relevance to corrective maintenance work because task duration often has a one-to-one impact on the relevant schedule. Similarly, all tools and special equipment for the corrective task must also be readily available. Some corrective tasks may require use of a workshop to fabricate specialty parts. The operation and maintenance organization should also provide suitable workshop facilities, with sufficient space and equipment to support maintenance activities.

4.3.1. Breakdown maintenance

This unexpected category of corrective maintenance usually involves the correction of one or more failed SSCs that abruptly interrupt continued reactor operation. Breakdown maintenance is not regularly scheduled maintenance and, therefore, conditions to facilitate repair may not readily be available. Many other factors may dictate timely recovery, such as radiation dose rates, lack of replacement components, lack of tooling or specialized equipment, or the lack of qualified personnel. As with corrective maintenance, the availability of qualified and experienced staff can help mitigate the impact of breakdown maintenance.

Since it is by definition significant and unplanned, proactive efforts to minimize the occurrence of breakdown maintenance will have a direct and positive impact on availability and reliability. The risks of significant availability and reliability losses due to breakdown maintenance work may be reduced by implementing the results of maintenance assessment as described below.

4.4. MAINTENANCE ASSESSMENT

A risk informed maintenance assessment collects information on facility SSCs including:

- Original equipment manufacturer (OEM) design specifications and maintenance recommendations;
- Supplier data (such as number of qualified suppliers, equipment obsolescence, etc.);
- Component delivery lead time;
- Results from inspections, tests and surveillance;
- Maintenance histories.

An integrated, risk informed, review allows facility management to determine:

- Inclusion in a preventive, predictive or corrective maintenance programme;
- Repair or replacement decisions;
- Maintenance schedules;
- Inspection, test and surveillance schedules and required data review;
- Required inventories of critical spares;
- SSC and plant outage schedules;
- Required plant modifications (e.g. addition of redundant SSCs);
- Relevant resource requirements (e.g. specialized equipment or manpower requirements).

Information is continuously updated through the ongoing maintenance programme. Subsequent reviews lead to periodic adjustments to accommodate ongoing changes to programme implementation necessitated through plant modifications, vendor/supplier changes, equipment obsolescence, unexpected SSC performance (better or worse than expected), and fluctuations in available resources.

4.5. PLANT LIFE MANAGEMENT ASSESSMENT

With respect to long term availability and reliability, an assessment should be made of which SSCs may affect the life of the reactor in consideration of both physical and non-physical challenges. Physical challenges could include radiation, temperature, pressure, vibration, mechanical and thermal cycling, corrosion and chemical reactions. Non-physical challenges could include changes in technology, obsolescence (ageing), changes in safety requirements and regulatory changes. Plant life assessments can be quite similar to maintenance assessments but focus on a much longer operational timeframe [6].

Noteworthy considerations include:

— Identification of life critical SSC referencing, for example, the safety analysis report, operational records, maintenance histories, and available inspection, testing and surveillance data.
— Evaluation of life critical SSCs for the ageing related challenges mentioned above.
— Periodic inspection, testing and surveillance programmes to continuously check and predict the condition of life critical elements.
— For components or equipment that may become obsolete, a sufficient store of spare parts, or plans in place to otherwise address the issue. In addition, a refurbishment programme should be considered and the maintenance programme referenced.
— Availability of a multi-year life management programme.
— Assistance of external stakeholders to the operating organization to obtain resources for life management.

4.6. WORK CONTROL PROGRAMME

The day to day implementation and management of a maintenance programme is addressed through a work control programme, which manages the scope identification, planning and scheduling process. Programmes are established to address all maintenance aspects as required, from predictive and preventive to breakdown related tasks, including major upgrade and refurbishment project support and routine maintenance of non-reactor related equipment and building utilities. A work control programme should contain clearly identified system boundaries and organizational responsibilities.

Planning should screen the identified deficiencies to assign priorities and determine the required plant condition for maintenance. The results are then manifested in the resulting maintenance schedule. Work control also ensures that other requirements necessary for performing the work are completed, such as SSC isolations, issuance of radiation work permits, pre-maintenance briefings, etc.

Reactor operations should approve the maintenance schedule to ensure that proper configuration control can be maintained. Prerequisites for starting work include the authorization from the operating organization immediately prior to commencement of work and — depending on complexity — periodically throughout the job. Radiological considerations and work permits should be independently handled from the maintenance or operations group to ensure an unprejudiced approach to personnel exposure as low as reasonably achievable (ALARA).

It is necessary for the work control process to include restoration and post-maintenance testing. Completed work must be properly communicated and documented to maintain acceptable plant configuration and to ensure that maintenance histories are preserved and spare parts inventories replenished.

4.7. MAINTENANCE OF CRITICAL EXTERNAL SERVICES

The operation of any nuclear facility may be dependent on support from outside resources to supply utilities or services to sustain continued operation. These support organizations may not be under the direct control of the facility. Continuity of operation of the support services could have a significant impact on reactor availability and reliability. Utilities critical to the successful operation of the reactor, such as power, air and water (cooling and demineralized), must be available. Unplanned outages, or lack in supply quality, of one or more of these could directly and immediately affect reactor availability and reliability. Developing and maintaining good communications and planning with those responsible for the supply and maintenance of utilities must be coordinated to ensure maximum reactor performance.

Facilities involved in waste management, fuel supply, and fuel disposal also support reactor operations. Although outages in these facilities can be tolerated for short periods, prolonged unavailability could necessitate a facility shutdown. Mitigating actions and plans should be developed and implemented consistent with the level of organizational risk.

5. DESIGN CONSIDERATIONS

5.1. INTRODUCTION

It is assumed that the considerations of reactor safety, regulatory and local approvals are reviewed and approved in a parallel, formal process. Each design phase during the experiment or SSC design should include due consideration of the eventual reliability of the final design or the effect on research reactor availability and reliability. Further information on this topic may be found in Ref. [7].

Some items and issues to consider for larger design processes include:

— Adequate project management supported by a site project management infrastructure;
— An experienced and diverse group of reviewers involved in each phase of the design review (e.g. proposal, scoping, initial design) to evaluate availability and reliability;
— Minimization of staff turnover within a project.

5.2. REVIEW OF THE DESIGN FOR IMPACT ON REACTOR AVAILABILITY

All aspects of the design and phases of the project should be reviewed for their impact on availability to minimize reactor downtime during:

— Installation (optimization of the design and installation planning to minimize or eliminate required outage time);
— Commissioning optimization (including the use of ‘cold’, prototype and ‘hot’ testing as much as possible to minimize any negative impact on reactor operation);
— Operation (identification of operational constraints such as a specific reactor mode required for system startup, shutdown or manipulation);
— Maintenance (optimization of the design to accommodate maintenance with the reactor/other systems in operation).

5.3. REVIEW OF THE DESIGN FOR IMPACT ON REACTOR RELIABILITY

All aspects of the design and phases of the project require review for their impact on reliability to minimize reactor downtime. The available knowledge base needs to be reviewed to ensure the proper selection of components and an overall design that will ensure SSC reliability throughout the anticipated design lifetime. Some specific considerations include:

— Lessons learned (internal and external to the organization — use information from peer organizations);
— Reliability of subcomponents and failure modes;
— Impact of the design on interfacing support systems or external services (e.g. electrical, steam, chilled water, compressed air systems);

— Operational flexibility requirements (can the design accommodate the full range of operational requirements of the reactor including all modes of operation, the full range of expected temperatures, pressures, etc., from the relevant design basis?).

5.4. REVIEW OF THE DESIGN FOR MAINTAINABILITY

The long term impact of the installed, operating SSCs and, in particular, the requirements for all types of maintenance (predictive, preventive, corrective and breakdown activities) need to be considered. Some issues include:

— Spare parts availability (multiple suppliers);
— Sufficiently trained technicians to maintain systems;
— Correct and available tools to perform maintenance;
— Physical accessibility to equipment for maintenance — ALARA — without affecting availability and reliability;
— Redundancy, to allow SSC shutdown for maintenance with minimal or no effect on reactor availability and reliability.

5.5. REVIEW FOR SITE INTEGRATION

Operating organizations must plan for the new or modified SSC to be fully and smoothly integrated into the existing facility infrastructure and practices. Some considerations include:

— Consistency of design (e.g. indicators, operating philosophy, component labelling);
— Development of procedures;
— Incorporation of OEM/vendor manuals into the site configuration management system;
— Training requirements (to operate and/or maintain new SSCs).

As facilities gain experience, the incorporation of lessons learned will allow individual organizations to greatly expand on the above information. Organizations typically produce and implement customized design review programmes that work to optimize project implementation in general, but in particular minimize the impact of both major and minor endeavours on facility availability and reliability. Experienced organizations tend to fully integrate the reviews for availability, reliability, maintainability and site integration with those for safety/regulatory approval. Many of the benefits are mutually beneficial. For example, optimized planning to reduce SSC installation or maintenance time almost always results in lower personnel dose rates and the generation of lower volumes of waste.

6. CONFIGURATION MANAGEMENT

6.1. INTRODUCTION

Accurate plant status information and better control of plant changes lead to fewer errors and enhanced availability and reliability. Configuration management encompasses the processes addressing these issues, which include the following:

— Facility documentation (drawings, schematics, flow diagrams, operating procedures, etc.) is maintained in a state that reflects the 'as is' equipment configuration. Thus, changes to the plant are documented by updating the drawings, procedures, manuals, etc., to reflect what is installed in the field.
— Equipment changes and modifications are controlled (see change control process below) to ensure that equipment replacements are equivalent or better and they do not negatively affect the safety and reliability of the related system or overall facility operation.
— Plant equipment operational status is recorded and displayed, and plant configuration is controlled such that equipment outages due to maintenance and/or operational issues combined with unplanned equipment failure, do not result in an unanticipated upset or a plant configuration involving unacceptable risk.

6.2. DOCUMENTATION CONTROL PROGRAMME

It is important that all relevant documentation be updated to reflect the new plant status whenever a facility change occurs. In the case of hardware changes, drawings, flowsheets, etc., are the governing documents. When process changes are made, procedures, records, training material, etc., are the controlling documents. By maintaining up to date documentation, the potential for error in operating and design configuration is reduced. This can be accomplished by:

— Establishment of a set of baseline documents that are up to date and (following a risk informed analysis) deemed to be required to be maintained up to date for plant configuration control. Any documents that have to be revised to reflect the 'as is' status require attention and priority.
— Implementation of a control and distribution process to ensure that personnel have ready access to the latest revisions of essential documents (flowsheets, schematics, procedures, technical specifications, software and PLC control, instructions, etc.).

The document control programme (DCP) has two aspects:

— Control the generation of, and revisions to, procedures and policies;
— Control the storage of, and access to, records of work performed, design, training, regulatory related correspondence, etc.

The DCP works to ensure that current, approved management expectations are clearly and effectively communicated to staff.

Attributes of a DCP include provisions and processes to:

— Request changes to procedures, policy, plant documents, etc.;
— Review and approve the draft document;
— Ensure all necessary personnel are notified of the change and copy distributions are completed as required (dedicated registry and field copies are replaced with the new revisions to ensure up to date status control).

The control of key operating documents may include an automatic process of periodic review, approval and reissue. System/procedure 'ownership' concepts may improve the DCP efficiency as well as procedure quality and consistency. The section on management enhancement in this report contains more information on DCPs.

6.3. EQUIPMENT (SSC) CHANGE CONTROL

This is the process by which equipment (SSC) changes/modifications are introduced and reviewed for plant systems. A change is categorized based on its potential impact on facility risk. The categorization identifies the degree of independent review and approval required before the change can be initiated.

An equipment change can be as simple as the replacement of a component with an equivalent (but different) piece of equipment or as complex as the implementation of a major modification. A facility representative (a person or group) responsible for the change control process normally evaluates the proposed change and recommends the initial classification as a minor change or a change that must proceed through further review. Minor changes, when properly approved, may proceed immediately, together with the follow-up action including the appropriate and timely update of documents, procedures, training, etc. Various levels of change categorization could include:

— A proposed change which results in hazards different in nature, more severe consequences or increases the likelihood of accident/event occurrence beyond those previously assessed in the license documents; or which alters the design bases of SSCs credited in the safety analyses documents (level 1).
— A proposed change with significant facility impact to a system or component considered of prime importance to availability and reliability but which does not meet the level 1 criteria. These systems include non-reactor process control systems, alarm systems, radiation monitoring, ventilation systems, essential utilities and services, fuel handling systems, etc. (level 2).
— A proposed change that could not lead to a significant increase in the risk to facility safety or availability and reliability (level 3).
— A proposed change with little or no significance (level 4).

More complex changes are subject to a more rigorous review (possibly including the regulator), which typically consists of personnel with a background in one or more of the operations, maintenance, licensing, safety and engineering fields. Typically, level 1 and 2 changes would require an independent analysis to be completed prior to the change being implemented.

The above description is consistent with processes utilized in many research reactors to screen and review proposed changes for facility and off-site safety significance. This practice broadens this approach to include the consideration of potentially significant operation and maintenance impact as well as a component of overall facility risk (see the section on considerations for modifications and/or new plant design for further information). The change control process can also be used as a pre-approval process for a design or concept study.

