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Safety considerations for research reactors in extended shutdown

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FOREWORD

According to the IAEA Research Reactor Database (RRDB) 651 research reactors have been constructed around the world for civilian applications. On the basis of the RRDB, 284 research reactors are currently in operation, 258 are shut down and 109 have been decommissioned. More than half of all operating research reactors reached their first criticality more than thirty years ago. Some face concerns of obsolescence of equipment, lack of experiment programmes, lack of funding for operation and maintenance, loss of expertise, equipment ageing and retirement of staff.

The 258 research reactors that no longer operate are in some form of shutdown. Some of these are expected to restart sometime in the future, some are awaiting decommissioning, with or without nuclear fuel in the facility, and the remaining reactors have no clear definition about their future. The undefined status of these remaining research reactors gives rise to safety concerns, in particular in the areas of loss of corporate memory, personnel qualification, maintenance of components and systems, and preparation and maintenance of documentation.

This report reflects the experience in extended shutdown of operating organizations and/or regulatory bodies in Belgium, Germany, Hungary, Israel, the Netherlands, the Russian Federation, Turkey, Ukraine and the United States of America. The IAEA staff members responsible for the publication were D. Litai and J. Bastos of the Division of Nuclear Installation Safety.

EDITORIAL NOTE

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1. INTRODUCTION

1.1. BACKGROUND

According to the IAEA Research Reactor Database, in the last 20 years, 367 research reactors have been shut down. Of these, 109 have undergone decommissioning and the rest are in extended shutdown with no clear definition about their future. Still other research reactors are infrequently operated with no meaningful utilization programme.

These two situations present concerns related to safety such as loss of corporate memory, personnel qualification, maintenance of components and systems and preparation and maintenance of documentation.

There are many reasons to shut down a reactor; these may include:

- the need to carry out modifications in the reactor systems;
- the need for refurbishment to extend the lifetime of the reactor;
- the need to repair reactor structures, systems, or components;
- the need to remedy technical problems;
- regulatory or public concerns;
- local conflicts or wars;
- political convenience;
- the lack of resources.

While any one of these reasons may lead to shutdown of a reactor, each will present unique problems to the reactor management. The large variations from one research reactor to the next also will contribute to the uniqueness of the problems.

Any option that the reactor management adopts will affect the future of the facility. Options may include dealing with the cause of the shutdown and returning to normal operation, extending the shutdown period waiting a future decision, or decommissioning. Such options are carefully and properly analysed to ensure that the solution selected is the best in terms of reactor type and size, period of shutdown and legal, economic and social considerations.

This publication provides information in support of the IAEA safety standards for research reactors.

1.2. OBJECTIVE

This publication addresses problems of the facilities in extended shutdown with no clear definition about their future, but which may be returned to operation at some future time. If the option decided upon is decommissioning, relevant IAEA publications to be consulted include Refs [1–3].

The objective of this publication is to:

- state the problem of extended shutdown and its safety implications, such as the ageing and resignation of the operating and support staff;
- review the implications of extended shutdown on reactor components and systems;

- provide guidance aimed at assisting operating organizations in planning and implementing extended shutdown, and especially the maintenance or replacement of affected systems;
- assist the regulatory body in determining the requirements that are to be satisfied by an organization that is responsible for a reactor in extended shutdown and for the relicensing of a reactor previously in extended shutdown;
- provide guidance for decision makers to assist in the determination of the future of the reactor.

It is not the intention of this publication to encourage the practice of extended shutdown. In fact, it is advisable that a reactor be decommissioned if it cannot be operated or refurbished.

1.3. SCOPE

With the exceptions noted below, this publication is applicable to any type of research reactor. It may also be applied to critical or subcritical assemblies to the extent that is appropriate for these facilities.

In the context of this publication, the term research reactor covers the reactor itself, experimental facilities and all other facilities relevant to either the reactor or its experimental facilities located on the reactor site.

1.4. STRUCTURE

This text has been structured as follows: Section 2 gives the definition of extended shutdown. Section 3 deals with preparation and planning for extended shutdown, including staffing, documentation and quality assurance (QA) needs. Section 4 gives guidance on implementation of extended shutdown, with its staffing, documentation, QA and physical and radiation protection needs. Section 5 provides guidelines for the stage of research reactor life cycle following extended shutdown such as restart or decommissioning.

The three annexes contain information on the extended shutdown of three research reactor facilities in three Member States. The information is based on a questionnaire drawn up by the IAEA.

Annexes I, II and III discuss examples in Turkey, Ukraine and the Russian Federation, respectively.

2. THE EXTENDED SHUTDOWN REGIME

2.1. GENERAL CONSIDERATIONS

At some point in the life cycle of a research reactor it may become necessary to shut down the reactor because of some problem. Based on the nature of the problem and other data (technical aspects, manpower availability, delivery schedules, etc.), it may be possible to predict that the shutdown will be for a fixed period of time. During this period, the operating staff will continue to meet the requirements of the operating license by performing the surveillance, periodic testing, maintenance, personnel training and retraining and other requirements of the operating limits and conditions (OLCs).

While the operating staff of a shut down reactor may be smaller than that for an operating reactor, a large reduction in the staff is unusual because of regulatory and other concerns such as loss of corporate memory and difficulty in re-staffing. In addition, because of the expectations of a fixed and short duration of shutdown, it is usually not cost effective to seek savings beyond those inherent in shutting down the reactor.

During the shutdown period it may be found that the solution of the problem is more difficult than initially expected and the schedule slips, extending the shutdown period. At this point, the operating organization will reassess the situation to determine if additional actions are necessary to reduce costs by seeking regulatory relief of the operational requirements (i.e. a change in the OLCs, especially in frequencies of periodic testing and inspection).

2.2. PRESERVATION FOR FUTURE OPERATION

There are basically two options for preservation of the facility for future operation. The first option usually used for a short duration is to perform the usual maintenance and inspections as stated in the OLCs. The second option, usually chosen when there is no clear time when the facility will return to operation, is to mothball the facility.

