

# IAEA Safety Standards

for protecting people and the environment

## Safety of Nuclear Fuel Reprocessing Facilities

Specific Safety Guide

No. SSG-42



**IAEA**

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# IAEA SAFETY STANDARDS AND RELATED PUBLICATIONS

## IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorized to establish or adopt standards of safety for protection of health and minimization of danger to life and property, and to provide for the application of these standards.

The publications by means of which the IAEA establishes standards are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety. The publication categories in the series are **Safety Fundamentals**, **Safety Requirements** and **Safety Guides**.

Information on the IAEA's safety standards programme is available on the IAEA Internet site

<http://www-ns.iaea.org/standards/>

The site provides the texts in English of published and draft safety standards. The texts of safety standards issued in Arabic, Chinese, French, Russian and Spanish, the IAEA Safety Glossary and a status report for safety standards under development are also available. For further information, please contact the IAEA at: Vienna International Centre, PO Box 100, 1400 Vienna, Austria.

All users of IAEA safety standards are invited to inform the IAEA of experience in their use (e.g. as a basis for national regulations, for safety reviews and for training courses) for the purpose of ensuring that they continue to meet users' needs. Information may be provided via the IAEA Internet site or by post, as above, or by email to [Official.Mail@iaea.org](mailto:Official.Mail@iaea.org).

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The IAEA provides for the application of the standards and, under the terms of Articles III and VIII.C of its Statute, makes available and fosters the exchange of information relating to peaceful nuclear activities and serves as an intermediary among its Member States for this purpose.

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Security related publications are issued in the **IAEA Nuclear Security Series**.

The **IAEA Nuclear Energy Series** comprises informational publications to encourage and assist research on, and the development and practical application of, nuclear energy for peaceful purposes. It includes reports and guides on the status of and advances in technology, and on experience, good practices and practical examples in the areas of nuclear power, the nuclear fuel cycle, radioactive waste management and decommissioning.

# SAFETY OF NUCLEAR FUEL REPROCESSING FACILITIES



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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

IAEA SAFETY STANDARDS SERIES No. SSG-42

# SAFETY OF NUCLEAR FUEL REPROCESSING FACILITIES

SPECIFIC SAFETY GUIDE

INTERNATIONAL ATOMIC ENERGY AGENCY  
VIENNA, 2017

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# FOREWORD

**by Yukiya Amano**  
**Director General**

The IAEA's Statute authorizes the Agency to “establish or adopt... standards of safety for protection of health and minimization of danger to life and property” — standards that the IAEA must use in its own operations, and which States can apply by means of their regulatory provisions for nuclear and radiation safety. The IAEA does this in consultation with the competent organs of the United Nations and with the specialized agencies concerned. A comprehensive set of high quality standards under regular review is a key element of a stable and sustainable global safety regime, as is the IAEA's assistance in their application.

The IAEA commenced its safety standards programme in 1958. The emphasis placed on quality, fitness for purpose and continuous improvement has led to the widespread use of the IAEA standards throughout the world. The Safety Standards Series now includes unified Fundamental Safety Principles, which represent an international consensus on what must constitute a high level of protection and safety. With the strong support of the Commission on Safety Standards, the IAEA is working to promote the global acceptance and use of its standards.

Standards are only effective if they are properly applied in practice. The IAEA's safety services encompass design, siting and engineering safety, operational safety, radiation safety, safe transport of radioactive material and safe management of radioactive waste, as well as governmental organization, regulatory matters and safety culture in organizations. These safety services assist Member States in the application of the standards and enable valuable experience and insights to be shared.

Regulating safety is a national responsibility, and many States have decided to adopt the IAEA's standards for use in their national regulations. For parties to the various international safety conventions, IAEA standards provide a consistent, reliable means of ensuring the effective fulfilment of obligations under the conventions. The standards are also applied by regulatory bodies and operators around the world to enhance safety in nuclear power generation and in nuclear applications in medicine, industry, agriculture and research.

Safety is not an end in itself but a prerequisite for the purpose of the protection of people in all States and of the environment — now and in the future. The risks associated with ionizing radiation must be assessed and controlled without unduly limiting the contribution of nuclear energy to equitable and sustainable development. Governments, regulatory bodies and operators everywhere must ensure that nuclear material and radiation sources are used beneficially, safely and ethically. The IAEA safety standards are designed to facilitate this, and I encourage all Member States to make use of them.



# THE IAEA SAFETY STANDARDS

## BACKGROUND

Radioactivity is a natural phenomenon and natural sources of radiation are features of the environment. Radiation and radioactive substances have many beneficial applications, ranging from power generation to uses in medicine, industry and agriculture. The radiation risks to workers and the public and to the environment that may arise from these applications have to be assessed and, if necessary, controlled.