6.4. TEMPORARY PLANT CONFIGURATION CHANGES

Maintenance outages, special operating configurations, etc., can result in abnormal plant configurations differing from the initial design basis. In some instances maintenance outages for two or more components in separate portions of a facility could put the plant at risk of reduced reliability and possibly reduced safety margins. Maintaining the plant within an acceptable configuration is desirable to ensure acceptable system availability (that meets or exceeds regulatory and customer requirements):

— A single point of contact (i.e. shift supervisor, manager and/or supervisor) is responsible to coordinate, approve and review planned work to ensure that equipment outages do not negatively impact plant safety, availability or reliability. This specific contact point, as well as the relevant responsibilities, may be dictated by operating procedures (operating limits and conditions (OLCs)/limiting conditions of operation (LCOs)) or other licensing documents.
— Prior to the actual maintenance outage, maintenance planning and operations staff are also charged with ensuring that acceptable configuration control is not challenged.
— Abnormal configurations are logged and reviewed at appropriate staff meetings (turnover, daily meetings, etc.). Field inspections provide an independent review of plant status.
— Controls are needed to ensure that equipment has been returned to service as required.

The implementation of the above is best facilitated by the development of overarching policies and procedures. These can be further supported through appropriate training and reinforced within the organizational management culture.

Configuration control also relies on properly implemented, effective processes and procedures to minimize the likelihood of errors, such as manipulating the wrong equipment, that negatively impact facility availability and reliability. Verification, self-checking, pre-job brief, procedural use and adherence, and three way communications are all effective error reduction tools to prevent undesired equipment outages (see the management enhancement section of this report for further information).

7. REGULATORY INTERFACE

7.1. INTRODUCTION

Facility availability and reliability can be affected if regulatory requirements are not satisfied. It is not within the scope of this report to address specific types of regulatory requirements in detail, but some common examples include legal criteria, mandatory code compliance, facility commitments, detailed procedure and process compliance, SSC operability consistent with an approved design basis and/or safety analysis report (SAR), and minimum qualified staffing levels.

Effectively managing the relationship with relevant regulatory bodies minimizes the risk of regulatory actions that may adversely affect availability and reliability. Ensuring effective communication at a variety of organizational levels helps to ensure that requirements are clearly understood and that the regulator is aware of facility status, operating events and the completion of any required actions or commitments. Implementation of a regulatory tracking database could be beneficial to organizations with more complicated facilities and/or regulatory requirements. Nurturing a positive and constructive regulatory communications philosophy throughout the organization can help to optimize the relationship between the facility and regulator.

7.2. COMMUNICATION LEVELS

Effective communication with the regulatory body is essential for optimal operation of the facility. An informal and more personal communication system needs to be established in addition to the official reporting system. Informal communication, if possible, may result in faster feedback, improved mutual understanding, trust and transparency.

Within a typical regulatory body, inspectors are used to inspect the facility. Subject matter experts working for the regulator review submitted technical documents. Verification of implementation and compliance with license requirements is completed by both inspectors and experts of the regulatory body.

Communication between the operating organization and the regulatory body can exist at different levels:

— Regulatory body director/operating organization — senior management;
— Inspectorate/operating organization;
— Expert level/operating organization — technical counterpart, etc.

7.2.1. Regulatory body director/operating organization — senior management level

Communication between the director of the regulatory body and the head of the operating organization can involve strategic, policy and political issues. Openness on the side of the operating organization will improve the relationship and build trust through mutual understanding and communication. The frequency of communication is dependent on the number and type of issues. To keep the quality of communication at a high level it is recommended to have periodically scheduled meetings.

7.2.2. Inspectorate/operating organization

Communication between the regulatory body inspectors and the operating organization occurs on a more frequent basis. Inspections can be announced or unannounced. However, unannounced inspections tend to negatively influence the relationship between the regulatory body and the operating organization in some cases. To prevent this, clear agreements can be made in advance to align mutual expectations. Also, instructions to the relevant employees of the operating organization regarding the function of the regulatory body can enhance the understanding and thus improve communication. The frequency of the inspections may vary and is dependent on the type of regulator, facility complexity and performance. The frequency and type of inspection may also be influenced by perceived transparency and the level of trust established at the different levels of both organizations.

7.2.3. Expert level/operating organization — technical counterpart

Communication between experts of the regulatory body and technical counterparts within the operating organization is primarily about technical documents (e.g. modification proposals, utilization and irradiation reports, OLCs, incident reporting, etc.). To enhance the process of review and assessment, clear agreements between the experts and their counterparts can be made before the process starts (organization of a kick-off meeting). Such agreements may include the definition or clarification of submittal contents, format, schedule and any relevant constraints such as standards, regulations or guidelines. After the process has started, conducting meetings at this level can be a means to enhance communication. The amount and frequency depend on the number and complexity of technical submissions presented to the regulator as well as the duration of the activity or project.

7.2.4. Communication principals

The regulatory body is responsible for independent oversight to ensure that facilities meet their responsibilities to the public. Fostering the following attributes of an overall positive and constructive communication philosophy may improve communication, understanding, trust and organizational efficiency. Some specific examples are added for clarity. Note that the list below reflects attributes and examples beyond any communication required by relevant regulations such as mandatory submittals, reportable events, etc.:

- Openness (keeping everyone informed):
  - announce significant, planned operation and maintenance evolutions (particularly if infrequent);
  - provide regular reports of facility status (even if ‘nothing to report’);
- Transparency (show what you do):
  - be invited to observe periodic planning meetings, including emergency drills;
  - be informed of non-reportable ‘near-miss’ events (courtesy calls);
- Professionalism (establishing and satisfying clear expectations):
  - keep appointments;
  - meet deadlines;
  - satisfy commitments;
  - close actions;
  - complete follow-ups;
- Proactive attitude:
  - be invited to major activity/project kick-off meetings;
  - provide frequent updates during change process;
  - take the initiative prior to being asked.

7.3. ACTION/COMMITMENT TRACKING PROGRAMME

A tracking programme can be used to monitor actions and commitments agreed upon between the regulator and operating organization. The following examples typically fall within the scope of such programmes:

- List of open/closed actions from inspections and expert level meetings. Within this list, the following aspects can be described:
  - corrective/preventive actions taken;
  - comments from employees;
  - feedback from the regulator;
- List of agreements and commitments between the regulator and operating organization;
- License requirements that need special attention, including monitoring of follow-up tasks.

Furthermore, if relevant, a trend analysis tool can be used in the programme to monitor the follow-up of the different actions and commitments. Thorough management and tracking of regulatory actions and commitments can minimize related adverse availability and reliability impacts.

8. HUMAN RESOURCE MANAGEMENT

8.1. INTRODUCTION

Thorough staff planning and implementation of those plans can manifest itself in improved performance through reduced occurrences of human error (typically due to fatigue, poor training, improper planning, etc.), decreased backlogs (maintenance tasks, testing, or surveillance tasks) and improved communication. For additional information, see Ref. [6] and also section 7 of Ref. [5].

8.2. PLANNING

Staff planning should ideally be part of the facility strategic plan as developed under the guidance in Ref. [1]. Forward-looking programmes typically include a five year staffing plan that accounts for unexpected attrition, retirement, professional advancement and ample coverage for training, sick/vacation leave or the performance of highly specialized evolutions. The hiring plan may need to account for budgetary changes or changes in reactor utilization (for example, changing from one to multiple shifts to accommodate increased isotope production).

8.3. HIRING

The facility needs to develop clear positional descriptions and necessary knowledge and skills requirements for each position to be filled. The interview process should evaluate the potential employee's current technical competence but, more importantly, their technical potential for the position interviewed. The individual to be hired should clearly understand what is expected in terms of licensing or certification in a reasonable period of time and the potential for professional development in the organization. Once hired, it is necessary to place the individual immediately into a defined, facility directed training programme that will evaluate, during a probationary period, if the individual will succeed as an operator. This hiring and training process is also applicable to non-reactor operator appointees such as instrument technicians or system engineers.

8.4. CONTINUING TRAINING AND QUALIFICATION

A continuing training programme should be in place for operating and support personnel. It should include integrated system knowledge and application of theoretical concepts to practical operating evolutions as well as relevant operating experience events from both within and outside the organization. Effectiveness of training needs to be measured on a routine basis through examinations and performance of practical evolutions. Operator's qualification progress should be closely monitored. Appropriate mentorship and performance-based consequence programmes should be implemented to maintain a high degree of competence. For additional information, refer to the human resources section in Ref. [7] as well as IAEA guidance on a Systematic Approach to Training (SAT). Information on SAT is described in Refs [8–10].

8.5. KNOWLEDGE MANAGEMENT AND SUCCESSION PLANNING

A formal programme should be in place to retain knowledge and skills within the organization as personnel advance to more senior positions out of the operation and maintenance organization or for planned personnel retirement. This programme may include a mentoring programme, cross-training, or a more detailed documentation system for infrequent facility evolutions.

8.6. OUTSOURCING

In some cases it may be necessary to hire consultants or contractors to perform tasks that could potentially be performed by available staff resources. These tasks may be so specific or short term that it would not be cost effective to train a full time staff member to routinely perform this task or when time constraints require an increase in the available resources to complete a project in a timely fashion.

The advantages of outsourcing include the ability to rapidly address changing resource demands as well as acquiring very specific skills and experience. Disadvantages include the loss of knowledge and experience as short term contracts are allowed to expire. There is no optimum level of outsourcing to maximize facility availability and reliability. Each organization must find its own balance depending on its specific needs and available resources (both internal and external).

8.7. MANAGEMENT SUPPORT

Organizational management support is the key to a successful staffing plan. Communicating resource needs to upper management will facilitate the addition of new appointees as part of the budgeting and strategic planning process. Management commitment is necessary to support and fund the staffing required to address facility priorities, optimize availability and reliability, and fulfil the needs of the reactor customers. Support for career and succession planning is required to sustain the work force and effectively compete to retain technical talent.

9. MANAGEMENT INITIATED IMPROVEMENTS

9.1. INTRODUCTION

A variety of management initiated improvement programmes can be used to achieve, maintain and enhance the availability and reliability of research reactors. The programmes should facilitate efficient, high quality performance and teamwork among research reactor staff to achieve and maintain the desired performance goals. The details of any specific programme, action, policy or expectation needs to be reflected in the facility integrated management system.

9.2. CORRECTIVE ACTION PROGRAMMES (ALSO CALLED CONTINUOUS IMPROVEMENT OR OPERATING EXPERIENCE (OPEX) PROGRAMMES)

The corrective action programme (CAP) encourages all staff members to report failures, errors, potential problems, near misses or even procedural and facility issues. The CAP is set up to classify reported items by their magnitude of significance with respect to facility risk. The aim of the programme is to ensure timely review by competent senior staff for the assignment of priority and allocation of resources for correction. The review should include consideration of safety, licensing, operability, quality and organizational efficiency, as well as the possible need for immediate mitigating action. The CAP is critical for equipment, systems, procedures, staff, etc., to work as intended for optimum and continually improving overall performance of the facility. Management frequently reviews entries in the CAP system to ensure that task planning, work process assignment and resource allocations are efficient and effective. Progress on corrective action implementation, related planning, etc., should be regularly updated to provide all staff members access to current issue status.

9.3. DOCUMENT CONTROL PROGRAMMES

Related to the configuration management discussion above, a system must be established to ensure the facility's ability to generate documents that are uniquely identified, classified, revised, filed and retrievable. In order to achieve these goals, a document control programme (DCP) should be fully integrated into the facility management system and include the following:

— A scheme to uniquely identify a document (i.e. an alpha numeric system, bar codes, etc.).
— Documents classified by type (i.e. policy statements, technical, engineering, drawings, operating procedures, health physics procedures, official correspondence, etc.).
— A facility policy on format and style for documents (internal/external memos, technical documents, engineering documents and drawings, etc.).
— A document storage and filing schedule or plan (short, interim and long term).
— A standardized document storage method (i.e. paper copy, computer disk, hard drive, etc.).
— A policy to access documents for purposes of revision must be controlled and restricted.
— A procedure to make revised documents available to facility users with a clearly designated revision marking. This will ensure the use of the latest copy of the document.

By addressing the above items the facility can efficiently and effectively control its documents. Proper document control improves reactor performance by minimizing the risk of plant power interruptions that can occur through the use of incorrect revisions, inaccurate, or improperly reviewed documents (see the section on configuration management in this report for further information) [7].

9.4. EQUIPMENT CONFIGURATION CONTROL (ALSO CALLED PHYSICAL PLANT STATUS OR ALIGNMENT CONTROL)

Management must ensure that procedures and processes clearly address configuration control. This involves the operations staff being in control of the physical status of SSCs important to plant availability and reliability (alignment of pumps, valves, electrical switchgear, control logic, etc.). Operations staff must approve, or alternatively formally accept, any significant changes to these systems. They must verify that the requested change does not threaten operation within the context of overall facility configuration at the time, and does not result in the violation of regulations or administrative controls of the facility. This applies equally to all reactor operating modes.