2.2.1. Shutdown of limited duration

For a shutdown of limited duration the operating organization will continue to meet all the requirements of the operating license. As mentioned, relief from some regulatory provisions to reflect the fact that the facility is shut down may be sought from the regulatory body.

2.2.2. Mothballing

Mothballing means to place the facility in a condition of preservation in order to prevent degradation. Mothballing is characterized by the treatment afforded to major components of the reactor. Components and systems to be preserved might be physically removed from the environment in which they have been operating to a new environment where they are protected from degradation. For example, during shutdown of limited duration the core may or may not be unloaded depending on the complexity of the reactor type and safety considerations. However, for mothballing, core unloading is usually done.

The estimated duration of mothballing will determine the degree or level of preservation that will be performed. The extent of changes to the facility during mothballing will be based on the effort to achieve the desired preservation level and on the desired recovery from the mothballed condition.

It is important that all the activities conducted to achieve and sustain the preserved condition do not decrease the safety of the reactor facility below that of the facility when it is operating.

3. PLANNING THE EXTENDED SHUTDOWN

3.1. GENERAL CONSIDERATIONS

The planning for extended shutdown consists of a judicious selection of relief that can be allowed in place of the normal operational regime maintained in the facility. This relief may be sought in any of the following areas:

- reactor component requirements (e.g., fuel, moderator, etc.);
- staffing;
- surveillance, periodic testing and preventive maintenance;
- radiation protection supervision; and
- physical protection and safeguards.

It is important that this relief not lead to a decrease the safety of the installation. Therefore the extended shutdown needs be well planned in advance. The planning includes securing the necessary approvals.

The extended shutdown plan consists of:

- a list of systems to be taken out of operation or temporarily dismantled;
- procedures and measures to disconnect, dismantle and preserve these systems;
- modifications of the Safety Analysis Report (SAR) and the OLCs;
- determination of staff and shift needs (number of technicians, skills and experience) during the extended shutdown period;
- requirements for periodic testing and maintenance;
- procedures for the adaptation of drawings, procedures and instructions; and
- modification of the emergency planning and evaluation of radiological consequences.

One of the main incentives for extended shutdown is the reduction of the operating costs of the facility without decreasing its safety. The extent of the measures to be implemented will depend on the time frame assumed for the extended shutdown. Therefore, in selecting the extent of the measures, the combined costs of implementing the shutdown regime and the costs of returning to the original operational condition should be evaluated to see whether significant savings are achieved.

3.2. PREVENTING CRITICALITY

Measures to prevent the core from becoming critical are taken in order to allow a significant reduction in the attention given to the facility and to reduce the number of systems that remain operational. In many cases, the fuel is removed from the core and stored in an appropriate facility that assures subcriticality. When this is not feasible or too complicated in view of the envisaged time frame, other measures shall be taken to ensure that the reactor cannot become critical. Such measures may include disabling the reactivity control system, rearranging the core, inserting additional absorbers into the core or simply adopting new administrative controls.

For a heavy water research reactor, the D_2O used as moderator-coolant may be stored in a closed storage tank following the standard operational practice.

When subcriticality has been ensured, it is possible to look for relief from the normal operational regime and to start the implementation of the shutdown plan. Some measures may need changes in the prevailing OLCs, which need to be discussed with the safety committee and approved by the regulatory body while others do not involve changes in OLCs and their implementation may not need such consultation and approval.

3.3. PREPARATION FOR EXTENDED SHUTDOWN

In order to establish a safe extended shutdown period with some relief from the normal operating regime, the measures to be taken are planned in detail and reviewed by the competent committee(s) and/or authority. If the period of extended shutdown increases over time, the plan is reviewed and revised accordingly.

As a first step in the preparation of the extended shutdown period a decision needs to be made concerning the systems and the surveillance activities to be maintained as during normal operation. Systems to be considered include:

- ventilation system with the related monitoring devices;
- site utilities (electricity, water, heating, etc.);
- radioactive liquid waste discharge system;
- water purification system;
- on and off-site radiation monitoring system;
- instruments and control systems, as needed;
- emergency power supply;
- fire protection system;
- personnel access control systems;
- personnel monitoring systems;
- solid waste packaging and handling systems;
- lightning protection systems;
- elevator/hoisting devices;
- communication and physical protection systems.

In some cases, the maintenance and testing of these systems can be reduced compared with the operational state. This needs to be carefully examined and the influence on the OLCs and the SAR considered.

Consideration is given to those systems that may be taken out of service. This depends strongly on the reactor type. For those systems to be taken out of service, measures to minimize deterioration and prevent unauthorized use are instituted, such as:

- maintaining water quality to minimize corrosion;
- disconnecting the electrical power supply;
- maintaining appropriate environmental conditions (e.g., humidity).

It is very important to carefully verify the links and functions of auxiliary systems and the systems and equipment they serve before taking the auxiliary systems out of service. Care is needed when removing subsystems or auxiliary systems from service to ensure that the systems they service are not required.

When removing facilities that are operated by non-operations personnel (e.g., experimental facilities), care is needed to have sufficient information about these facilities to place them in a safe state. Special consideration is given to experimental facilities (and equipment) to be taken out of operation containing fissionable material, highly radioactive samples, samples sensitive to corrosion, etc. Special attention is given to possible unstable chemical processes.

Measures with implications in OLCs

In order to obtain relief with respect to some of the OLCs, a review is carried out resulting in a proposal for changes in the OLCs. The proposed modification of the OLCs is submitted to the regulatory body for its review, assessment and approval. After approval, the modification of the OLCs is formalized and implemented by the managers of the reactor.

An example of a relief in the OLCs for the extended shutdown is a ventilation system that contains consumable items such as filters. The ventilation established for normal operation when radioactive releases are produced may not be wholly needed in the shutdown condition. A reduction in ventilation rates may result in considerable savings in electrical power consumption and filter replacement.