Activities such as the medical uses of radiation, the operation of nuclear installations, the production, transport and use of radioactive material, and the management of radioactive waste must therefore be subject to standards of safety.

Regulating safety is a national responsibility. However, radiation risks may transcend national borders, and international cooperation serves to promote and enhance safety globally by exchanging experience and by improving capabilities to control hazards, to prevent accidents, to respond to emergencies and to mitigate any harmful consequences.

States have an obligation of diligence and duty of care, and are expected to fulfil their national and international undertakings and obligations.

International safety standards provide support for States in meeting their obligations under general principles of international law, such as those relating to environmental protection. International safety standards also promote and assure confidence in safety and facilitate international commerce and trade.

A global nuclear safety regime is in place and is being continuously improved. IAEA safety standards, which support the implementation of binding international instruments and national safety infrastructures, are a cornerstone of this global regime. The IAEA safety standards constitute a useful tool for contracting parties to assess their performance under these international conventions.

## THE IAEA SAFETY STANDARDS

The status of the IAEA safety standards derives from the IAEA's Statute, which authorizes the IAEA to establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection of health and minimization of danger to life and property, and to provide for their application.

With a view to ensuring the protection of people and the environment from harmful effects of ionizing radiation, the IAEA safety standards establish fundamental safety principles, requirements and measures to control the radiation exposure of people and the release of radioactive material to the environment, to restrict the likelihood of events that might lead to a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation, and to mitigate the consequences of such events if they were to occur. The standards apply to facilities and activities that give rise to radiation risks, including nuclear installations, the use of radiation and radioactive sources, the transport of radioactive material and the management of radioactive waste.

Safety measures and security measures<sup>1</sup> have in common the aim of protecting human life and health and the environment. Safety measures and security measures must be designed and implemented in an integrated manner so that security measures do not compromise safety and safety measures do not compromise security.

The IAEA safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation. They are issued in the IAEA Safety Standards Series, which has three categories (see Fig. 1).

### **Safety Fundamentals**

Safety Fundamentals present the fundamental safety objective and principles of protection and safety, and provide the basis for the safety requirements.

### **Safety Requirements**

An integrated and consistent set of Safety Requirements establishes the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements are governed by the objective and principles of the Safety Fundamentals. If the requirements are not met, measures must be taken to reach or restore the required level of safety. The format and style of the requirements facilitate their use for the establishment, in a harmonized manner, of a national regulatory framework. Requirements, including numbered ‘overarching’ requirements, are expressed as ‘shall’ statements. Many requirements are not addressed to a specific party, the implication being that the appropriate parties are responsible for fulfilling them.

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<sup>1</sup> See also publications issued in the IAEA Nuclear Security Series.

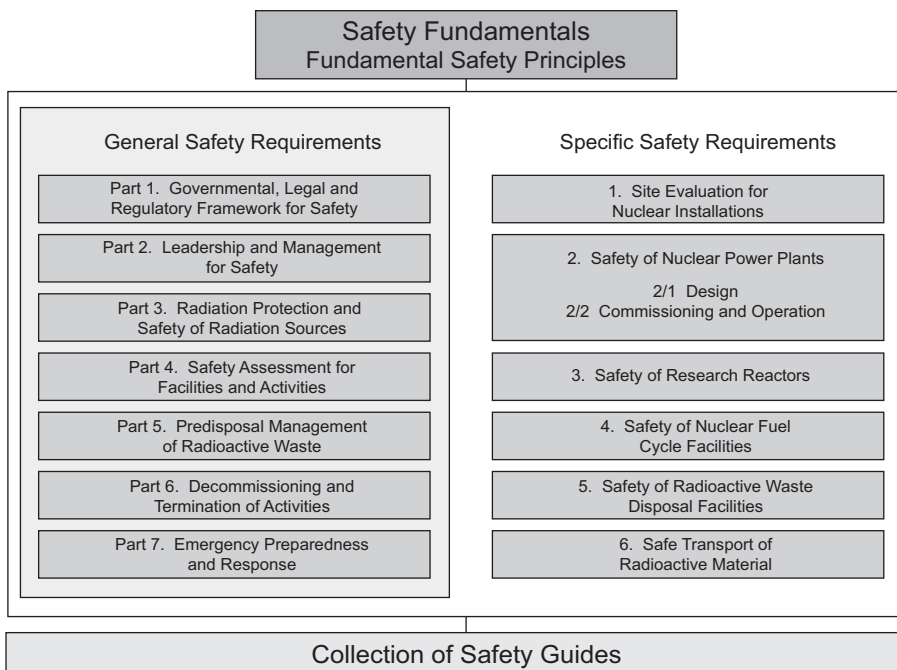


FIG. 1. The long term structure of the IAEA Safety Standards Series.