The control room staff must maintain the current plant configuration, including operating SSCs, valve line-up status and temporary modifications (including electrical bypasses or ‘jumpers’) as required to support reactor operation or to satisfy other operability requirements depending on plant operating mode. The current plant configuration should be clearly addressed as part of the shift turnover. Facilities may consider formalizing and/or documenting shift turnovers. The management process for handling maintenance and upgrades has to clearly address the plant conditions required to be able to perform the designated scope of work. It must also include updating drawings and procedures for any changes to the facility configuration.

Good configuration control practices and/or a formal configuration control programme contribute to high availability and reliability by reducing unplanned operating events and helping to ensure all systems perform as expected (see the discussion on work control in the maintenance section of this report for further information).

9.5. COMMUNICATION IMPROVEMENT PROGRAMMES

The communication improvement programme is set up to optimize the flow of information between all individuals in the organization. Since being informed is one of the pillars of any improvement initiative, optimized communication should have broad benefits across the organization.

Communication improvement programmes typically include strategies to enhance:

— Organizational top–down information stream;
— Organizational bottom–up information stream;
— Cross-organizational (interdepartment, shift–shift, etc.) information stream;
— Formal communication in the control room, during critical evolutions or while responding to site events such as emergency plan activation or drills (three way communication);
— Shift turnovers;
— Pre-job briefings;
— Information stream to visiting scientists/temporary employees;
— Meeting effectiveness;
— Personal communication between supervisor and personnel;
— Communication between facility and off-site agencies or organizations if relevant (e.g. emergency preparedness).

More complex organizations may consider more formal communications plans, where, for example, a list of factual discussion points may be generated for an event of interest. The directors may meet and be briefed on the event — referencing the discussion points. After this meeting, each director would then hold a similar meeting with their respective managers and again reference and distribute the discussion points. Finally, each manager would then conduct a similar meeting with their staff using the same discussion points. Such an approach can work to quickly relay information to all staff and reduce the spread of incorrect information.

9.6. OPERATION AND MAINTENANCE PHILOSOPHY

The philosophy of research reactor operation and maintenance should take on a conservative approach. Conservatism could not only be encouraged during actual work processes, but also during planning, procurement, staff training, and resource allocation. Internal and external checking and reviews are recommended. Emphasis should also be on procedural development as well as the use of, and adherence to, approved procedures within a facility integrated management system. A proper philosophy, facilitating an overarching culture of excellence, helps ensure optimum operation by providing an additional barrier to human error.

9.6.1. Conservative decision making

Facility decisions should be made with a conservative approach to the management of research reactor operation and maintenance. This applies to staffing, training, planning and scheduling (e.g. projections of equipment failures, spares inventories and workload assignments during an outage).

Staff members can also be encouraged to adopt a conservative attitude towards their work. The attributes of such an attitude include:

- Avoiding the taking of risks — if uncertain, place the SSC in a safe configuration and contact the responsible person (management);
- Using verified versions of procedures;
- Adopting a questioning attitude, 'when in doubt, ask.';
- Encouraging the questioning and challenging the decisions of peers and superiors when in doubt;
- Seek and provide peer checks and verifications.

9.6.2. Internal and external assessments

Management must encourage periodic internal and external peer assessments of operation and maintenance programmes. External assessments should be as independent as possible, and may include reviews of management performance and organizational structures. All assessments must be followed up with reports for documentation and for staff information. Recommendations and open items should be followed up in a timely manner. In more complex organizations, a formal programme may be used to track the status of reviews and open items.

Individual staff members should also be encouraged to perform assessments of their peers or other parts of the organization. Formal verification programmes may exist where complex tasks are performed, for example, by two operators, where one performs the action while the second ensures that the procedural steps are followed as intended. Other examples of such reviews include: management observations of shift turnover or pre-job briefs; management reviews of meetings (such as an engineering design review meeting); management plant tours and walkthroughs; and management observation of a plant system startup or other procedure use. As part of these reviews it is recommended that coaching be performed where beneficial to provide feedback to the process.

9.6.3. Procedural use and compliance

Management should encourage and facilitate procedure development as the best practice to capture learned experience so that future iterations can be performed with safety, efficiency and effectiveness. Procedures must be reviewed periodically to ensure their versatility and that they are compliant with facility status. All staff needs to be trained to adhere to procedures.

Procedure development and use should reflect the level of complexity and risk associated with the relevant scope. A philosophy of procedure compliance should be developed and applied. Procedures may be assigned levels, where one level must be 'in hand' and followed verbatim during implementation (such as reactor startup), and another is generally for reference but if followed will produce an acceptable result. (For example, the engineering documentation of site modification, administrative or human resource management procedures). This is not to imply that these procedures, along with their compliance, are not critical to the organization, but only that after a few iterations the users typically do not have the procedures 'in hand' while completing the individual tasks.

Only specifically identified management and staff may be permitted to approve temporary changes to procedures. Permanent changes may only be made following the appropriate level of reviews. For example, senior licensed operators may have the authority to implement a change to an operating procedure due to a changed SSC configuration resulting from off-hours maintenance work. Such changes may undergo a peer review by another licensed operator prior to implementation. The change may then be submitted to a more formal review or an authorization by senior operations staff on the following business day.

9.7. PEER NETWORKING

Working with peer representatives from other research reactors can facilitate the exchange of best practices, lessons learned and other relevant information valuable to facility availability and reliability. Value is obtained by such networking at various levels of a research reactor organization. Examples of opportunities for such activities include:

- Participation in relevant local, regional and international conferences, seminars, workshops and meetings;
- Resource exchange (to help with significant evolutions, for example short to medium term operator or engineer assignments, or maintenance technicians supporting a major facility outage);
- Participation in peer organizations such as (web sites current at the time of publication):
  - IAEA Technical Working Group on Research Reactors (TWGRR);
  - International Group on Research Reactors (IGORR — http://www.igorr.com/);
  - National Organization of Testing Research and Training Reactors (TRTR — http://www.trtr.org/);
  - Forum for Nuclear Cooperation in Asia (FNCA — http://www.fnca.mext.go.jp/english/index.html);
  - European Atomic Energy Society Research Reactor Operators' Group (EAES/RROG).
- Participation in a more formal research reactor coalition.

10. PUBLIC RELATIONS

10.1. GENERAL

Effective public relations are critical to future facility operation and the nuclear industry in general. Public acceptance could be dependent on the general political situation, but local opinion may significantly affect operation, either positively or negatively. Research reactors have to be as open and transparent as possible, for example, guided tours help to encourage public acceptance. Regular, positive media communication may also significantly have an impact on public opinion.

10.2. VISITS

Guided tours will improve public acceptance; these visits must be professionally conducted and tailored to the audience. They will enhance understanding of the research reactor's role and value, and address preconceived beliefs on the safety aspects and applications of nuclear facilities.

Items that should be addressed in the policy for visits include:

- Assigning a single point of contact for visits to ensure proper and consistent organization and execution:
  - conflicts with significant operational activities must be avoided;
  - security requirements must be satisfied;
  - conflicts with other tours avoided.
- Identify possible target groups for tours such as:
  - influential people from the local community (mayor, legislators, teachers, professors, community leaders, etc.);
  - local media (television, radio, newspapers, etc.);
  - local community (local citizens, employees' family day);
  - national media;
  - organizations (schools, universities, environmental groups, non-governmental organizations (NGOs), rotaries, etc.);
  - hospitals and medical centres.

- — Provide transparent and consistent information — the use of factually correct brochures or hand-outs is advisable;
- — Provide trained tour guides;
- — Tailor the tour for the audience, e.g.:
  - tour leader;
  - information to be supplied;
  - areas to be visited;
  - hand-outs to be distributed.
- — Conduct a debriefing at the end of the tour to ensure that all questions have been answered;
- — Solicit feedback from visitors.

10.3. INTERNAL COMMUNICATION

It is important to proactively communicate to employees, i.e. not to wait and react to their questions. It is essential to include factual, positive information. Prompt, transparent communication of details regarding operating events builds trust within the organization. It is also worthwhile to provide information on new facilities, new equipment, new applications, modernization projects, results of research, community benefits of facility operation, etc. Lessons learned from operating experience should be broadly communicated face to face to promote interaction as well as through more general means. Team building is part of internal communication.

Examples of good internal communication techniques are:

- — Newsletters containing objectives, principles, achievements, research results, visits performed, etc;
- — Press releases on news and events;
- — Well maintained and current web pages (internal and external);
- — Symposia and colloquia;
- — Interviews;
- — Meetings (general staff meetings and managerial meetings);
- — Posters and billboards;
- — Sports days, etc.

See the communication improvement discussion in the section on management enhancement for further information.

10.4. EXTERNAL COMMUNICATION

It is important to proactively communicate to the media, i.e. not to wait and react to their questions. It is essential to include factual, positive information and to avoid a focus on incidents in general. It is also worthwhile to provide information on new facilities, new equipment, new applications, modernization projects, results of research, community benefits of facility operation, etc.

The attributes of good external communication are:

- — Assign a single point of contact;
- — Newsletters containing objectives, principles, achievements, research results, visits performed, etc.;
- — Press releases on news and events;
- — Promote community impact of the facility;
- — Invite the media to newsworthy events;
- — Allow interviews;
- — Up to date web pages, brochures, etc.;
- — Consider announcing and inviting media to emergency drills;
- — Encourage staff at all levels to become involved in community events.

10.5. CONTINUITY AND CONSISTENCY

A key point regarding both internal and external communication is unity within the general nuclear industry. One has to avoid negative comparisons (e.g. ‘research reactors are much safer than nuclear power plants’ — is an example of a frequently used, negative statement).

11. PERFORMANCE MONITORING

The performance of research reactors is monitored for tracking, trending and strategic planning to maximize safety, efficiency, availability and reliability. The monitoring provides evidence of the operational and safety behaviour of the facility. Research reactor performance is not only measured by how reliably it is operated, but also from multiple additional indicators. Facilities typically integrate availability and reliability performance monitoring programmes with those developed to monitor plant safety. Documents describing such programmes and specific performance indicators are listed at the end of this report (for example, Ref. [2]). Utilizing common databases, means of collecting and reporting data, etc., can help add efficiency to the relevant programmes.

Availability and reliability performance include operational performance (and staff performance and training), maintenance performance and health physics/radiological controls performance. By closely monitoring, reviewing and analysing performance data, the operating organization can identify weaknesses in specific areas and implement corrective actions/measures to improve the area concerned. Using trend analysis the operating organization has a tool to set up or adjust long term plans for operation, maintenance and refurbishment. This will enable the facility to improve the availability and reliability or to adjust the annual operating schedule. It will also justify and support programmes in view of plant life time management.

In addition to these characteristics, indicators chosen to support an operational monitoring programme should include a combination that reflects actual performance (called lagging indicators), and those that provide an early warning of declining performance (called leading indicators). Specific indicators should capture lower level problems to allow for timely identification and intervention that can prevent more significant events. The performance indicators are typically identified in the following manner:

- The definition of indicators should be sufficiently clear that everyone within the organization can easily understand their meaning and the background of their choice.
- Indicators should be SMART (specific, measurable, achievable, relevant/realistic, time-boundable).
- The use of indicators that may show the overall performance are preferred to the use of indicators that show the status of single activity or the status of a single component.

11.1. OPERATIONAL PERFORMANCE

The list below includes examples of performance indicators related to availability and reliability. Tracking and effectively managing these indicators can lead to reductions in unplanned shutdowns or power reductions as well as unplanned outage extensions.

Examples of operational performance indicators include the following:

- Availability;
- Reliability;
- Utilization;
- Time spent in specific operating modes (e.g. training, flux measurements, etc.);
- Frequency of unplanned shutdowns and power reductions;
- Duration of unplanned shutdowns and power reductions;

— Root and contributing causes of unplanned shutdowns and power reductions;
— Time to fully implement identified corrective actions and their effectiveness;
— Number of regulatory violations/regulatory reportable occurrences;
— Number of unusual occurrences, near misses, and SSC failure reports;
— Number of overdue scheduled tests and surveillances;
— Trends of equipment performance (from operational tests and surveillance);
— Number of SSCs out of service (plant material condition, also referred to as the maintenance backlog);
— Human performance (from root and contributing cause determinations — quantification of loss attributable to human error, number and frequency of human errors, etc.);
— Number of operator licensing exam failures;
— Number of operator re-qualification exam failure;
— Staffing levels;
— Effectiveness of communication, operators to operators, operators to supervisors, operators to management, and vice versa (questionnaires may help quantify information);
— Results (observations, findings and ratings if/as quantifiable) of regulatory inspections, independent and peer review audits;
— Record keeping effectiveness, in compliance with regulatory codes;
— Effectiveness of quality control and assurance (number of non-conformance reports (NCRs), time to disposition, etc.);
— Trend of fuel inventory.

Beyond the potential impact on plant safety, regulatory inspections provide an opportunity to incorporate independent perception and information into a performance monitoring programme. Such information is relevant to availability and reliability since — in the worst case operationally — severe findings can result in prolonged facility shutdowns. The trend of the number of findings or frequency of inspections may indicate whether the regulator or outside body is satisfied with overall performance. The analysis of findings based on the relevant SSC may reveal systems, functions or equipment that require either increased maintenance and engineering attention or improved communication between the operating organization and the regulator (see the regulatory issues section of this report for further information).