An example of change in the OLCs is the primary coolant and water purification systems. These systems may be placed in a dry or wet condition, and many factors are considered in making the decision. The storage location in a wet condition of the fuel assemblies will need high purity water coolant and the needed water chemistry parameters can be easily achieved using the installed systems. The operating staff needs to be familiar with the techniques for maintaining the coolant in such a condition that corrosion rates of fuel and components are acceptable. Periodic testing to determine characteristics of the coolant also requires circulation of the water for proper sampling. For other types of storage (e.g. dry storage), new technology is needed. On the other hand, dry storage, once established, may be more desirable for very long storage periods because of low maintenance needs and less corrosion.

3.4. MAINTENANCE AND PERIODIC TESTING

During the extended shutdown period a modification of the preventive maintenance and periodic inspection programme can be introduced. Relief is possible in those activities that are a function of operating time or power generated such as:

- in-service inspection;
- maintenance activities;
- periodic surveys;
- other activities derived from the OLCs.

The preventive maintenance and periodic inspection programme and the related procedures need to be adapted to the above-mentioned modifications.

The extended shutdown period can be used for additional inspections not included in the original OLCs on components and/or systems inaccessible during normal operation, (e.g., because the core cannot be unloaded or the beryllium reflector cannot be dismantled) such as:

- inspection of reactor vessel or core support structure;
- inspection of core structure internals, including the connection bolts;

- dimensional control and alignment of the core internals and control rod drives mechanism;
- inspection of beam ports.

It is important to turn special attention to inspections that could indicate degradation of mechanical and electrical systems and components. In addition, attention is directed at the applicability of computer software and hardware to the extended shutdown conditions.

3.5. HUMAN RESOURCES

The measures discussed above will influence the staff needs of the operating organization. In order to minimize the loss of operating experience and knowledge of the reactor facility, additional tasks are defined for operators, as well as for other staff members. Staff members could be involved in the preparation and implementation of extended shutdown plan activities. Delegating additional tasks to staff members will require appropriate education and training in the new duties.

The number of persons needed for a reactor in extended shutdown may be less than that needed for a running reactor. This may lead to a temporary reorganization of the operating organization that may need approval of the regulatory body. Special care is needed to retain enough personnel to respond to emergency situations.

As the shutdown period extends, knowledge of the facility and experience in maintenance and operation decrease as personnel leave the facility. Thus, at the time of restarting there may be an insufficient workforce present with adequate knowledge to guarantee a safe restart. It is desirable that a well-defined and implemented recruitment and training programme be used to offset losses of experienced staff.

Training and retraining of the personnel of a reactor in extended shutdown is an important issue. The usual intent of the operating organization is to restart the reactor when the reason for the shutdown is corrected. If the causes for the shutdown remain, the reactor may be decommissioned. Both options, return to operation or decommissioning, need experienced staff. Training people for these activities can be a long and expensive process if the personnel policy of the operating organization is not carefully planned.

3.6. PREPARATION OF DOCUMENTATION

A report should be prepared for review by local safety committees and the regulatory body, with the following content:

- the extended shutdown plan;
- projected duration of the shutdown period;
- overview of the present facility status;
- evaluation of the facility status to be achieved to preserve the present safety level of the facility including the revised preventive maintenance and periodic testing plan;
- overview of the systems to be disconnected with the measures utilized to protect these systems against deterioration.

The preparations for the extended shutdown period include the development of a written plan by the operating organization, reviewed and assessed by the regulatory body. The plan details the needs for sustaining the shutdown condition.

If changes in the OLCs are made, the reactor documentation is revised. Revisions are made to the SAR, the Emergency Preparedness Plan and to the operating and maintenance procedures.

All operating procedures are reviewed in order to ascertain their applicability to the new status of the facility. As a result of the review, some procedures will be applied as stipulated, others revised, and some withdrawn.

Original versions of the procedures have to be retained because they will be needed when the facility is returned to operation.

It is desirable that special attention be given to identification and control of documents, especially to those documents which will be used again during and after return to operation such as: original check-out procedures, operating procedures, drawings, maintenance and periodic testing programmes, and quality assurance (QA) documentation.

3.7. QUALITY ASSURANCE

The plan of extended shutdown includes appropriate QA requirements. The purpose of these requirements is to demonstrate and ensure that adequate arrangements have been made to achieve successful management of the reactor during the extended shutdown period. If there are no changes in the OLCs, the QA programme of the operational facility can be used without any change. If the OLCs have been modified, the existing QA programme has to be revised.

In many cases, during the extended shutdown, some refurbishment or reconstruction may occur. For these projects, a separate QA programme may be developed and applied.

During the period of extended shutdown, information relating to the locations, configurations, quantities and types of radioactive materials remaining at the reactor facility are maintained. If components or experiments are taken out of service but not immediately dismantled, the plan specifies the future maintenance and surveillance activities, as well as the need for documentation of the results of these activities.

3.8. REGULATORY ASPECTS

In some Member States, existing regulations may not specifically address extended shutdown. Therefore, before entering into extended shutdown, it is advisable to assess the existing regulatory framework to determine its suitability to regulate extended shutdown. If extended shutdown regulations do not exist, it is important for the operating organization to establish an early dialogue with the regulatory body.

The regulatory body needs to be consulted before decisions are made concerning the extended shutdown. The regulatory process for extended shutdown may differ from that applicable to reactor operation.

The main responsibility of the regulatory body is to review, assess and approve the extended shutdown plan and supplemental documentation including the modified SAR and OLCs, to be submitted to it by the operating organization. Depending on the legal framework of the Member State, a special permission or a license amendment with specific safety requirements may be issued by the regulatory body for the extended shutdown period.