## Safety Guides

Safety Guides provide recommendations and guidance on how to comply with the safety requirements, indicating an international consensus that it is necessary to take the measures recommended (or equivalent alternative measures). The Safety Guides present international good practices, and increasingly they reflect best practices, to help users striving to achieve high levels of safety. The recommendations provided in Safety Guides are expressed as ‘should’ statements.

## APPLICATION OF THE IAEA SAFETY STANDARDS

The principal users of safety standards in IAEA Member States are regulatory bodies and other relevant national authorities. The IAEA safety standards are also used by co-sponsoring organizations and by many organizations that design, construct and operate nuclear facilities, as well as organizations involved in the use of radiation and radioactive sources.

The IAEA safety standards are applicable, as relevant, throughout the entire lifetime of all facilities and activities — existing and new — utilized for peaceful purposes and to protective actions to reduce existing radiation risks. They can be used by States as a reference for their national regulations in respect of facilities and activities.

The IAEA's Statute makes the safety standards binding on the IAEA in relation to its own operations and also on States in relation to IAEA assisted operations.

The IAEA safety standards also form the basis for the IAEA's safety review services, and they are used by the IAEA in support of competence building, including the development of educational curricula and training courses.

International conventions contain requirements similar to those in the IAEA safety standards and make them binding on contracting parties. The IAEA safety standards, supplemented by international conventions, industry standards and detailed national requirements, establish a consistent basis for protecting people and the environment. There will also be some special aspects of safety that need to be assessed at the national level. For example, many of the IAEA safety standards, in particular those addressing aspects of safety in planning or design, are intended to apply primarily to new facilities and activities. The requirements established in the IAEA safety standards might not be fully met at some existing facilities that were built to earlier standards. The way in which IAEA safety standards are to be applied to such facilities is a decision for individual States.

The scientific considerations underlying the IAEA safety standards provide an objective basis for decisions concerning safety; however, decision makers must also make informed judgements and must determine how best to balance the benefits of an action or an activity against the associated radiation risks and any other detrimental impacts to which it gives rise.

## DEVELOPMENT PROCESS FOR THE IAEA SAFETY STANDARDS

The preparation and review of the safety standards involves the IAEA Secretariat and five safety standards committees, for emergency preparedness and response (EPReSC) (as of 2016), nuclear safety (NUSSC), radiation safety (RASSC), the safety of radioactive waste (WASSC) and the safe transport of radioactive material (TRANSSC), and a Commission on Safety Standards (CSS) which oversees the IAEA safety standards programme (see Fig. 2).

All IAEA Member States may nominate experts for the safety standards committees and may provide comments on draft standards. The membership of

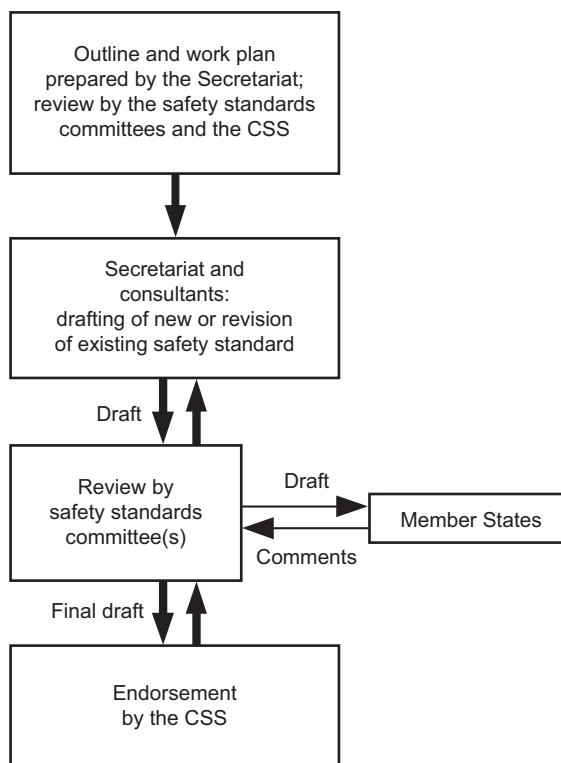


FIG. 2. The process for developing a new safety standard or revising an existing standard.

the Commission on Safety Standards is appointed by the Director General and includes senior governmental officials having responsibility for establishing national standards.