11.2. MAINTENANCE PERFORMANCE

Maintenance performance indicators are typically used to track maintenance programme effectiveness. From these, the operator may determine whether any changes in equipment design, inspection, test or surveillance programme, staffing and resource distribution are required. Examples of maintenance performance indicators include:

— Rework.
— Post-maintenance testing failures.
— Number and cause of corrective maintenance occurrences.
— Number and cause of breakdown maintenance occurrences.
— Schedule compliance.
— Maintenance backlog.
— SSC maintenance histories (can be mined for different information, including numerous trends at the component and/or system level. Work orders can be analysed based on related systems or root causes. Also, the time spent for the resolution of issues can be trended and evaluated).

11.3. HEALTH PHYSICS/RADIOLOGICAL CONTROL PERFORMANCE

Health physics/radiological control indicators can be supportive of availability and reliability programmes as well as safety programmes. For example, reductions in unplanned outages, unplanned outage extensions, etc., will in turn reduce occupational exposure and active waste. Examples of specific indicators include:

- Waste management and effluents:
  - gaseous release to environment or effluent activity versus allowed limit;
  - liquid effluents to environment;
  - solid waste generation volumes;
  - analysis of radioisotopes in the reactor primary system and in the spent fuel storage pool;
- Effective dose to operating staff, contractors and visitors:
  - maximum individual dose;
  - average yearly dose;
  - collective dose;
  - number of workers receiving dose above internal and external limits;
  - incidents related to health physics /radiological controls;
  - percentage and frequency of area that is contaminated (number of contamination control incidents).

11.4. PERFORMANCE REPORTING

Indicators are typically selected depending on the specific needs of the operating organization in consideration of available resources and the amount of work involved generating trends and reports. Reporting may include a simple review of the trends or more robust reports, including written evaluations.

Appendix I

GLOSSARY

Some general definitions were discussed during the meetings to develop this report. While it is not the intent to arrive at a consensus with regard to the use of this terminology, they are included to help ensure different readers arrive at a consistent interpretation of this report and the output from the supporting meetings. Every effort was made to remain consistent with Ref. [3] where possible.

Availability

The fraction of time for which a system is capable of fulfilling its intended purpose. [3]

Here: Some means to reflect actual operating time to planned operating time. Facilities define this term differently. Examples include:

$$\frac{\text{actual operating time}}{\text{planned operating time}} \times 100$$

$$\frac{\text{actual operating time}}{\text{total time of report period}} \times 100$$

This second equation is simply the first equation multiplied by the ‘utilization’ equation below.

Some research reactors spend considerable time in a standby condition (shutdown, but able to operate) and replace ‘operating time’ with ‘time capable of operation’ in the above ratios.

Note — *Care should be taken when quantitatively discussing availability, reliability or utilization with representatives of other nuclear/research reactor operating organizations due to the range of definitions in use at the time of this publication.*

Back end

That part of the nuclear fuel cycle that occurs from the point when the fuel is removed from the core for the final time (from the reactor to geological [ultimate] disposal).

Breakdown maintenance

A specific category of corrective maintenance (see Ref. [3]) where the SSC failure has a direct and immediate impact on plant operation (forcing a shutdown or significant power reduction) and is therefore an emergent priority, leaving little time for effective planning and resource allocation.

Configuration control

Alignment of plant systems and components to ensure minimum required operability.

Configuration management

The process of identifying and documenting the characteristics of a facility’s structures, systems and components (including computer systems and software), and of ensuring that changes to these characteristics are properly developed, assessed, approved, issued, implemented, verified, recorded and incorporated into the facility documentation. (Configuration is used in the sense of the physical, functional and operational characteristics of the structures, systems and components and parts of a facility.) [3]

Here: All of the above, with particular emphasis on the control of temporary changes made to facilitate specific operations or maintenance activities.

Corrective action programme (CAP)

A management programme to improve facility performance by implementing corrective actions from lessons learned. CAP programmes can vary in complexity but typically ensure the capture, management review and complete implementation of mitigating or preventive actions for a broad array of events or near misses including those related to facility safety, operability, quality and organizational efficiency.

Corrective maintenance

Actions that restore, by repair, overhaul or replacement, the capability of a failed structure, system or component to function within acceptance criteria [3].

Front end That part of the nuclear fuel cycle that occurs up to the point when the fuel is initially loaded into the core (from the ore to the reactor).

Maintenance backlog Work which has not been completed by the nominated required by date. The period for which each work order is overdue is defined as the difference between the current date and the required by date. All work for which no required by date has been specified is generally included on the backlog. Backlog is generally measured in 'crew-weeks', that is, the total number of labour hours represented by the work on the backlog, divided by the number of labour hours available to be worked in an average week by the work crew responsible for completing this work. As such, it is one of the common key performance indicators used in maintenance [11].

Maintenance history A historical record of all maintenance performed on a given plant SSC. Records typically include SSC failure cause, failure rate, frequency and type of preventive as well as corrective maintenance, major overhauls, etc. Sometimes referred to as component history.

Maintenance programme A long term plan, covering all aspects of maintenance management which sets the direction for maintenance management, and contains firm action plans for achieving a desired future state for the maintenance function [11].

Predictive maintenance Form of preventive maintenance performed continuously or at intervals governed by observed condition to monitor, diagnose or trend a structure, system or component's condition indicators; results indicate present and future functional ability or the nature of and schedule for planned maintenance. [3]

Here: An equipment maintenance strategy based on measuring the condition of equipment in order to assess whether it will fail during some future period, and then taking appropriate action to avoid the consequences of that failure. The condition of equipment could be monitored using condition monitoring, statistical process control techniques, by monitoring equipment performance, or through the use of the human senses [11].

Preventive maintenance Actions that detect, preclude or mitigate degradation of a functional structure, system or component to sustain or extend its useful life by controlling degradation and failures to an acceptable level. [3]

Here: An equipment maintenance strategy based on replacing, overhauling or remanufacturing an item at a fixed interval, regardless of its condition at the time [11].

Reliability The probability that a system or component will meet its minimum performance requirements when called upon to do so. [3]

Here: A means to quantify unplanned lost operating time for a given facility. Each facility must work to define 'unplanned'. Typically, for example, if a facility is forced to shut down to perform maintenance but has time to inform stakeholders and customers in time for them to take mitigating actions (including any required maintenance planning), the shutdown is not considered 'unplanned'. Inadvertent scrams or outage extensions are examples of unplanned loss.

$$\frac{\text{actual operating time}}{(\text{actual operating time} + \text{time of unplanned shutdowns})} \times 100$$

Some research reactors spend considerable time in a standby condition (shut down, but able to operate) and replace 'operating time' with 'time capable of operation' in the above ratios.

Note: — *Care should be taken when quantitatively discussing availability, reliability or utilization with representatives of other nuclear/research reactor operating organizations due to the range of definitions in use at the time of this publication.*

Rework Repeated maintenance on a given SSC for the same problem or failure.

Risk informed — Incorporating an assessment of availability and reliability significance or relative risk in operation and maintenance planning and actions. Making sure that the management burden imposed by individual activities or processes is commensurate with the importance of that activity or process to optimizing plant availability and reliability.

Schedule compliance — Used to measure the effectiveness of an organization to plan and implement various activities. The specific metrics can be as complicated as an earned value analysis or simply the ratio of the number of planned activities completed in a given period to the total number of activities planned for that period.

System/procedure 'ownership' — A facility management philosophy where primary responsibility for a plant system or procedure is assigned to a responsible individual or 'owner'. The owner takes the lead on related planning efforts, reviews recommended changes such as physical modifications or procedure changes and is the principal interface for that system or procedure.

Utilization — A measure of a facility's planned operation or duty.

$$\frac{\text{planned operating time}}{\text{total time of report period}} \times 100$$

Also used to describe that part of the nuclear fuel cycle between the front end and the back end.

Note — *Care should be taken when quantitatively discussing availability, reliability or utilization with representatives of other nuclear/research reactor operating organizations due to the range of definitions in use at the time of this publication.*

Work order — The prime document used by the maintenance function to manage maintenance tasks. It may include such information as a description of the work required, the task priority, the job procedure to be followed, the parts, materials, tools and equipment required to complete the job, the labour hours, costs and materials consumed in completing the task, as well as key information on failure causes, what work was performed, etc. [11].

Work control programme — A formal programme to control and authorize work on any facility SSC. Typically such programmes are either part of, or thoroughly integrated into, safety, maintenance and/or configuration management programmes.

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Annex I

EXAMPLES OF IN-SERVICE INSPECTIONS AND A TYPICAL MAINTENANCE SCHEDULE FOR LOW-POWER RESEARCH REACTORS*

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1. INTRODUCTION

In-service inspection methods for low-power research reactors are described in this module. Two practical examples of an in-service inspection and maintenance task at a Training, Research, Isotopes, General Atomics (TRIGA) reactor and at a materials test reactor (MTR) are given, and a typical maintenance schedule is presented in Annex 1. The inspection methods and the maintenance schedule are based on 42 years of operation and maintenance experience with a typical 250 kW TRIGA Mark-II reactor. Although this experience is related to a TRIGA reactor, most of the ISI methods and a large part of the maintenance schedule can be applied, with minor changes, to other types of low power research reactors such as ARGONAUT, SLOWPOKE, and MNSR type reactors.

The useful lifetime and the safe operation of a research reactor depends on two main criteria which are:

(1) Regular maintenance of all reactor components and systems,
(2) Periodic in-service inspection (ISI) using various non destructive testing (NDT) methods.

For a research reactor maintenance programme, a maintenance schedule has to be established. It should list all systems and components necessary for a safe reactor operation. These are, however, not only the direct related safety related systems and components but also auxiliary systems and components, which may have an indirect effect on the safety systems or the safety of the facility. The frequency of maintenance depends on the importance of the components and also on operational experience but it will usually be at least once a year. More frequent inspections should be considered for components that show an increasing deterioration rate, require frequent corrective maintenance or are operating significantly beyond their original expected lifetime.

In-service inspection (ISI) will be carried out with more sophisticated equipment using various methods described in chapter 3. During this ISI, one component is investigated in detail; usually an inspection report is prepared both for the operation license holder and, in many cases, also for the regulatory body. The ISI methods may vary from simple visual inspections and measurements to very sophisticated and expensive NDT inspections. The reactor type and its power level should be taken into consideration when selecting the appropriate inspection method. Typical examples of instances requiring more sophisticated inspections are the visual inspection of the reactor tank, of the reflector or the inspection of welds in the primary piping system by NDT methods.

The staff of the reactor operation group holds the responsibility for in-service inspections in many cases.. Experiences with a 250 kW TRIGA reactor has shown that the manpower involved in a simple monthly ISI is about 2 man-days but a complete yearly ISI may be in the range of 14 man-days [1-7]. The number of safety systems and fuel elements requiring inspection at facilities up to 1 MW are only marginally larger so the maintenance periods are similar to the 250 kW facilities. Larger, high power reactor facilities, may have more systems requiring routine maintenance but often their larger staff sizes will compensate.

2. RELIABILITY AND MAINTAINABILITY OF RESEARCH REACTORS

2.1. General Considerations

The development of a maintenance and in-service inspection schedule for a complex technical system must be based both upon certain theoretical considerations such as reliability of components, failure rates and upon practical past experience with components to be maintained. The evaluation of the facility needs may be quite complicated with several computerized databases generated. However, a facility may adequately evaluate the system components by maintaining a good written record of repairs and modifications to all equipment in the facility. The procedures given below may be used by the facility over the lifetime of a component.

2.1.1. Theoretical considerations

Ideally, failure data used for reliability analyses should be based on facility specific data. However, the availability of accurate facility specific data requires the expenditure of considerable resources to develop and maintain an extensive database. The collection of database source information from the field, i.e. from reactor maintenance and/or operation reports, requires a systematic approach and ongoing commitment, if the information is to be processed efficiently and kept up to date. In addition to the need for operational and maintenance staff to provide the raw data input, a software system and analytical personnel to process the raw data are also required. Data processing primarily produces component reliability parameter statistics and trend analysis data. The reliability parameter data is often formatted so that information can interface directly with Probabilistic Safety Analysis (PSA) studies. For example, component failure rate data may be linked to a PSA specific basic event labelling format. The use of generic data by themselves will not provide an adequate data source to aid in a trend analysis of facility specific system equipment. However, generic data can still indicate whether there may be facility specific features or facility specific equipment problems that may be considerably different from that predicted from international generic sources of other research reactors.

Component reliability is a function of design, use and maintenance. Components designed for specific research reactor application (especially safety related) are usually highly reliable and should be maintained as such during their lifetime. The reliability data, however, often show variations, which are related to operating conditions and practices, component application maintenance and testing practices. A brief discussion of the influence of each of these is given below.

Operating conditions and practices

A facility's operating conditions and practices may greatly influence component reliability. Some of the factors are:

— operating mode,
— operating time and demands,
— operating environment.