In some Member States, a licensed or certified reactor operator is obligated to perform a minimum number of manipulations per year to retain his license. If the reactor is under extended shutdown, it may be impossible to meet this obligation, and therefore, relief from the regulatory body will be necessary.

4. IMPLEMENTATION OF THE EXTENDED SHUTDOWN PLAN

4.1. GENERAL CONSIDERATIONS

The reactor manager is responsible for the implementation of the extended shutdown plan. The systems to be taken out of service are identified and removed from service in a logical order taking into account criticality prevention. These systems status need to be indicated by using tags, tape or paint. The operating procedures are reviewed to determine whether appropriate instructions are available to prevent undesired use of the systems taken out of service, such as:

- the electrical power supply;
- the isolation valves;
- radiation controlled areas, as needed.

Special attention is given to those systems which will be partly taken out of service such as: the uninterruptible power supply; coolant systems; and interlock systems.

Appropriate procedures are prepared and approved describing the measures to be taken to protect the systems against deterioration.

Depending on the degree of modification, substantial reduction of routine operations may be appropriate. An overview of the routine operations related to the status of the reactor is presented in Table I.

Although in many cases full ventilation provisions are not mandatory, it is necessary to maintain a reduced ventilation flow for air conditioning of the reactor building. The exhaust monitor system needs to be readjusted in accordance with the reduced ventilation flow.

To avoid confusion due to misleading signals, instrumentation and control systems for components and equipment out of services are disconnected from the control panel in the control room to the extent possible.

A complete disconnection of the instrumentation and control systems are avoided since essential interlock and monitoring control and alarm functions are still needed, such as:

- fire protection;
- radiation protection;

TABLE I. OPTIONS FOR SHUTDOWN REGIMES

	OPERATIONAL MODE	**EXTENDED SHUTDOWN MODE**	**MOTHBALLED MODE**
STAFF NEEDS			
Operations		Generally reduce staff; only backup/on-call services and for regular inspections	Greatly reduced; only “skeleton” crew to be retained
Maintenance	All staff maintained; reduce number of shifts and shift size as needed	Retain electronics, and electricians personnel	
Radiation Protection		As needed	No local staff needed if on-call surveillance is available
Other Services (administrative)		As needed	
Security		As and where needed	As and where needed
INFRASTRUCTURE NEEDS	All infrastructure needed	All infrastructure needed	All infrastructure needed
SYSTEM NEEDS			Unused systems may be disconnected and safely stored
I&C*	All	Signals from out of service systems/ components should be disconnected	Signals from out of service systems/ components should be disconnected
Pumps	Main pumps in operation	Auxiliary pumps available	Auxiliary pumps available
Ventilation	In operation	Reduced ventilation	Reduced ventilation
Radiation Protection (fixed area monitors); Fire Detection; Water Purification.	In operation	In operation	In operation
Emergency Power Supply	In operation	Auxiliary power supply needed, but not immediate automatic start.	Auxiliary power supply needed, but not immediate automatic start
PERIODIC TESTS / SURVEILLANCE	Normal operational regime continued	Reduced regime; mostly reduced frequencies	Further reduction of number and frequency of inspections
REGULATORY REQUIREMENTS	All OLCs valid	Little or no relief in OLCs sought	Substantial relief in the OLCs

*Instrumentation and control.

- flooding;
- water level in pools and vessels;
- air pressure valves;
- physical protection alarms.

Thresholds and alarm limits are readjusted if necessary in compliance with the modified and approved OLCs and current status of the facility.

Special attention needs to be paid to implementing additional maintenance and radiological requirements such as:

- preventing stagnant water in the spent fuel storage pool and maintaining water chemistry as needed;
- operating the pumps, valves and, ventilators periodically;
- preventing systems containing radioactive contamination from drying out (purification systems, coolant systems, experimental facilities, sumps, hot and other drain systems).

Radiological protection of staff and the environment can be assured through a well-planned and adequately implemented radiological surveillance programme. Rezoning of radiological protection areas may justify relief from practices in effect for normal operation. It is necessary that the extended shutdown plans contain the details of the new zoning of areas, if any.

4.2. EXTENDED SHUTDOWN WITH NO IMPLICATIONS FOR OLCs

In most cases, the research reactor will be brought into extended shutdown while remaining in a fully operable condition, with normal maintenance and periodic testing activities being conducted pursuant to normal, unrevised procedures, and without seeking OLC changes. There can be relief only in those preventive maintenance activities (e.g. oil, bearings or filter replacement) whose frequencies are a function of the operating time of the equipment. Operational testing of systems continues and, if a malfunction is discovered, the failed system is repaired and made operational again.

Staff qualification is preserved by continuing the training and re-training programme and by performing the activities of the maintenance and periodic testing programme. To the extent possible, operator training is advisable at similar facilities or carried out by simulation.

4.3. EXTENDED SHUTDOWN WITH IMPLICATIONS FOR OLCs

If revised OLCs (e.g., reduced surveillance and maintenance activities) are requested for the extended shutdown, the operating organization needs to justify them. This justification includes the modifications carried out on the reactor systems and equipment. In this case, the SAR is revised and updated.

The modifications are summarized in a report including the result of the safety review and the proposed amendments to the license, which needs to be submitted for approval to the regulatory body. The operating and maintenance personnel is to be trained and retrained in the modified OLCs.

4.4. REASSESSMENT REVIEW

In order to evaluate the effectiveness of the measures taken for the extended shutdown period, reviews are performed on a regular basis. Although their exact interval depends on the extent of the measures taken and the expected time for restarting the reactor, a review at least annually is desirable. If the extended shutdown regime is prolonged beyond the initial time limit, a new review has to be performed.

This review also evaluates further modifications of all the items discussed in relation to the ongoing needs. If the review demonstrates that further modifications are desired that lead to a new request for OLC changes, the modified shutdown plan needs to be reviewed and approved by the regulatory body.