A management system has been established for the processes of planning, developing, reviewing, revising and establishing the IAEA safety standards. It articulates the mandate of the IAEA, the vision for the future application of the safety standards, policies and strategies, and corresponding functions and responsibilities.

## INTERACTION WITH OTHER INTERNATIONAL ORGANIZATIONS

The findings of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the recommendations of international

expert bodies, notably the International Commission on Radiological Protection (ICRP), are taken into account in developing the IAEA safety standards. Some safety standards are developed in cooperation with other bodies in the United Nations system or other specialized agencies, including the Food and Agriculture Organization of the United Nations, the United Nations Environment Programme, the International Labour Organization, the OECD Nuclear Energy Agency, the Pan American Health Organization and the World Health Organization.

## INTERPRETATION OF THE TEXT

Safety related terms are to be understood as defined in the IAEA Safety Glossary (see <http://www-ns.iaea.org/standards/safety-glossary.htm>). Otherwise, words are used with the spellings and meanings assigned to them in the latest edition of The Concise Oxford Dictionary. For Safety Guides, the English version of the text is the authoritative version.

The background and context of each standard in the IAEA Safety Standards Series and its objective, scope and structure are explained in Section 1, Introduction, of each publication.

Material for which there is no appropriate place in the body text (e.g. material that is subsidiary to or separate from the body text, is included in support of statements in the body text, or describes methods of calculation, procedures or limits and conditions) may be presented in appendices or annexes.

An appendix, if included, is considered to form an integral part of the safety standard. Material in an appendix has the same status as the body text, and the IAEA assumes authorship of it. Annexes and footnotes to the main text, if included, are used to provide practical examples or additional information or explanation. Annexes and footnotes are not integral parts of the main text. Annex material published by the IAEA is not necessarily issued under its authorship; material under other authorship may be presented in annexes to the safety standards. Extraneous material presented in annexes is excerpted and adapted as necessary to be generally useful.

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# 1. INTRODUCTION

## BACKGROUND

1.1. This Safety Guide on the Safety of Nuclear Fuel Reprocessing Facilities provides recommendations on how to meet the requirements established in the Safety Requirements publication on the Safety of Nuclear Fuel Cycle Facilities, IAEA Safety Standards Series No. NS-R-5 (Rev. 1) [1]. It supplements and develops those requirements by providing guidance relevant to aqueous reprocessing of nuclear fuel.

1.2. The safety of nuclear fuel reprocessing facilities<sup>1</sup> is ensured by means of their proper siting, design, construction, commissioning, operation and decommissioning. This Safety Guide addresses all these stages in the lifetime of a reprocessing facility as defined in NS-R-5 (Rev. 1) [1], on an industrial scale, with emphasis placed on safety in the design and operation of such facilities.

1.3. The radioactivity and radiotoxicity of spent fuel, dissolved spent fuel, fission product solutions, plutonium and other actinides and their solutions are high. Close attention should be paid to ensuring safety at all stages in the reprocessing of spent fuel and breeder material. Uranium, plutonium, fission products and all waste from reprocessing facilities should be handled, processed, treated and stored safely, to maintain low levels of exposure of the public and workers and to minimize the radioactive material discharged to the environment, and to limit the potential impact of an accident on workers, the public and the environment.

## OBJECTIVE

1.4. The objective of this Safety Guide is to provide up to date guidance, based on experience gained in Member States, on engineering measures, actions, conditions and procedures necessary for meeting the requirements established in NS-R-5 (Rev. 1) [1]. This Safety Guide is intended to be of use to designers, operating organizations and regulatory bodies for ensuring safety for all stages in the lifetime of a reprocessing facility.

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<sup>1</sup> Nuclear fuel reprocessing facilities are referred to in this Safety Guide as ‘reprocessing facilities’.

## SCOPE

1.5. This Safety Guide provides recommendations on meeting the requirements established in NS-R-5 (Rev. 1), sections 5–10 and appendix IV. The safety requirements applicable to all types of nuclear fuel cycle facility (i.e. facilities for uranium ore processing and refining, conversion, enrichment, fabrication of fuel including mixed oxide fuel, storage and reprocessing of spent fuel, associated conditioning and storage of waste, and facilities for the related research and development) are established in the main text of NS-R-5 (Rev. 1) [1]. The requirements specifically applicable to reprocessing facilities are established in appendix IV of NS-R-5 (Rev. 1) [1] and apply to plants using the PUREX process to reprocess fuels containing uranium and plutonium on a commercial scale. This Safety Guide does not specifically address thorium breeder reprocessing (THOREX) as there is insufficient experience of these facilities at a commercial scale in many States. However, the similarity between aqueous processes means that these recommendations will apply, with suitable adjustments, to plants reprocessing many types of nuclear fuel.