The operating mode has been recognized as influencing equipment reliability, especially on active components (such as pumps). Some data sources provide separate data for running, alternating and standby categories. In an IAEA survey [7] variations of more than two orders of magnitude have been documented for failure to run motor operated pumps, comparing alternating pumps, running pumps and pumps where no mode had been specified. This finding supports the view that failure data for similar equipment having differing operating modes should be kept separate.

A component's failure to start may be caused by a demand related stress (e.g. vibration), or stress in standby (e.g. corrosion) or a combination of both. Most data sources disregard these differences and provide data on failure to start either as demand related or time related. When time related data are provided, the failure rate denomination is usually calendar time, or sometimes plant operating time. Since similar components at different locations may have substantially different test intervals, the actual number of demands over a period may vary, which in turn may greatly influence the failure rate. Some data collection systems also collect information on the number of demands systematically; in others the number of demands is estimated on the basis of the costs of collecting the information.

Operating conditions may also influence component reliability. Examples of this would be ambient temperature, humidity, chemical control, radiation fields and vibration.

Design and application

A component's design and application will have an important influence on it's reliability. The application of the component will determine the operating mode and the environment. Variation due to these causes has been discussed in previous sections.

Environmental conditions

In general, the failure rate of equipment depends on the environmental conditions. Therefore, these circumstances should ideally be taken into consideration in all data acquisition activities. However, few data bases provide the environmental application factors needed to do this and they are generally only available for electrical and electronic components [9].

The environmental application factor is a multiplicative constant used to modify a failure rate to incorporate the effects of other normal and abnormal environmental operating conditions.

Generic abnormal environmental conditions are:

(mechanical):	impact, vibration, high pressure, stress, grit, moisture, ...
(thermal):	over temperature, freezing, humidity, ...
(electrical):	electromagnetic interference, contact with conducting medium, power surge voltage or current, short circuit, ...
(radiation):	radiation damage, insulation failures, gamma heating, neutron activation, ...
(chemical):	acidic corrosion, oxidation, chemical reactions, poisonous gases, ...
(human interaction):	students in the control room, ...
(others):	missile hazards, explosion, ...

Maintenance and testing practices

Significant plant to plant variations for otherwise identical components can be identified. These variations are most probably caused by facility specific maintenance and testing differences. The influence of the testing interval and practice has been extensively investigated. The testing interval has an influence on the failure rate, but it is strongly related to the component type. The testing interval has greater influence on components where standby stress dominate failure probability (usually motor operated valves) and lower influence on components with higher demand stress (such as diesel generators or compressors).

In order to compare reliability data from different facilities for similar components, all data must be based on common definitions. A set of definitions also used within IAEA documents (i.e. [8, 9]) is given below.

Definitions related to the calculation of reliability parameters

Failure rate

The failure rate is a numerical value, which represents the probability of specified failures of a component per time unit. The all modes failure rate of a component is an aggregate of failure rates summed over relevant failure modes.

The failure rate $\lambda(t)$ of a system, subsystem or component is defined as

$$\lambda(t) = \frac{f(t)}{1 - F(t)},$$

where

f(t) ...... probability density for a failure of the device
1-F(t)... probability that the device did not fail up to the time t.

For many devices, the behaviour of $\lambda(t)$ follows the classic bathtub curve (Figure 1):

(1) Early in life, the failure rate for most devices is high because of ‘break-in failures’ or failures arising due to poor quality assurance during manufacturing or installation.
(2) During the middle of lifetime, failures occur at a rather uniform rate corresponding to random failures.
(3) Late in life, $\lambda(t)$ begins to increase because of ‘wear-out failures’ caused by equipment aging.

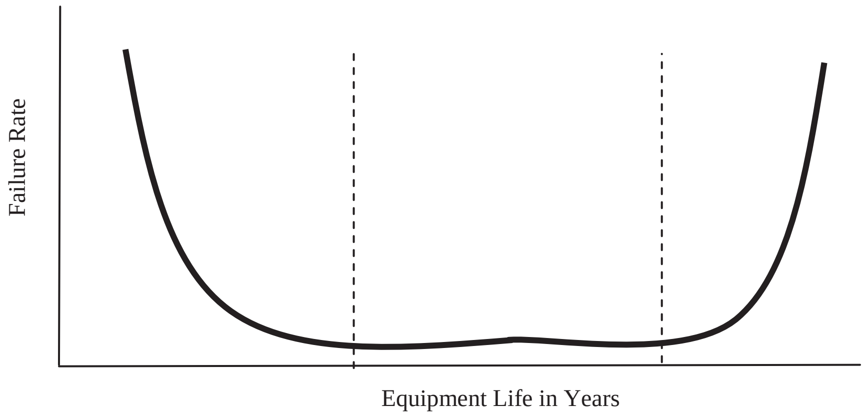

FIG. 1. Classic 'Bathtub' Reliability Curve.

Time related failure rates

Two time related failure rates are defined:

— operating failure rate,
— standby failure rate.

The failure rate for continuously operated equipment (operating failure rate) is the expected number of failures of a given type in a given time interval (failures per hour, per year) - while the equipment is continuously in use.

Examples of failure rates of continuously operated components:

(electronic):	capacitor short circuit failures per million operating hours while under nominal voltage,
(sensors):	self-powered neutron detector degraded current output failure per thousand full power days.

The standby failure rate is the expected number of failures per time unit for those components normally dormant or in a standby state until tested or required to operate. Data representing standby failure rates is often not available in practice.

Failure on demand

Failures on demand are relevant to failures occurring on periodically or cyclically operated equipment. Failure on demand is the expected number of failures of a given type during a given number of operating cycles on demand when required to start, change state, or function.

Example of failure rates of demand operated components:

(electromechanical): relay contact failure per million switching cycles.

Operating time

The operating time is the accumulated time period during which an item, component or a system performs it's intended function within specified limits.

Standby time

The standby time is the accumulated time period during which an item, a component or a system performs it's intended function as standby equipment.

Outage time

The outage time is the time when the equipment is not available for its specified service due to failure or maintenance. Outage times can be divided into three categories: out of service, restoration and repair.

Out of service time

The out of service time is the time required to identify the failure, analyze it, obtain spare parts, repair, and return the equipment to service, including planned delays.

Restoration time

The restoration time is the time period from the moment the failure is revealed to full restoration to operable state. It is the same as out of service time except that planned delays are excluded.

Repair time

The repair time counts from when the failure is revealed, and includes the time to analyze the failure, prepare for repair, repair, test, qualify, and return the equipment to service. The repair time is, therefore, the time necessary to repair the equipment and restore it to operation or standby (this excludes all planned delays and waiting for spare parts and tools). The repair time is the same as the out of service time except for spare part waiting.

Active repair time

The active repair time is the time, which is actually spent for the repair of a piece of equipment.

Maintenance time

The maintenance time is defined as the time required to plan, administrate, and prepare for test or inspection, test or inspect, and return the component back to service.

Active maintenance time

The active maintenance time is the time spent on the maintenance (test, inspection, ...) itself.

2.1.2. Practical Experience

First hand practical experience with the reliability of a given component originates from one's own facility and observant operators. Therefore, it is very important to maintain an accurate documentation on all experience gained during the history of a given component. A standardized format is highly recommended, i.e. Event Record (Annex 1) where all necessary data of a component failure are concentrated. If other facilities use the same component, an exchange of information between the operators is relatively easy. Due to the relatively few research reactors in the world, compilation of failure data is slow and the data is often limited or sparse. This makes is more difficult to calculate meaningful average failure rates or mean time between failures (MTBF). Another source of failure rate information are data banks established by several groups [10, 11], though they might be difficult to access in many cases due to costs and restriction. Failure rates for various components have been calculated based on the component failure data collection system used at the Atominstitut der

Österreichischen Universitäten since 1988 [12], and are listed in Annex 2. The inspection and maintenance frequencies for particular components are reflected in these failure rate values.

It is necessary to define all ***systems*** necessary for a safe reactor operation, following the license from the regulatory body, in order to establish a maintenance schedule for a low power research reactor. Typical systems to be maintained regularly are, i.e. the

- reactor tank and shielding structure,
- reactor safety system,
- reactor cooling system.

Once the systems have been defined each system has to be broken down into ***sub-systems*** or ***components***, such as

— reactor core
— nuclear channels
— primary pump.

Each of these sub-systems or individual components have to be maintained, inspected or recalibrated in different ***time intervals***, which may be

— once a month (1xm)
— four times a year (4xy)
— two times a year (2xy)

Other intervals, ranging from daily checks to once a year, are possible. After having defined the frequency of maintenance, it is necessary to define the ***type of maintenance*** work to be carried out. In many cases this would be just a visual check, it could be a test run (i.e. for a pump), it could be readings of a scale (i.e. differential pressure across filters) or it could be a complete recalibration using signal generators (i.e. for the nuclear safety channels).

Finally, for each maintenance task to be carried out it has to be defined ***who*** will carry out this task. Usually it is the reactor staff that has the best operating experience of all the systems and components. However, in some cases the reactor staff is either not qualified to carry out maintenance (i.e. reactor crane, emergency diesel generators) or is not authorized to do the work without supervision or control of an independent expert. In some cases the independent expert is appointed by and acts on behalf of the regulatory body.

It is now possible to establish a maintenance schedule for a low power research reactor. As an example, such a schedule is given in Annex 3 for a typical 250 kW TRIGA Mark-II reactor. Twelve systems, each one with several sub-systems or components have been identified. These sub-systems are maintained in periodic intervals by different personnel according to their qualifications. For each sub-system a maintenance check list has been developed as basis for the maintenance work. Long term experience has shown that a typical monthly maintenance period following the schedule requires about 2 man-days while an annual maintenance requires about 14 man-days of labour.

3. IN-SERVICE INSPECTION EQUIPMENT FOR A LOW POWER RESEARCH REACTOR

At low power research reactors, in-service inspection (ISI) is usually carried out on components that are not directly accessible due to a high radiation level; such as the reactor tank, the core structure, fuel elements, etc. For these ISI inspections tools and methods have been developed based on experience in non-nuclear applications and modified or adapted to the nuclear environment. Some ISI methods that are used at TRIGA facilities are:

— visual inspections using
  - underwater telescope

  - endoscopes
  - underwater cameras using radiation hardened systems
- replica method

Other non-radioactive components may be inspected with methods used in conventional industries. The following methods and tools are typically used in a TRIGA Mark-II reactor but may easily be adapted for any other low or even high-power research reactor.

3.1. Nuclear Underwater Telescope

Nuclear underwater telescopes are high resolution devices (resolution 0.1 mm) with continuously variable magnification. They allow remote underwater viewing of the reactor tank and core components such as fuel elements, core support structures, etc. both vertically and also horizontally. Such a telescope penetrates the water level while the water fills up the periscope tube, providing complete radiation shielding for the viewer. Since no radiation-sensitive optical element is built in at the lower end of the unit the optical image quality is not diminished of, due to radiation induced decolourization, reflection losses or distortions. In order to facilitate acquisition of the object and detail observation, the magnification can be continuously controlled. Photo and video recording is also possible for some equipment types.

3.2. Endoscope (Fig. 2)

For the inspection of the inner surface of neutron beam tubes or internal core structures, a modular endoscope is found to give excellent results. A typical system consists of a set of a 1-meter long (diameter 18 mm) ocular and rigid optical extension pieces. These modules can be coupled to the desired length, up to several meters. The front end of the endoscope houses the objective together with an integrated 100 W/12 V

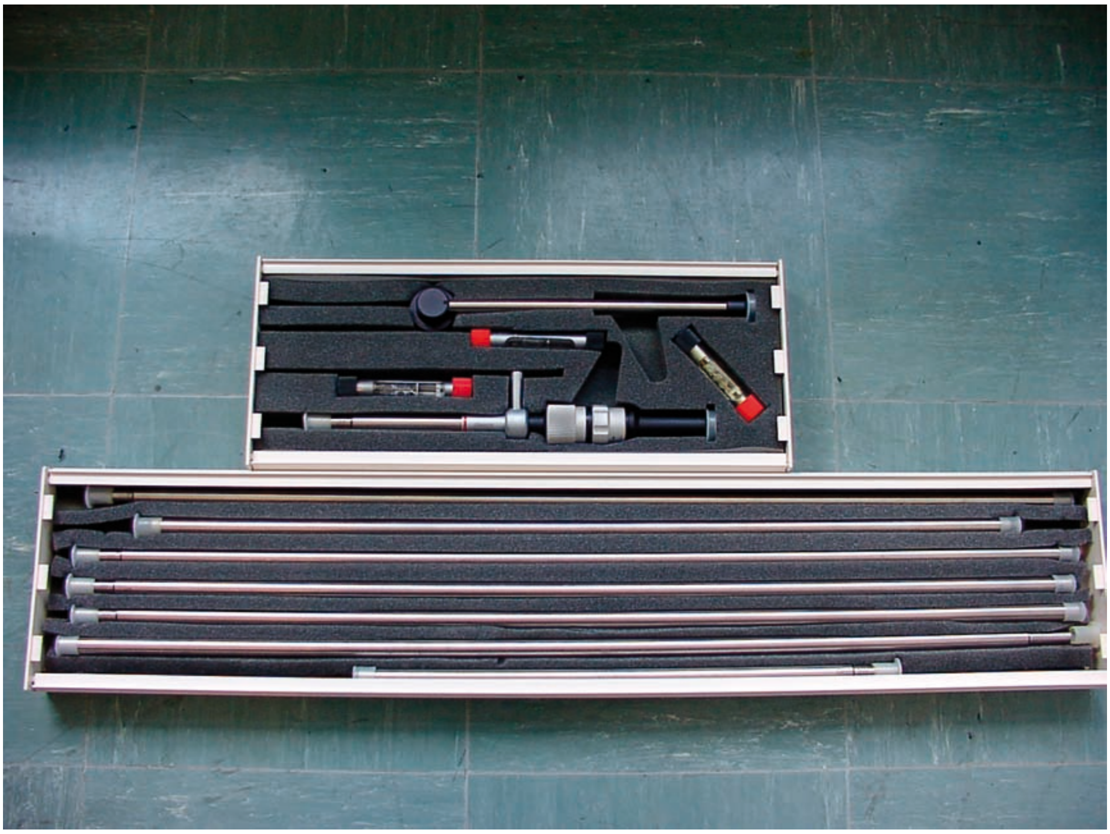

FIG. 2. Underwater endoscope.

lamp powered by a transformer. Various objectives with forward-, 45°-forward-, 90° and 45°-backward viewing angles are available. Photos or videotapes can also be taken through the endoscope for permanent record. In case of gamma radiation streaming out of the beam tube, the ocular can also be mounted at an angle of 90° and viewing can be performed from outside the radiation field. Some systems have flexible sections that may turn as needed to reach remote areas.