4.5. DOCUMENTATION

The period of extended shutdown is used for revision of the existing facility documentation. The maintenance activities should be documented and the work permits, records and certificates archived. The logbooks are kept up to date with all activities recorded.

All activities are documented in order to preserve the systems and components for future operation. Depending on the shutdown period, staff changes may occur before restarting the reactor. Therefore, a detailed and accurate documentation of the modifications implemented is needed.

4.6. QUALITY ASSURANCE

The QA needs for the shutdown reactor will essentially be the same as those of the operating reactor. In many cases, preservation in the extended shutdown condition means dismantling of components. Since the QA programme of an operational reactor usually does not cover these activities, the programme is to be extended to include them.

4.7. RADIATION PROTECTION

As nuclear and irradiated materials are still present in the facility, a radiation control programme needs to be in place. The radiation protection and monitoring system remains in operable condition during the extended shutdown and eventual restarting or decommissioning.

4.8. PHYSICAL PROTECTION

If spent and/or fresh nuclear fuel or other nuclear material is stored in the facility, the physical protection measures are preserved. If the fuel is unloaded from the core, the safeguard measures and provisions are ensured for the new storage location. If fuel is transported to another facility, the physical protection measures may be revised and relief may be obtained. In the case of a long term extended shutdown involving storage of the spent fuel elements at the site, attention should be given to the “self-protection” of the fuel that can change the nuclear material categorization, which will affect the physical protection needs. Since fewer routine activities are occurring in the facility, increasing the frequency of security patrols may be desirable.

4.9. REGULATORY ASPECTS

During the extended shutdown period, the regulatory body is responsible for conducting inspections of the facility. Depending on the size of the operating organization and the complexity of the facility, the scope and frequency of the inspections may be decreased from those established for normal operation.

The inspections may be of the following nature:

- a general inspection which includes all of the technical and administrative issues related to maintaining an adequate safety level in the facility during the extended shutdown; or
- a specific inspection, if a particular issue needs the attention of the regulatory body.

The basic purpose of such inspections is to confirm that the approved extended shutdown plan is being implemented and specific safety requirements established for this period are being met. From these the most important issues to emphasize are as follows:

- nuclear safety (handling and storage of fuel to avoid criticality whether in the reactor core or in a storage facility);
- radiation protection (protection of the operating staff and the public against excessive exposure and measures to prevent radioactive materials from being released to the environment);
- technical issues (degradation of systems, structures and components important to safety);
- operating staff (training, re-training and re-licensing).

It is important that the results of each inspection are well documented and, if needed, appropriate enforcement measures implemented.

5. RETURN TO OPERATION OR DECOMMISSIONING

5.1. RESTART WITH NO IMPLICATIONS FOR OLCs

As needed, the information submitted to the regulatory body to support the return to operation may include the following:

- a brief description of the extended shutdown, (e.g., reasons, intended options after the extended shutdown), including:
  - (i) a list of systems and equipment that were subjected to normal operation and maintenance during the shutdown;
  - (ii) a list of systems and equipment that were subjected to reduced operation and maintenance and systems and equipment that were retired from service and stored under protective conditions;
  - (iii) the results and records of the maintenance and periodic testing during the extended shutdown period;
  - (iv) the results of the pre-operational tests conducted on the systems and equipment that were subjected to reduced operation and maintenance or retired from service and stored under protective conditions.

- the provisions for organization of reactor management for the return to operation, for retraining of the existing staff, and for recruitment of new staff and their qualification, training and licensing;
- a description of the intended utilization programme for the reactor facility.

5.2. RESTART WITH IMPLICATIONS FOR OLCs

In this case, the information submitted to the regulatory body to support a request to resume operation is the same as given in the previous section, but also contains a report describing the reassessment of reactor facility safety. This reassessment needs to place emphasis on the status of the systems and equipment that were not subjected to periodic testing and in-service inspection as a consequence of the modification of OLCs during extended shutdown.

All systems and components are subjected to re-commissioning and acceptance tests equal to those carried out during the initial commissioning of the reactor.

If the core used prior the extended shutdown is re-used, special care is needed when approaching criticality and when power escalation is in progress. It is very important that the last known core configuration be assembled. When approaching criticality, the changes in the excess reactivity and the shutdown margin compared with the previous state can be determined accounting for changes in the worth of the control elements, beryllium poisoning, etc. Because of the possibility of cladding failures during the shutdown period, it is desirable that inspections (sipping tests, visual inspection, etc.) be performed to the extent possible before reloading the fuel and to perform the power escalation slowly, performing fission product leak testing at several steps.

5.3. RESPONSIBILITIES OF THE OPERATING ORGANIZATION

The ultimate responsibility for the safe return to operation rests with the operating organization. In this connection, the operating organization:

- reviews the operational status of the reactor systems and components, particularly those that may have been modified during the shutdown period;
- verifies the adequacy of the staff and its qualification and training;
- prepares a safety evaluation which includes the return to normal operational conditions (revision of SAR);
- prepares a recommissioning plan and emergency preparedness plan to be submitted to the regulatory body for approval;
- prepares a report with the results of the above to be submitted to the regulatory body;
- following approvals, implements the recommissioning plan.

5.4. DOCUMENTATION

If needed, prior to recommissioning, the operating organization revises and submits to the regulatory body for review and approval the following documentation:

- a report of the history of the extended shutdown including a report of the activities conducted during the shutdown;
- the revised SAR;

- the recommissioning programme including an emergency preparedness plan for this activity.

Depending on the results of the recommissioning, modification of the SAR and the Emergency Preparedness Plan may become necessary.

The existing operating and maintenance procedures of the facility need to be examined to determine if they need revision.

The documents essential to the performance and verification of re-commissioning activities are controlled. Records pertaining to recommissioning are controlled so that at all times they provide particulars that will enable their identification, review, approval, filing, storage, maintenance and disposal.

5.5. QUALITY ASSURANCE

Prior to activities for restarting the reactor, the QA plan is reviewed to ensure that it is applicable to the recommissioning programme.