1.6. This Safety Guide deals specifically with the following processes:

- (a) The handling of spent fuel;
- (b) The dismantling, shearing<sup>2</sup> or decladding<sup>3</sup> and dissolution of spent fuel;
- (c) The separation of uranium and plutonium from fission products;
- (d) The separation and purification of uranium and plutonium;
- (e) The production and storage of plutonium and uranium oxides and uranyl nitrate to be used as a feed material to form ‘fresh’ uranium or mixed (UO<sub>2</sub>/PuO<sub>2</sub>) oxide fuel rods and assemblies;
- (f) The initial treatment and handling of the various waste streams.

1.7. The fuel reprocessing processes covered by this Safety Guide are a mixture of high and low hazard, chemical and mechanical processes, including high hazard fine particulate processes and processing involving hazardous solid, liquid, gaseous and particulate (dry, air and water-borne) wastes and effluents.

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<sup>2</sup> Shearing involves cutting spent fuel into short lengths to allow its dissolution inside its metallic cladding.

<sup>3</sup> Decladding involves removing the metallic cladding of spent fuel prior to its dissolution.

1.8. This Safety Guide covers the safety of reprocessing facilities and the protection of workers, the public and the environment. It does not deal with ancillary processing facilities in which waste and effluent are treated, conditioned, stored or disposed of except in so far as all waste generated has to comply with the requirements established in NS-R-5 (Rev. 1) [1], paras 6.31, 6.32 and 9.54–9.57 and, in appendix IV, paras IV.49, IV.50 and IV.80–IV.82, and in Predisposal Management of Radioactive Waste, IAEA Safety Standards Series No. GSR Part 5 [2]). In general, however, many of the hazards in such ancillary processing facilities are similar to those in a reprocessing facility, owing, for example, to the characteristics of the materials being treated.

1.9. Safety requirements on the legal and governmental framework and on regulatory supervision are established in Governmental, Legal and Regulatory Framework for Safety, IAEA Safety Standards Series No. GSR Part 1 (Rev. 1) [3]. Guidance on meeting the requirements for the management system and for the verification of safety established in Leadership and Management for Safety, IAEA Safety Standards Series No. GSR Part 2 [4] is provided in The Management System for Nuclear Installations, IAEA Safety Standards Series No. GS-G-3.5 [5] and Application of the Management System for Facilities and Activities, IAEA Safety Standards Series No. GS-G-3.1 [6].

1.10. Sections 3–8 of this Safety Guide provide recommendations on meeting the safety requirements on radiation protection established in Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA Safety Standards Series No. GSR Part 3 [7]. The recommendations in this Safety Guide supplement the recommendations on occupational radiation protection provided in Occupational Radiation Protection, IAEA Safety Standards Series No. GSG-7 [8].

1.11. Terms in this publication are to be understood as defined and explained in the IAEA Safety Glossary [9], unless otherwise stated.

## STRUCTURE

1.12. This Safety Guide consists of eight sections and two annexes. The sections follow the general structure of NS-R-5 (Rev. 1) [1]. Section 2 of this publication provides general safety recommendations for a reprocessing facility. Section 3 describes the safety aspects to be considered in the evaluation and selection of a site to avoid or minimize any environmental impact of operations. Section 4 deals with safety considerations at the design stage, including safety analysis for

operational states and accident conditions<sup>4</sup>, the safety aspects of radioactive waste management in a reprocessing facility and other design considerations. Section 5 addresses safety considerations in the construction stage. Section 6 discusses safety considerations in commissioning. Section 7 provides recommendations on safety during operation of a facility, including the management of operations, maintenance, inspection and periodic testing, control of modifications, criticality control, radiation protection, industrial safety, management of waste and effluents, and emergency planning and preparedness. Section 8 provides recommendations on meeting the safety requirements for preparing for the decommissioning of a reprocessing facility. Annex I shows the typical main process routes for a reprocessing facility. Annex II provides examples of structures, systems and components important to safety in reprocessing facilities, grouped in accordance with the processes identified in Annex I.

1.13. This Safety Guide contains guidance specific to reprocessing facilities. The recommendations in this guide have been referenced to the corresponding requirements in NS-R-5 (Rev. 1) [1] and other IAEA safety standards, where consistent with the readability of the text. This Safety Guide covers all the important stages in the lifetime of a reprocessing facility, including site evaluation, design, construction, commissioning, operation and preparation for decommissioning. It also considers modifications, maintenance, calibration, testing and inspection as well as emergency preparedness, where specific guidance exists. References are also made to other IAEA standards for requirements and guidance on generic topics (such as radioactive waste management and radiation protection) and to publications in the IAEA Nuclear Security Series for security issues that are not specific to reprocessing facilities.