3.3. Underwater Camera

Some facilities may use specially designed underwater video cameras or place a video camera inside a watertight housing to perform routine or non-routine ISI. Often, a set of underwater lamps are necessary to illuminate the object deep inside the reactor pool. The output from the camera may be sent to a recorder or video monitor for inspection.

3.4. Replica Material (Fig. 3)

To determine the dimension of a corrosion spot (or i.e. the surface structure of small activated items in the core region) a two component silicon-based material (similar to that used by dentists) has been found very useful. In the present case, a plastic cap of a powder bottle was mounted at the end of an aluminium rod and filled with the mixed silicon paste. This material remains soft or pliable for about 3 minutes in ambient air. Then the rod was lowered into the reactor tank (water temperature about 30 °C) and immediately pressed on the corrosion crater for 4 to 5 minutes. Within this period, the silicon paste hardens completely and the system can be removed from the reactor tank. The hardened material gives an exact replica of the corrosion crater for further investigation.

FIG. 3. Replica material to determine the dimension of a corrosion spot.

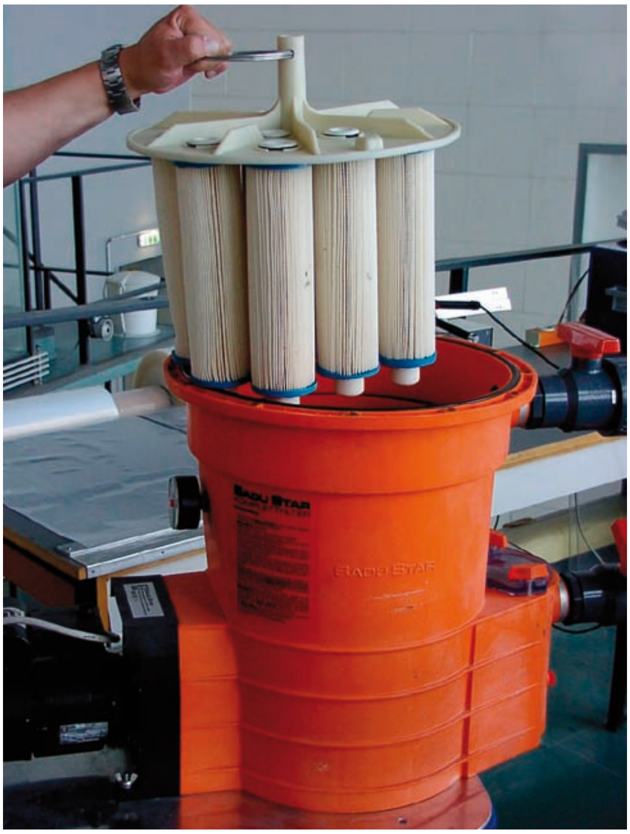

FIG. 4. Tank cleaning pump with integrated filters.

Operators must control the type of materials that enter the reactor tank. Not all 'impression clay' is chemically compatible with materials in the reactor tank or could increase the pool water conductivity. Some materials may have a high neutron absorption cross section and become radiation hazards when the reactor is restarted. The chemicals in dental plaster or similar molding materials are likely acceptable because they are used in people's mouths. However, materials coming in contact with fuel cladding (especially aluminium) must be careful evaluated to prevent the inspection from actually causing a failure.

3.5. Tank Cleaning Vacuum with Integrated Filters (Fig. 4)

Dirt or debris in the reactor tank may cause cloudiness or potentially cause thermal and hydraulic problems within the reactor fuel. The most effective manner of keeping the reactor tank clean is to eliminate the source by covering the pool with a transparent cover and remaining diligent to not drop materials into the water when working above the pool. Most research reactors have some system of purifying the primary coolant. These systems are generally not designed to remove relatively large debris that sinks quickly to the pool bottom. A conventional plastic pump used for cleaning swimming-pools has been found useful to clean the tank bottom from small debris. This system is equipped with a coarse filter to collect larger objects (such as screws) and twelve units of candle-type fine filters for collecting small particles. One advantage is that these fine filters are reusable, they may be washed and reinstalled into the pump. Some reactor facilities will perform a pool cleaning annually if the equipment is routinely available.

FIG. 5. Underwater jet to remove deposits.

3.6. Underwater Jet to Remove Deposits (Fig. 5)

One tool that has been found very useful in cleaning remote areas in reactor tanks from debris is a strong water jet (160 bars) produced by a portable compressor together with different types of jet nozzles. The material stirred up from the tank bottom or any deposits removed from the tank wall will ultimately by collected in the filters of the water purification system. However, it would be ideal to remove the material quickly with a local vacuuming system as described in section 3.4. Some of these jet nozzles are small enough to be inserted through a hole of the top grid plate right into the core volume and can be used to clean the core of debris or corrosion deposits. Operators must be cautioned that high pressure water jets can cause damage to sensitive reactor components and therefore the jet should not be aimed directly at fuel elements.

3.7. High Intensity Underwater Lights

Miniature, strong underwater lamps are necessary to inspect remote areas in reactor tanks. Generally, this is done in conjunction with the use of an underwater camera or a pair of binoculars used at the pool surface. This 24 V DC lamp (13 cm length, 6 cm diameter) has a power of 250 Watts and can only be operated under water. The lamp, mounted on modular 1 meter aluminium tubes that are coupled to the desired length, can be directed to any desired position in the reactor tank for optimal viewing. Another useful system for illuminating objects underwater has been the high intensity directional lamp used from the pool surface. These 12 VDC lamps are usually extremely bright (1,000,000 candle-power) and focused in a very tight beam of perhaps 6–10 cm in diameter.

3.8. Rotating Underwater Brush

In many areas of a reactor tank, small surface spots of corrosion may be seen during inspections. If desired, these spots can be brushed away using an underwater rotating brush connected to a standard drilling machine by an extension shaft. Practically all areas inside the reactor tank can be cleaned using various types of brushes (radial, pot-type). As with other cleaning equipment used around the reactor, operators must be extremely cautious to prevent damaging the object they are attempting to clean.

4. PRACTICAL EXAMPLE OF AN IN-SERVICE INSPECTION CARRIED OUT AT A TRIGA REACTOR AND AT A MTR REACTOR

The TRIGA facility at the Atominstitut Wien (in Vienna, Austria) was requested to provide equipment for detailed inspection of core internals and remote cleaning of the pools of several research reactor facilities. The following equipment was provided:

- an underwater endoscope with 6.5 m length and three viewing angles (0°, 45° forward, 90°)
- a high pressure water jet to stir up debris from tank internals
- a circulation pump with coarse and fine filters
- a pick-up tool for small pieces
- photo and video equipment

4.1. Typical Inspection Programme at a Small Reactor Facility [13]

After setting up all equipment, the tank inspection usually starts in one sector of the tank and continues clockwise through the other sectors. The tank bottom, the reflector, the respective beam tubes and their connection to the tank are optically inspected by the endoscope in each sector. Many particles of different sizes are normally found and the larger particles or objects (e.g. bolts and screws) are removed with the pick-up tool developed at the Atominstitut. The optical inspection usually lasts for two days followed by cleaning of the tank bottom with the circulation pump.

After another visual check, the high pressure water jet is used to stir up all deposits and flush the tank surfaces. This task takes about half a day and causes the tank water to become very cloudy and semi-transparent due to suspended particles. At the same time, the circulation pump filters out these particles. The primary and the purification loops are kept operating overnight to filter the water and to remove the suspended particles. Normally, by the following day, all tank surfaces and the tank water are clean and no deposits are found at the tank bottom (Figs. 5 to 7).

4.1.1. Inspection of a 250 kW TRIGA type reactor

It was found in one particular case that the central thimble (CT) showed a deformation below the top grid plate and could not be moved more than 10 cm vertically. This was clearly seen in a video inspection using an underwater endoscope. The Reactor Safety Committee convened and reviewed and approved the removal of the top grid plate. All three rod drive mechanisms had to be disconnected and removed from the reactor bridge and the reactor core unloaded before removing the top grid plat. When the top grid plate was unbolted and removed the operators were able to cut the CT about 30 cm above the grid plate. The CT was then removed downwards through the center hole. The dose rate from the grid plate was about 0.5 mSv/h when pulled up within 30 cm below pool water level and measured at bridge level.

It was obvious during reinstallation of the grid plate, that the guide tube for the regulating rod was not firmly fixed into the lower grid plate. Optical viewing with the endoscope showed a 5 mm gap between the bottom of the guide tube and the lower grid plate. With the 90° endoscope, the bottom area of the lower grid plate was inspected and the locking device was found not fixed in place and probably damaged. Therefore, the whole regulating rod guide tube was removed from the tank and inspected behind an appropriate shielding. The

FIG. 6. Pick-up tool.

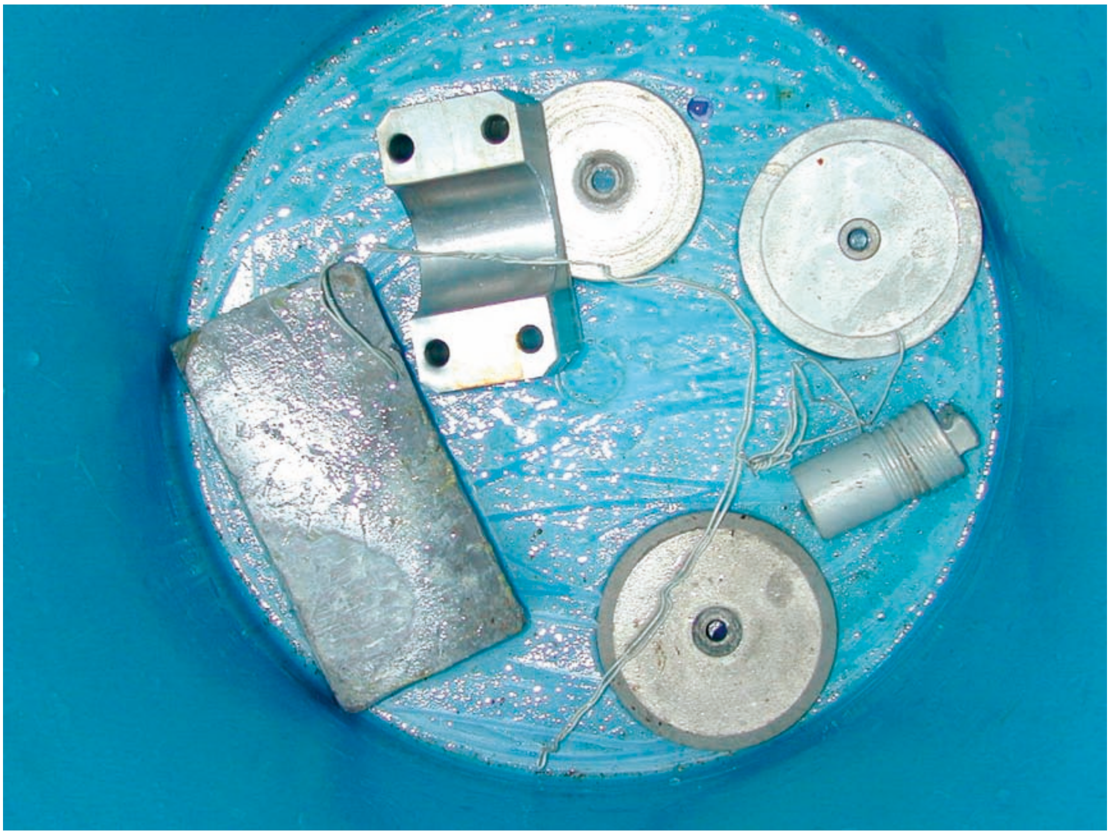

FIG. 7. Collected pieces with the pick-up tool.