The QA programme applies to the recommissioning of all components, services and processes important to safety and includes means of establishing controls over recommissioning activities to provide confidence that recommissioning is performed according to the approved plan.

The QA programme describes the system that controls the development and implementation of the recommissioning process. The QA programme rests on a programme description and documented procedures and work instructions. The work instructions document both the recommissioning activities and the verifications associated with specific recommissioning activities. The QA programme needs to be communicated to the staff. Guidance on the requirements for a QA programme for a research reactor is presented in Ref. [4].

5.6. REGULATORY ASPECTS OF RESTART

The return to operation may need a formal approval or authorization from the regulatory body. In this case, the operating organization prepares an official request to the regulatory body, which will base its decision on the information submitted by the operating organization and on the information that the regulatory body may have acquired from inspections during the extended shutdown. The information submitted by the operating organization will depend on whether new licensing conditions have arisen or whether the extended shutdown has involved changes in the OLCs.

Depending on the legal framework and the regulations of the Member State, the operating organization prepares recommissioning documentation as discussed in Section 5.4 and submits it to the regulatory body for approval prior to re-commissioning.

For return to operation, the regulatory body:

- reviews the report and recommissioning plan submitted by the operating organization and, if the evaluation is satisfactory, approves the recommissioning of the reactor;

- issues a formal authorization for the reactor operation;
- carries out inspections during the recommissioning of the reactor, as needed.

5.7. DECOMMISSIONING

If the problems that have caused the extended shutdown cannot be solved satisfactorily within a reasonable time, a decision may be made to decommission the reactor. While a discussion of the methods and techniques for decommissioning a research reactor facility is beyond the scope of this publication, the IAEA has developed guidance material on decommissioning e.g. [1–3]. The references include guidance material for the decommissioning of nuclear power plants that may be applicable to high power level research reactors.

While the decommissioning process may vary among Member States, all will need a decommissioning plan prepared by the operating organization for submission to the regulatory body for approval. An important component of the plan is a radiological survey of the research reactor facility to determine the extent and magnitude of the radioactivity and contamination. Of equal importance is the plan for a final radiological survey of the facility before it is relieved of licensing requirements and released for unrestricted use.

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Annex I
EXTENDED SHUTDOWN OF THE RESEARCH REACTOR TR-2, TURKEY

Country: TURKEY	
Research reactor name: TR-2 Turkish Reactor 2	Power: 5000 kW
Research reactor code: TR-0002	Designer:
Reactor type: POOL	Start of operation: December 1981

	Out of service during ES*	Partly dismantled	Degradation detected	Modification for returning to operation
Reactivity control system				
Control rod drive system	N	N	N	N
Regulating rod system	—	—	—	—
Neutron flux monitoring	N	N	N	N
Other systems such as				
Instrumentation and control systems				
Reactor power control system	N	N	N	N
Annunciation/alarm system	N	N	N	N
Process monitoring (temperature, flow, level, leak detection….)	N	N	N	N
Computer hardware	N	N	Y	Y
Computer software	—	—	—	—
Electrical systems				
AC power supply	N	N	Y	Y
DC power supply	Y	Y	Y	Y
Emergency power supply	N	N	N	N
Water systems				
Primary cooling system	N	N	N	N
Primary pressure control, including safety relief valves	—	—	—	—
Secondary cooling system	N	N	N	N
Cooling tower	N	N	Y	N
Emergency core cooling system	—	—	—	—
Residual heat removal system	—	—	—	—
Pool cooling system	—	—	—	—
Water purification system	N	N	N	N
Demineralized water supply system	N	N	N	N
Heating, ventilation and air conditioning systems				
Containment/confinement	N	N	Y	Y
Control room	N	N	N	N
Spent fuel building	—	—	—	—
Waste management building	—	—	—	—
Radiation monitoring systems				
Internal radiation monitoring	N	N	N	N
Environmental monitoring	N	N	N	N

*ES: extended shutdown.

	Out of service during ES	Partly dismantled	Degradation detected	Modification for returning to operation
Support systems				
Compressed air	N	N	N	N
Other systems	N	N	N	N
Fire systems				
Fire detection system	—	—	—	Y
Fire fighting system	N	N	Y	Y
Experimental devices				
Neutron irradiation devices	N	N	N	Y
Gamma irradiation devices	—	—	—	—
Isotope production facilities	N	—	Y	Y
Beam tubes	—	—	—	—
Hot cells	—	—	—	—
Other systems				

*ES: extended shutdown.

Reason for extended shutdown

Requirements to re-licensing the facility considering earthquake resistance of the reactor building, and to perform the necessary reinforcement and refurbishment works.

Measure to prevent criticality

On July 20, 1995 the reactor was shutdown and the reactor core was unloaded. Because of the lengthening of the re-licensing period and review of the SAR, TAEK (Turkish Atomic Energy Authority) gave permission for limited operation to maintain the system's operability and the validity of the operators' license. By the end of 2000 the core was unloaded again.

Adaptation of the Safety Analysis Report

The SAR was updated and reviewed according to the Agency's Safety Guide SS 35-G1. Some parts of the SAR were revised or supplement material added. This concerns mainly the seismic behaviour of the building, re-definition of the most severe accident and doses associated.

Operational limits and conditions

After shutting down the reactor, TAEK issued permission for the reactor to be operated on a limited basis. There were no changes in the Operational Limits and Conditions except for the operation time. Initially the permission allowed the reactor to be operated from 5 to 6 hours a month at full power. After some time this procedure was modified and TAEK started to require an application each time the reactor was going to be put into operation. The maximum power was limited to 3 MW and no more than 4 hours of continuous operation was permitted. Operations were definitively stopped in July 1999 and at the end of 2000 the core was unloaded.