## **2. GENERAL SAFETY RECOMMENDATIONS**

2.1. In a fuel reprocessing facility, large quantities of fissile material, radioactive material and other hazardous materials are present (stored, processed

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<sup>4</sup> Accident conditions include design basis accidents and design extension conditions [9]. Design extension conditions are postulated accident conditions that are not considered for design basis accidents, but that are considered in the design process for the facility in accordance with best estimate methodology, and for which releases of radioactive material are kept within acceptable limits; see Safety of Nuclear Power Plants: Design, IAEA Safety Standards Series No. SSR-2/1 (Rev. 1) [10].

and generated), often in easily dispersible forms (e.g. solutions, powders and gases) and sometimes subjected to vigorous chemical and physical reactions. Reprocessing facilities have the potential for serious nuclear and radiological emergencies. A graded approach that is proportionate to the potential hazards associated with reprocessing facilities should be used when applying the requirements established in section 1 of NS-R-5 (Rev. 1) [1] and in Preparedness and Response for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GSR Part 7 [11].

2.2. The main risks are criticality, loss of confinement, radiation exposure and associated chemical hazards, against which workers, the public and the environment need to be protected by adequate technical and administrative measures taken in the siting, design, construction, commissioning, operation and decommissioning of the facility.

2.3. In normal operation, reprocessing facilities generate significant volumes of gaseous and liquid effluents with a variety of radioactive and chemical constituents. The facility's processes and equipment should be designed and operated to reduce and recycle these effluents as far as practicable, with account taken of the possible accumulation of undesirable species or changes in the composition of recycled reagents and other feeds, such as chlorides in cooling water, aromatic hydrocarbons in solvent extraction systems and radiolysis (degradation) products in organic diluents. In accordance with the optimization of protection and safety, specific design provisions should be made to ensure that recycled materials are safe and compatible with their reuse in the facility, which may involve the generation of additional effluents.

2.4. Effluents and discharges should be managed by the addition of specific engineering features to remove and reduce levels of activity and amounts of toxic chemicals. The operating organization of the reprocessing facility (and the operating organizations of any associated effluent treatment facilities) should monitor and report on discharges. As a minimum, they are required to comply with all authorized limits and to optimize protection and safety (see GSR Part 5 [2], GSR Part 3 [7], Predisposal Management of Radioactive Waste from Nuclear Fuel Cycle Facilities, IAEA Safety Standards Series No. SSG-41 [12], and Regulatory Control of Radioactive Discharges to the Environment, IAEA Safety Standards Series No. WS-G-2.3 [13]). When periodic safety reviews are being carried out, the records of previous discharges should be examined thoroughly to confirm that the current engineered provisions and operational practices are such that protection and safety is optimized. In addition, developments in processes

and in technology for the reduction and treatment of effluents should be examined for potential improvements.

2.5. The specific aspects of reprocessing facilities that should be taken into account in meeting the safety requirements established in NS-R-5 (Rev. 1) [1] are the following:

- (a) The wide range and nature of radioactive inventories present at such facilities;
- (b) The wide range and nature of process chemicals used, and their chemical reactions;
- (c) The range and nature of fissile material, i.e. the potential for criticality in both liquid and solid systems;
- (d) The range of dispersible or difficult to control radioactive material present, including:
  - Solids, such as contaminated items and scrap;
  - Aqueous and organic liquids;
  - Gases and volatile species;
  - Particulates dispersed in gases and liquids.

2.6. The specific aspects associated with reprocessing facilities result in a broad range of hazardous conditions and possible events that need to be considered in the safety analysis to ensure that they are adequately prevented and/or detected and mitigated.

2.7. For the application of the concept of defence in depth (see NS-R-5 (Rev. 1) [1], paras 2.4–2.8), the first two levels are the most significant, as the risks should be eliminated mainly by design and appropriate operating procedures (see Sections 4 and 7 of this Safety Guide). However, all levels of defence in depth are required to be addressed. The third level should be provided by the iteration and development of the safety assessment and the design to incorporate appropriate passive and active structures, systems and components important to safety, with the necessary robust auxiliary systems, infrastructure (e.g. services and maintenance) and appropriate operation instructions and training (see Sections 4 and 7 of this Safety Guide). The recommendations for accident conditions (levels four and five of the concept of defence in depth) are provided in the sections of this Safety Guide on emergency preparedness (paras 4.161–4.167 and 7.119–7.121).