FIG. 8. Collected pieces in the coarse filter.

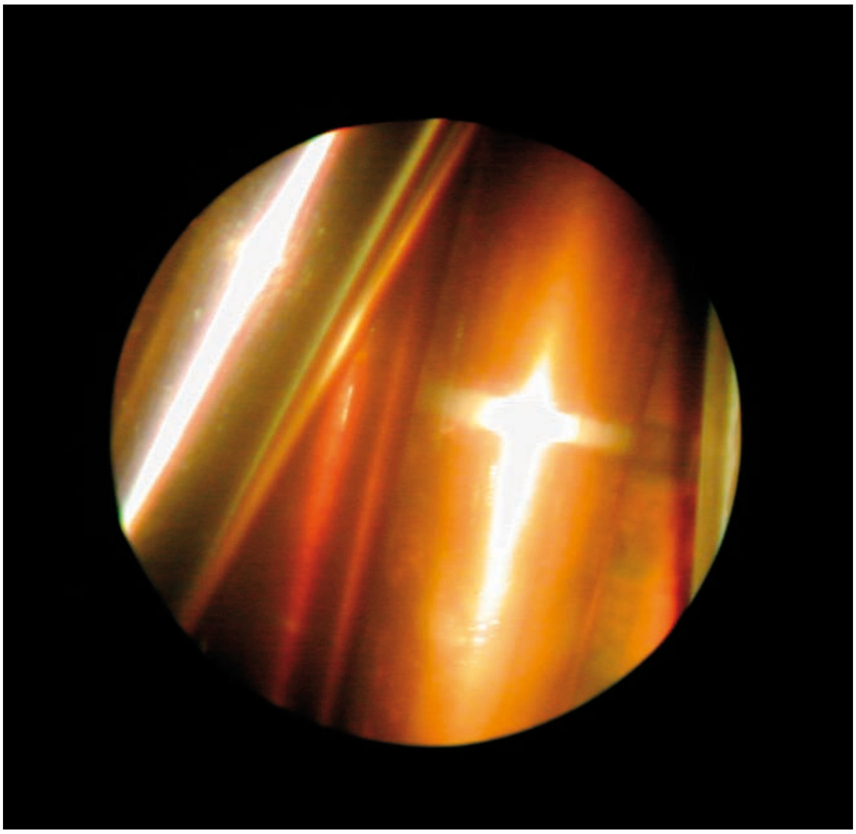

FIG. 9. Stored fuel element in the spent fuel storage.

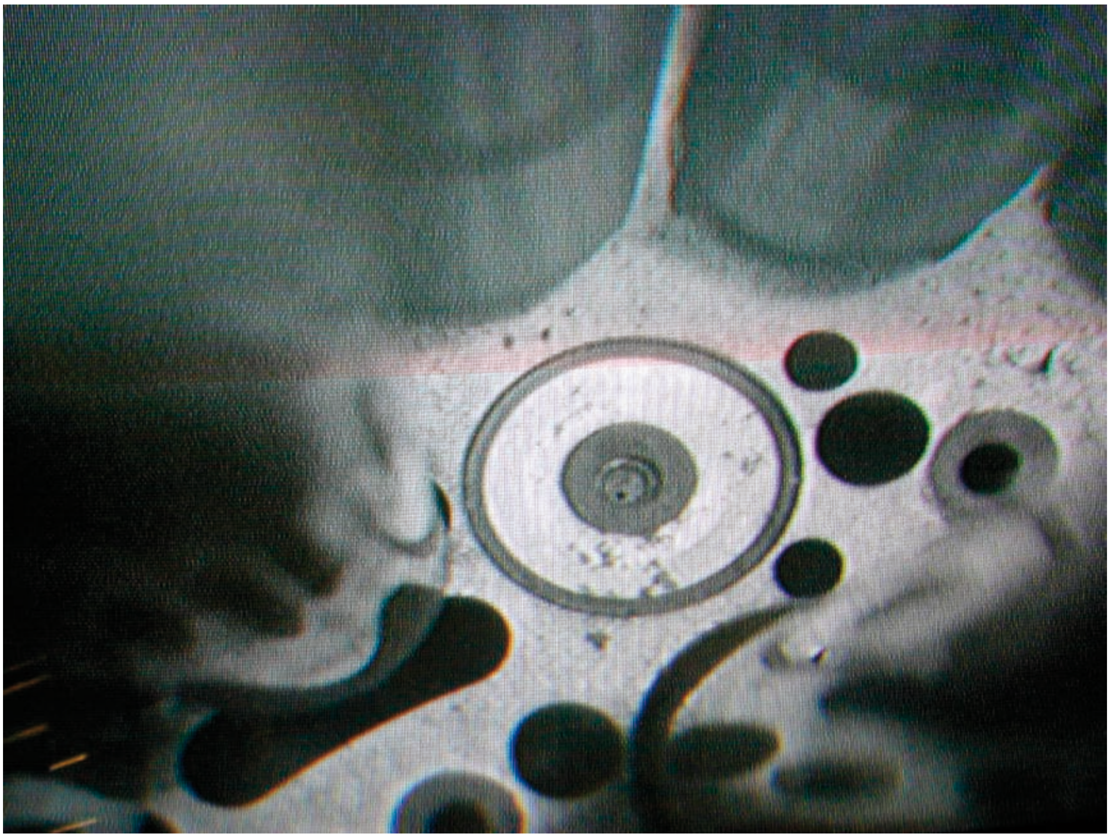

FIG. 10. Lower grid plate.

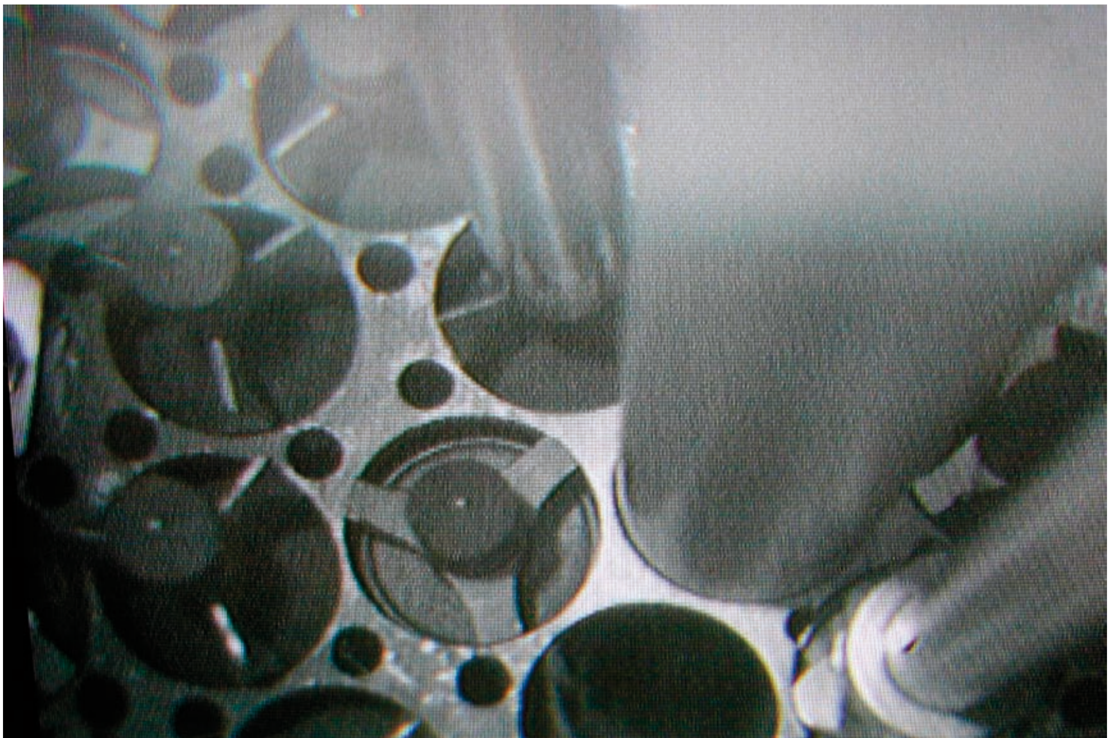

FIG. 11. Upper grid plate.

dose rate from the guide tube was about 0.1 Sv/h . It was found by direct inspection, that the guide tube locking wire did not penetrate fully into its position resulting in a very loose and unstable connection between guide tube and lower grid plate. The guide tube was returned into its position and the locking screw was tightened remotely from the tank top. The guide tube connection was inspected optically with the endoscope and documented by video to verify the position. The full task required approximately 30 Man-hrs to complete. After this task, the reactor tank and all the tank internals were inspected and found to be excellent condition, no major corrosion spots were found.

4.2. Inspection and repair at a 4 MW MTR reactor

A small crack in the primary circuit tubing of a 4 MW MTR reactor made an optical inspection and repair necessary. Using an endoscope mounted on a platform with reduced pool water level, the position of the crack was identified and a stainless steel sleeve was inserted to plug the crack. The correct positioning of the sleeve was inspected, verified and a pressure test was successfully carried out following the equipment repairs.

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ANNEX I.1

Event Record to be Used for Data Collection at the TRIGA Wien

[NOTE: THIS INFORMATION IS SPECIFIC TO ONE REACTOR AND HAS BEEN INCLUDED AS AN EXAMPLE ONLY.]

EVENT RECORD			
Event Code(s)		Date	
		Time	
Facility	*TRIGA Mark II Vienna*		
Reactor power level at event			
System			
	Reactor safety & control system		
	Reactor core & fuel		
	Confinement & ventilation system		
	Electrical & emergency supply system		
	Radiation protection system		
	Primary coolant circuit		
	Secondary coolant circuit		
	Purification circuit		
	Radioactive waste treatment system		
	Experimental facilities		
	Others		
Main component			
Sub-component			
	Model type		
	Manufacturer		
	Date of first installation		
	Frequency of inspection		
	Last inspection date		
	Average # of demands per year		
Failure mode			
Stand-by systems			
	Fails to start on demand		
	False start (e.g. spurious trip)		

EVENT RECORD			
Event Code(s)		Date	
		Time	
Facility	*TRIGA Mark II Vienna*		
Continuously operating system			
	Fails to run (pump, circulate ...)		
	Fails to stop (trip, close ...)		
Both system types			
	– fails to operate as specified (e.g. shift in calibration, leakage ...)		
Type of failure			
	Mechanical		
	Electrical or electronically		
	Chemical		
	Human error		
	Calibration failure		
	Common mode		
	Others (like maintenance, wear)		
Failure reason			
Failure detection during			
	Routine operation on demand		
	Routine operation self-annunciating		
	Shut down		
	Inspection & service		
	Others		
Any present alarm level triggered (yes/no)			
	Alarm level setting		
	Maximum alarm		
	Level reached		
Consequences			
	Reactor shut down		
	Activity release		
	Radiation exposure		
	Contamination		
	Chemical hazard		
	Fire		
	Others (e.g. temporary loss of redundancy)		

EVENT RECORD			
Event Code(s)		Date	
		Time	
Facility	*TRIGA Mark II Vienna*		
Environmental conditions at failed component			
	Normal temperature		
	Event temperature		
	Normal relative humidity		
	Event relative humidity		
	Normal radiation		
	Event radiation		
	Other normal and event data		
Suggestions for improvement			

ANNEX I.2

Component failure rates evaluated at the TRIGA Mark-II reactor Wien

[NOTE: THIS INFORMATION IS SPECIFIC TO ONE REACTO AND HAS BEEN INCLUDED AS AN EXAMPLE ONLY.]