Maintenance and periodic testing

The reactor staff is performing the required maintenance and periodic testing of the systems. The cooling systems are put into operation between 4 to 5 hours every week and the water purification system is operating continuously to maintain the quality of the pool water. Instrumentation and control (I&C) systems are checked twice a year and detected failures are repaired.

Procedures

All the procedures are the same as for the operating reactor. There are no specific procedures prepared for the extended shutdown situation. Failure and repair records of the I&C systems and daily checklists for the facility are maintained.

Utilization

The reactor was under-utilized. Radioisotope production (small amounts of ^{99}Mo and ^{192}Ir), activation analysis and training of University students (nuclear engineering, physics, chemistry and biology) constituted the main uses.

Radiation protection

Risks of radiation exposure and contamination during the shutdown period are limited. The loading and unloading of the core are potentially the activities involving more risks for the operators. Health physicists are carrying out radiation and contamination checks of the facility in a monthly basis. Radioprotection channels on I&C continuously monitor the reactor hall and the exhaust air from the building.

Emergency preparedness

There is an emergency plan as a part of the SAR, but no drills have been conducted up to now.

Human resources (workforce, training and qualification)

A small number of well-qualified personnel remain at the facility (one engineer and four technicians). They perform daily checks, maintenance and repairs of mechanical components. There are no reactor operators at present. The shift supervisors carry out the duties of the operators. There are four supervisors with background in physics, mechanical engineering and nuclear engineering. There are no technicians for electrical and electronic work, which is performed by the supervisors.

Degradation of systems

The most vulnerable parts are the cooling systems. The performance of the systems is checked weekly by running the pumps and the cooling towers. Failures and small defects are repaired, but large maintenance projects are mostly delayed.

Some components of electrical systems such as contactors, uninterruptible power supply (UPS) and some cabling might be replaced before the reactor restarts. The same applies to some parts of the I&C system (such as recorders and detectors).

Irradiated fuel elements are also subject to ageing because most fuel elements are stored in the pool for almost 18 years. However all of them are in good condition as determined by inspection and the radioactivity control of the pool water.

Regulatory aspects

Regulatory control of the facility is performed by TAEK, which is the owner of the reactor. TAEK has initiated a Technical Cooperation Project with the IAEA for the analysis of the building structure. The project is in its final stage. The SAR will be updated accordingly for the future license application.

Problems encountered during return to operation

Although it does not appear that the building will require extensive modifications and reinforcement, financial support will be needed if the analysis proves otherwise.

Other issues for returning to operation are the improvement in the utilization of the reactor and manpower for the operating team. There is a need for reactor operators and electric and electronic technicians.

Annex II
EXTENDED SHUTDOWN OF THE RESEARCH REACTOR WWR-M, KIEV, UKRAINE

Country: Ukraine	
Research reactor name: WWR-M Kiev	Power: 10 000 kW
Research reactor code: UA-0001	Designer:
Reactor type: Tank WWR	Start of operation: 12.02.60

The reason for shutting down the WWR-M reactor of Kiev Institute for Nuclear Research was the requirement of the Ukrainian Nuclear Regulatory Administration to improve physical protection and fire protection systems. It was expected that the duration of the shutdown would not be too long. However, the shutdown period was extended because of lack of resources.

The core was unloaded into the spent fuel pool one month after shutdown to inspect the supporting grid while the reactor was not in operation. Before this operation, excess of reactivity was determined in terms of the position of control rods at the minimum level of power.

Since the duration of shutdown was expected not to be long, all reactor systems, except the core, remained in fully operable condition. The maintenance and periodic testing activities were conducted as required by the operating procedures. If a malfunction was detected, the failed system was repaired and made operational again. Procedures were not revised. Personnel qualification was maintained by providing regular training and by performing maintenance and periodic testing.

Four years later the Ukrainian Nuclear Regulatory Administration gave permission to load the core since all requirements were met. After the loading process it was observed an excess reactivity 2.0$ less than expected (by comparison to the last configuration before the shutdown). The regulatory authority requested an explanation for the discrepancy before authorizing the reactor restart.

The difference in coolant temperature and concentrations of Xe and Sm could not explain the difference. Careful checks were performed to verify that the new core configuration was identical to the last one before the reactor shutdown. Systems that could affect the reactor reactivity were also carefully checked.

The effect of ^{241}Pu decay on excess of reactivity after 4 years of shutdown was calculated to be less than 0.2$.

After extensive analysis it was concluded that the main reason for the reduction of the excess reactivity was the "poisoning" of the Be reflectors by ^{3}He due to the $^{3}H \rightarrow {}^{3}He$ reaction. The half-life of ^3H is 12.35 years while the thermal neutron capture cross-section for ^3He is 5500 barn. The main source of ^3He in the Be reflectors was the following:

1. $^9Be + n \rightarrow {^4He} + {^6He}$ (cross-section of this reaction as a function of neutron energy is shown in Fig. II-1);
2. $^6He \rightarrow {^6Li}$ (half-life of ^6He is 0.8s);
3. $^6Li + n \rightarrow {^3H} + {^4He}$ (thermal neutron cross-section of this reaction is 945 barn).

After the reactor re-start operation the amount of the ^3He in the Be reflectors decreased. However, for the WWR-M Kiev reactor the reactivity increase resulting from the reduction of ^3He was less than the reactivity decrease due to fuel burn-up. In this way the net excess reactivity was always decreasing for any power and at any period of reactor operation.