2.8. The design, construction and operation of a reprocessing facility require the use of well-proven process technologies and engineering knowledge. Engineering solutions adopted to ensure the safety of the reprocessing facility should be of high quality, proven by previous experience or, in accordance with a graded approach, by rigorous testing, research and development, or experience of operating prototypes. This strategy should be applied in the design of the reprocessing facility, in the development and design of equipment, in construction, in operation, in carrying out modifications and in preparation for the decommissioning of the reprocessing facility, including any upgrades or modernization.

2.9. Owing to the anticipated long lifetime of industrial scale reprocessing facilities and in accordance with the specific mechanical, thermal, chemical and radiation conditions of the processes in use, particular consideration should be given to the potential for ageing and degradation of structures, systems and components important to safety, especially for those components judged difficult or impracticable to replace. In selecting and designing structures, systems and components important to safety, the processes that could cause the degradation of structural materials should be taken into account. Programmes should be developed and implemented to detect and monitor ageing and degradation processes. These should include provisions for monitoring, inspection, sampling, surveillance and testing and, to the extent necessary, specific design provisions and equipment for inaccessible structures, systems and components important to safety.

2.10. The reliability of process equipment should be ensured by adequate design, specification, manufacturing, storage (if necessary), installation, commissioning, operation, maintenance and facility management, supported by the application of an integrated management system (that provides for quality assurance and quality control) during all the stages of the lifetime of the facility. Inspection and testing should be carried out against unambiguous, established performance standards and expectations.

2.11. Adequately designed passive engineering structures, systems and components important to safety, followed by active engineering structures, systems and components important to safety, are more reliable than administrative controls and are preferred in operational states and in accident conditions (see NS-R-5 (Rev. 1) [1], para. 6.6). Automatic systems should be highly reliable and designed to maintain process parameters within the operational limits and

conditions or to bring the process to a safe and stable state, which is generally a shutdown state<sup>5</sup> (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.47).

2.12. When administrative controls are considered as an option, the criteria for selection of an automated system versus administrative control should be based on the availability of adequate time for the operator to respond (grace period) and on careful consideration of the risks and hazards associated with a failure to act. Where an operator would need to select an optimum response from a number of possible options, consideration should be given to providing a simple automatic or manual response action and/or passive design features. These should be designed to limit the consequences for safety in the event that the operator fails to take sufficient or timely action, by providing additional defence in depth.

2.13. In addition to the structures, systems and components identified as important to safety in the safety analysis, instrumentation and control systems used in normal operation are also relevant to the overall safety of the reprocessing facility. Such systems include indicating and recording instrumentation, control components and alarm and communications systems that limit process fluctuations and occurrences but that are not identified as important to safety. Such structures, systems and components (that control normal operation) should be of high quality. Adequate and reliable controls and appropriate instrumentation should be provided to maintain variables within specified ranges and to initiate automatic safety actions, where necessary. Where computers or programmable devices are used in such systems, there should be evidence that the hardware and software are designed, manufactured, installed and tested appropriately, in accordance with the established management system. For software, this should include verification and validation. The reprocessing facility should have alarm systems to initiate full or partial facility evacuation in the event of an emergency (e.g. criticality, fire and high radiation levels).

2.14. Ergonomic considerations should be applied to all aspects of the design and operation of the reprocessing facility. Careful consideration should be given to human factors in the design of control rooms and all remote control stations and work locations. As a minimum, this consideration should apply to controls, alarms and indicators relating to structures, systems and components important to safety and to operational limits and conditions. It should also apply to all control, indication and alarm systems and to the control room(s) as a whole.

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<sup>5</sup> A safe shutdown state implies there is no movement of radioactive material or liquids, with ventilation and (essential) cooling only.

2.15. Utility supply services are necessary to maintain the safety systems of the reprocessing facility in an operational state at all times, and to provide services to structures, systems and components important to safety. Continuity of service should be achieved by means of robust design, including sufficient diverse and redundant supplies. Services for the safety systems of the reprocessing facility should be designed so that, as far as possible, the simultaneous loss of both normal services and backup services will not lead to unacceptable consequences. Wherever possible, the consequences of loss of motive power to devices such as valves should be assessed and the item should be designed to be fail-safe<sup>6</sup>.

2.16. The situations that necessitate a shutdown of the reprocessing facility process and putting the facility into a safe and stable state, with no movement or transfer of chemicals and/or fissile material, should be analysed. Such situations should be well defined in procedures in accordance with the assessment performed. These procedures should be executed, when required, in accordance with the nature and urgency of the hazard or risk. Such situations include potential criticality sequences, and natural or human induced internal or external events. The subsequent recovery sequences should be similarly analysed, defined and executed, when required, in a timely manner; for example, the managed recovery or reduction of fissile material in a multi-stage contactor<sup>7</sup>.