Reactor	Components	Cumulative calendar time	Cumulative operating time	Demands	Failure modes		Failures	Failure rate	Failure probability	90% Confidence bounds	
code	#	Mill. hours	Mill. hours	#	crit	degr	#	1E-6/h	1/demand	0,05	0,95
AT	3	0,297			F		2	6,73	—	1,20	15,97
AT	1	0,099			F		2	20,20	—	3,59	47,92
AT	12	1,190			F		2	1,68	—	0,30	3,99
AT	1	0,031			I		1	31,93	—	1,64	95,65
AT	1	0,027			F		1	36,49	—	1,87	109,30
AT	1	0,009			F		1	115,42	—	5,92	345,77
AT	1	0,009				B	1	115,10	—	5,90	344,81
AT	25	2,677			F		3	1,12	—	0,31	2,35
AT	4	0,397			F		3	7,56	—	2,06	15,86
AT	3	0,096				B	2	20,78	—	3,69	49,29
AT	16	0,491			F		14	28,52	—	17,24	42,11
AT	4	0,104			I		3	28,89	—	7,87	60,63
AT	1	0,140			F		1	7,13	—	0,37	21,36
AT	2	0,198			F		1	5,05	—	0,26	15,13
AT	6	0,063			F		1	15,84	—	0,81	47,44
AT	3	0,297			F		3	10,10	—	2,75	21,20
AT	3	0,297			Y		1	3,37	—	0,17	10,09
AT	10	0,992			F		2	2,02	—	0,36	4,78
AT	15	1,487			F		40	26,90	—	20,31	34,26
AT	1	0,069			F		1	14,52	—	0,74	43,51
AT	20	1,983			F		10	5,04	—	2,74	7,92
AT	1	0,062			F		1	16,23	—	0,83	48,61
AT	2	0,198				B	2	10,10	—	1,79	23,96
AT	33	1,654			F		22	13,30	—	9,01	18,28
AT	5	0,060			K		5	83,70	—	32,98	153,23
AT	1	0,021			F		1	48,51	—	2,49	145,31
AT	1	0,009			K		1	106,29	—	5,45	318,42
AT	2	0,061				B	2	32,91	—	5,85	78,07

Reactor	Components	Cumulative calendar time	Cumulative operating time	Demands	Failure modes		Failures	Failure rate	Failure probability	90% Confidence bounds	
code	#	Mill. hours	Mill. hours	#	crit	degr	#	1E-6/h	1/demand	0,05	0,95
AT	2	0,025			F		2	78,76	—	14,00	186,83
AT	3	0,032			K		3	94,84	—	25,85	199,03
AT	3	0,297			M		2	6,73	—	1,20	15,97
AT	2	0,034			M		2	58,89	—	10,46	139,69
AT	3	0,297			M		2	6,73	—	1,20	15,97
AT	1	0,126			F		1	7,94	—	0,41	23,78
AT	1	0,072			R		1	13,87	—	0,71	41,54
AT	1	0,099			F		1	10,10	—	0,52	30,26
AT	1	0,099			R		1	10,10	—	0,52	30,26
AT	1	0,099			F		1	10,10	—	0,52	30,26
AT	1	0,025			F		1	39,31	—	2,02	117,76
AT	7	0,433			F		2	4,61	—	0,82	10,94
AT	1	0,064			F		1	15,74	—	0,81	47,14
AT	1	0,099			E		2	20,20	—	3,59	47,92
AT	30	2,975			F		1	0,34	—	0,02	1,01
AT	1	0,099			X		2	20,20	—	3,59	47,92
AT	9	0,892			Y		1	1,12	—	0,06	3,36
AT	85	8,429			Y		4	0,47	—	0,16	0,92
AT	1	0,087				Y	1	11,55	—	0,59	34,61

1. EXPLANATION OF ABBREVIATIONS

1.1. Period of maintenance

m	once a month
4xy	four times a year
2xy	two times a year
y	once a year

1.2. Type of maintenance work

V	Visual inspection of the component
CL	Cleaning of the component either manually or by flushing with water
TR	Test run of the component (i.e. pump, ventilator) and acoustical control
Δp	Verifying the pressure difference (i.e. across water filter, air filter, ion exchange resin)
ON/OFF	On/off switch (i.e. of indicator lamps, control room light)
Ca	Calibration: Using a certified instrument (i.e. signal generator) to recalibrate a complete measuring channel (i.e. neutron channel)
S	Sample test: Using, i.e., a radiation source to test the performance of an area monitor
R	Records: Recording a value (i.e. consumption of cooling water, electricity)
St	Maintenance according to available national standards (i.e. crane, lifting device, emergency power supply)
T	Test: Activating a component and control of its function (i.e. movement of a control rod)
M	Measurement: For example, control of excess reactivity, dimensions of fuel elements, etc.

1.3. Responsibility of maintenance

IP — Internal personnel of operating license holder (i.e. reactor staff, technicians employed with the license holder).

EP — External personnel: Persons not employed by the license holder (i.e. outside companies hired and paid by the license holder).

- BM — Building management: In some cases maintenance of buildings is carried out by a governmental building management division, it could also be IP or EP.
- IAEA — International Atomic Energy Agency or any other international group carrying out safeguards inspection (i.e. EURATOM).
- EX — Expert nominated by the national regulatory body to participate in selected maintenance work (i.e. recalibration of nuclear channels).

2. SYSTEMS TO BE INSPECTED

2.1. Reactor Building

2.1.1	Roof	1xy	BM	V			
2.1.2	Windows	1xy	BM	V			
2.1.3	Foundations	1xy	BM	V			
2.1.4	Service door	1xm	IP	V			
2.1.5	empty						
2.1.6	Other doors to reactor	1xm	IP	V			
2.1.7	Lights in hall	2xy	IP	V			
2.1.8	Other lamps	1xm	IP	V			
2.1.9	Crane				2xy	EP	St

2.1.10	Chains				1xy	EP	St
2.1.11	Fuel storage pits	2xy	IP	V	1xy	IAEA	V

2.2. Ventilation System

2.2.1	Reactor Hall Ventilation System	1xy	IP	TR			
2.2.2	Beam Tube Ventilation System	1xy	IP	TR			
2.2.3	Control Room Ventilation System	1xy	IP	TR			
2.2.4	Central Heating of Air Condition	1xy	IP	TR			
2.2.5	Inlet-, outlet filter	1xy	IP	Dp			
2.2.6	Blower, Valves	1xy	IP	TR			
2.2.7	Under pressure Reactor Hall	1xm	IP	Dp			
2.2.8	Ventilation flow	1xm	IP	M			
2.2.9	Inlet electro filter	1xm	IP	Cl			

2.3. Reactor Tank and Shielding Structure

2.3.1	Tank, beam tubes thermal column	1xy	IP	V			
2.3.2	Mechanical structure of core	1xy	IP	V			
2.3.3	Moisture control between tank and concrete	2xy	IP	V			
2.3.4	Under water lamps	4xy	IP	V			
2.3.5	Condition of shielding concrete (cracks, paint)	1xm	IP	V			
2.3.6	Distillation plant for tank water addition	4xy	IP	M			
2.3.7	Reinspection and cleaning of the reactor tank	4xy	IP	Cl			

2.4. Reactor Core

2.4.1	Fuel element position	4xy	IP	V	1xy	IAEA	V
2.4.2	Fuel dimensions control	1xy	IP	M			
2.4.3	Control rods (motors, micro switch)	1xm	IP	V, M, TR			
2.4.4	Control of excess reactivity	2xy	IP	M			
2.4.5	Rod calibration	2xy	IP	M			
2.4.6	Compressor for transient control rod	4xy	IP	TR, V			

2.5. Reactor Safety System

2.5.1	Nuclear channels (power calibration)	1xy	IP	Ca	1xy	Ex	Ca
2.5.2	High voltage supply	1xy	IP	M	1xy	Ex	Ca
2.5.3	Rod drop time	1xy	IP	Ca	1xy	Ex	Ca
2.5.4	Neutron source	4xy	IP	M	1xy	Ex	Ca
2.5.5	Fuel temperature channels	1xy	IP	M	1xy	Ex	Ca
2.5.6	Water temperature channel	1xy	IP	Ca	1xy	Ex	Ca
2.5.7	Water level channels	1xy	IP	T	1xy	Ex	Ca
2.5.8	Indicator lamps	1xy	IP	V	1xy	Ex	Ca

2.6. Primary and Purification System

2.6.1	Primary pump	1xm	IP	TR			
2.6.2	Purification pump	1xm	IP	TR			
2.6.3	Primary filter	1xm	IP	Dp			
2.6.4	Valves and sensor (tightness)	4xy	IP	V			
2.6.5	Flow indicator (primary, (purification, filters)	1xm	IP	M			
2.6.6	Conductivity meter	1xy	IP	Ca			
2.6.7	Temperature meter	1xy	IP	Ca			
2.6.8	Differential pressureacross heat exchanger	1xy	IP	V			
2.6.9	pH-value	4xy	IP	M			
2.6.10	Pipes and valves to empty the reactor tank	1xy	IP	V			
2.6.11	Sump pump near heat exchanger	1xm	IP	TR			
		1xy	IP	Cl			

2.7. Secondary Cooling System

2.7.1	Ground water well	1xy	IP	V			
2.7.2	Secondary pumps	4xy	IP	TR			
2.7.3	Exchange switch pump 1 to pump 2	4xy	IP	on/off			
2.7.4	Compressor for pressure increase system	4xy	IP	TR	1xy	EP	Cl
2.7.5	Motor valve	1xm	IP	V	1xy	EP	TR
2.7.6	Sand filter	1xy	IP	Cl			
2.7.7	All valves (tightness)	4xy	IP	V			
2.7.8	Sump pump of pressure increase system	4xy	IP	TR	1xy	EP	Cl
2.7.9	Water meter	1xm	IP	R			
2.7.10	Sump pump at Institute exit	4xy	IP	TR	1xy	EP	TR

2.8. Area Monitors, Off-gas Monitors, Water Activity Monitors

2.8.1	Set-points of alarm limits	1xm	IP	S			
2.8.2	Control of instrument function with radioactive sample	1xm	IP	S	1xy	Ex	S
2.8.3	Portable dose rate meters	1xm	IP	S			
		1xy	IP	Ca			
2.8.4	Primary water activity (γ-spectroscopy)	1xm	IP	M			
2.8.5	Contamination wipe test reactor platform	1xm	IP	M			
2.8.6	Contamination control of off-gas detectors	1xy	IP	M			
2.8.7	Aerosol monitor reactor top	1xm	IP	S			
		1xy	IP	Ca			
2.8.8	Water activity monitor (purification loop)	1xm	IP	S			
		1xy	IP	Ca			

2.8.9	Water activity monitor (institute discharge)	1xm	IP	S			
		1xy	IP	Ca			
2.8.10	Data logger	1xm	IP	S			

2.9. Fuel Element Handling

2.9.1	Fuel element handling tool	1xm	A	V			
2.9.2	Fuel transfer container	1xm	A	V	1xy	EP	St

2.10. Experimental Facilities

2.10.1	Irradiation tubes (or Lazy Susan) Control of position, humidity, loading	4xy	IP	V, TR
2.10.2	Central thimble	4xy	IP	V
2.10.3	Thermal column (motor and switches)	4xy	IP	V, TR
2.10.4	Pneumatic transfer system	4xy	IP	V, TR
2.10.5	Beam tubes	2xy	IP	V
2.10.6	Beam tube parts (doors, loading machine)	2xy	IP	V
2.10.7	Experimental tank	1xy	IP	V
2.10.8	Vacuum cleaner (function, location, spare parts)	4xy	IP	V

2.11. Electricity and Emergency Supply

2.11.1	Emergency diesel	1xm	IP	TR	1xy	Ex	St
2.11.2	Emergency batteries	1xm	IP	TR			
2.11.3	Emergency lights	1xm	IP	TR			
2.11.4	Uninterrupted power supply	1xm	IP	TR			
2.11.5	Emergency hand lamps	4xy	IP	on/off			

2.12. Security System

2.12.1	Door surveillance	1xm	IP	V		
2.12.2	Intercom system	4xy	IP	TR		
2.12.3	Alarm system	1xm	IP	TR		
2.12.4	Telephone system	1xy	BM			
2.12.5	Security system	2xy	IP	T		
2.12.6	Fire extinguisher Service	1xm	IP	V	1xy	EP
2.12.7	Keys and locks	1xm	IP	on/off		
2.12.8	Gate to compound and TV-surveillance	1xm	IP	V, TR	1xy	EP
2.12.9	Emergency equipment	1xm	IP	V		
2.12.10	Internal alarms	1xm	IP	TR		
2.12.11	Emergency drill exercise	1xy	IP	TR		
2.12.12	On-duty officer control	4xy	IP	V		
2.12.13	Meeting of emergency Group	2xy	IP	Discussion		
2.12.14	Retraining of reactor operators	1xy	IP	Lecture, technical excursion		

3. SOME EXAMPLES OF INSPECTION FORMS

Some examples of inspection forms are presented below. These sheets cannot be standardized as they depend strongly on local conditions and they have to be prepared for each facility individually. For more complex systems as the primary cooling system or the ventilation system it is advisable to add a schematic diagram of the system where all components to be checked are numbered one by one and these numbers are contained in the inspection form.

[NOTE: All but two examples from the original document have been removed from this Annex. Other examples, such as work order forms, may be found in IAEA Safety Standards Series No. NS-G-4.2, Maintenance, Periodic Testing and Inspections of Research Reactors, IAEA, Vienna (2007).]

2.3.1 TANK, BEAM TUBES, THERMAL COLUMN **Sheet:**

Responsibility: IP Inspection period: 1xy Date: ....
DD MM YY

Visual inspection of tank:

Beam tube A

B

C

D

Thermal column

Neutron radiography facility

Tank bottom cleaned by pump on:

Remarks

Unterschrift (Signature)

2.4.3 CONTROL RODS **Sheet:**

Responsibility: IP Inspection period: 1xm Date: ....
DD MM YY

Rod position indicators:

up:	R (reg. rod)	(down):	R
	T (shim rod)		T
	I (transient rod		I

Time interval in [s] from down to up

R =

T =

I =

shock absorber of transient rod

Failure of indicator lamps at push buttons

R	T	I
↓	↓	↓
↑	↑	↑
⊥	⊥	M
T	T	↓
		M
Scram	Scram	↑

Pressure of transient rod at different locations

Tightness of shock absorber

oil leakage

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control of magnets:

R

T

Zero-point for position indicators

R

T

I

Optical inspection of rod guide tubes in the core

R

T

I

Remarks

Unterschrift (Signature)

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