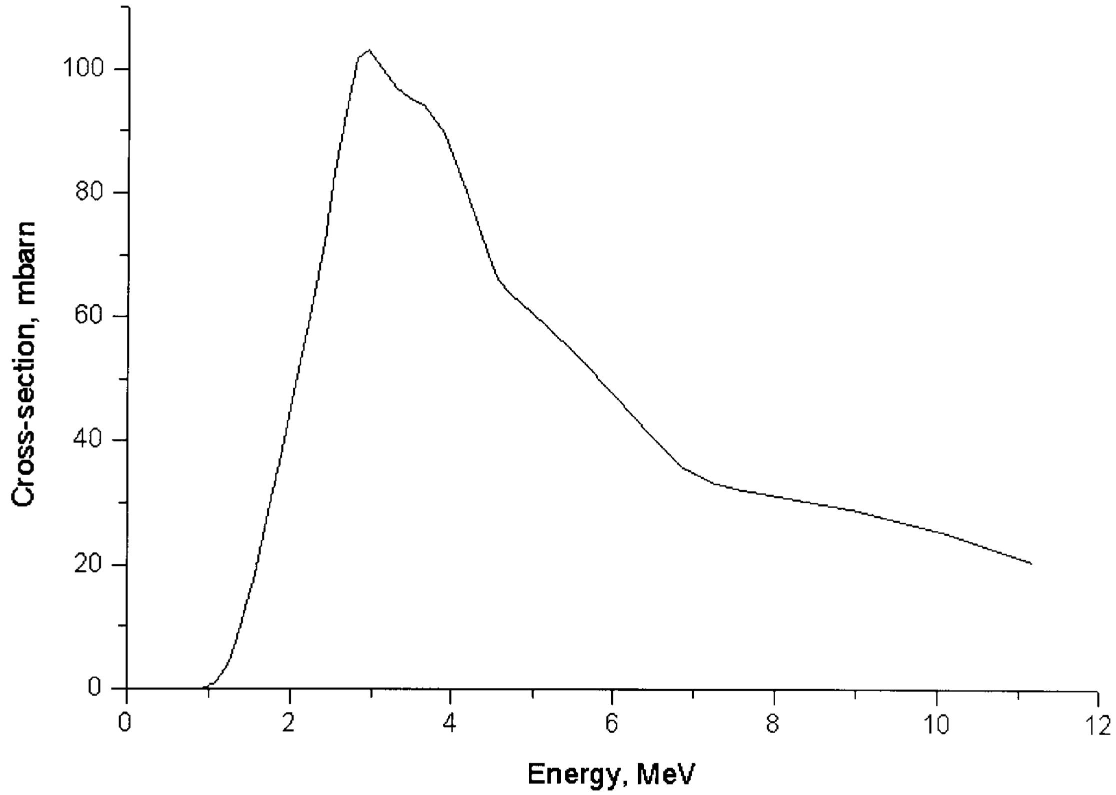

FIG II-1. Cross-section of ^9Be (γ, n) reaction as a function of neutron energy.

During core reloading photon-neutron background was high due to the $^9Be(\gamma,n)$ reaction. Reactivity measurements using the inverse count rate technique were possible only when criticality was approached. A special procedure was developed to safely reload the core. The main requirement of this procedure was to reload the core in the inverse order of the unloading.

During core unloading the excess reactivity was estimated based on the position of the control rods at the minimum power level. This operation was repeated several times. During core reloading excess reactivity was estimated by the same procedure and the results compared to the values obtained during core unloading. This assured the correct loading of the core.

Annex III
EXTENDED SHUTDOWN OF THE U-3 RESEARCH REACTOR, RUSSIAN FEDERATION

Country: Russian Federation	
Research Reactor Name: U-3	Power: 50 kW
Research Reactor Code: RU-0050	Designer:
Reactor Type: POOL	Start of operation: 01/01/1964

Owner: The Central Scientific and Research Institute named after scientist A.N. Krylov
Place: Saint-Petersburg, Russia Federation

The reactor started operation in December 1964. It is a 50 kW pool-type reactor moderated by light water and cooled by top-down forced circulation. The pool internal diameter is 1480 mm in the upper part and 450 mm in the lower part. The reactor core is located inside the pool 5 m below the pool water surface. The reactor core basket consists of two grid plates, upper and lower, which support 421 fuels elements of EK-10 type. The height of the core basket is 816 mm. Three heat exchangers submerged into the pool (0.95 m below the water surface and 4 m above the reactor core) assures the pool water cooling.

The reactor was intended for a variety of applied studies and investigations of materials properties, radioisotope production and for other purposes.

In September 1992, after 28 years of successful operation, a pool leakage of about 1 L/hour was detected. The leakage stopped with the water level 120 mm above the reactor upper grid plate. As a result of this event the reactor was shutdown and appropriate measures were undertaken to solve the problem.

The investigation techniques used to identify the defective region included visual inspection of the liner surface and welds with a magnifying device, and a camera to record the region under investigation. However, no defect was found.

The results of the investigation were reviewed by the competent organizations and it was assumed that the leakage was due to undetectable micro defects in welds or in the main material when the pool liner was manufactured.

In 1994, a decision was taken to cover the liner with a radiation-resistant metal polymer. The coating material had been extensively used in Russia and abroad in the nuclear industry for many years.

Before proceeding with the liner coating additional work was conducted to measure the wall thickness, to verify its load capability and finally to try once again to identify the defected region. To perform these works the reactor core was unloaded in July 1995.

Despite the efforts no defects were identified and a final decision was taken to coat the lower part of the liner with the metal polymer.

Before application, the material was submitted to appropriate radiation tests in an environment similar to that of the reactor.

The liner coating was performed and hydraulic tests showed no more leakage. The Russian Regulatory Authority established a criterion of maximum fluence of 10^{19} n/cm^2 (E ≥0,5 MeV) for the coating material.

Special coupons of the same material were introduced into the pool to periodically verify the coating conditions. Every two years the coupons are removed for analysis. The results obtained are used as a basis to authorize the reactor operation to the next period.

Gosatomnadzor of Russia issued the new license for operation in October 2000. During the three years of extended shutdown of the reactor (1992–1995), the operation was conducted under the same conditions as when the reactor was operating due to presence of fuel in the reactor core.

From 1995 to 2000, the regulatory requirements, including inspections, were relaxed to some extent. After the decision was taken to continue operation, the reactor was brought to the previous regulatory status.

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