2.17. To maintain the facility in a safe state, some systems should operate continuously or should be restarted within a defined delay period if they become unavailable. Examples of such systems are:

- (a) Active heat removal systems used to remove decay heat in storage areas or buffer tanks, in accountancy vessels or for high activity waste packages;
- (b) Exhaust ventilation systems that ensure dynamic containment of radioactive material;
- (c) Dilution (gas flow) systems used to prevent hazardous concentrations of hydrogen;
- (d) Safety significant instrumentation and control systems and utility supply systems.

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<sup>6</sup> The fail-safe state of a valve, controller or other device is a valve position, for example, that can be shown, by analysis, to be the least likely to cause a deterioration in the safety of the system or facility. Fail-safe devices are designed to fail to this position usually in response to a loss (failure) of motive power or control input, e.g. a spring that moves the valve to a preset position in the event of a power failure. The device might still fail in any position owing to other causes, e.g. mechanical failure, and these events should be analysed in the safety assessment.

<sup>7</sup> A contactor is a liquid-liquid extraction device.

### 3. SITE EVALUATION

3.1. Requirements for site evaluation, site selection criteria and the site selection process for a fuel reprocessing facility are established in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. NS-R-3 (Rev. 1) [14] and recommendations are provided in the following supporting Safety Guides: Seismic Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSG-9 [15], Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSG-18 [16], Volcanic Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSG-21 [17], Site Survey and Site Selection for Nuclear Installations, IAEA Safety Standards Series No. SSG-35 [18], and Dispersion of Radioactive Material in Air and Water and Consideration of Population Distribution in Site Evaluation for Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-3.2 [19]. These should be considered in addition to the requirements established in NS-R-5 (Rev. 1) [1], paras 5.1–5.8 and appendix IV, para. IV.1.

3.2. In the siting of new reprocessing facilities, particular consideration should be given to the following:

- (a) The site's ability to accommodate normal discharges of radioactive material to the environment during operation, including the physical factors affecting the dispersion and accumulation of released radioactive material and the radiation risk to workers, the public and the environment.
- (b) The suitability of the site to accommodate the engineering and infrastructure requirements of the facility, including:
  - Waste processing and storage (for all stages of the facility's lifetime);
  - The reliable provision of utility supply services;
  - The capability for safe and secure on-site and off-site transport of nuclear fuel and other radioactive material and chemical materials (including products and radioactive waste, if necessary).
- (c) The feasibility of implementing the requirements of GSR Part 7 [11] in an emergency, including:
  - The provision of off-site supplies in the event of an emergency (including diversity of water supplies);
  - Arrangements for access by off-site emergency services to the site;
  - The implementation of emergency arrangements for the evacuation of site personnel and, as appropriate, the surrounding population from affected areas.

- (d) External hazards that may particularly affect parts of a reprocessing facility, including:
  - Flooding, possibly leading to criticality, water penetration through openings in static barriers and damage to vulnerable items such as gloveboxes;
  - Earthquakes, possibly affecting containment structures for spent fuel, highly active liquids and fissile materials.
- (e) Nuclear security measures, in accordance with the guidance provided in the Nuclear Security Series publications, in particular Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities, IAEA Nuclear Security Series No. 13 [20] and Nuclear Security Recommendations on Radioactive Material and Associated Facilities, IAEA Nuclear Security Series No. 14 [21].

3.3. NS-R-5 (Rev. 1) [1] and NS-R-3 (Rev. 1) [14] establish the requirements for site evaluation for new and existing facilities and the use of a graded approach for reprocessing facilities. In addition, for reprocessing facilities, care should be taken and an adequate justification should be made for any grading of the application of the requirements for site evaluation. Particular attention should be paid to the following throughout the lifetime of the reprocessing facility (including its decommissioning):

- (a) The appropriate monitoring and systematic evaluation of site characteristics;
- (b) The incorporation of periodic, ongoing evaluation of the site parameters for natural processes and phenomena and human induced events in the design basis for the facility;
- (c) The identification and the need to take account of all foreseeable variations in the site evaluation data (e.g. new or planned significant industrial development, infrastructure or urban developments);
- (d) Revision of the safety assessment report (in the course of a periodic safety review or the equivalent) to take account of on-site and off-site changes that could affect safety at the reprocessing facility, with account taken of all current site evaluation data and the development of scientific knowledge and evaluation methodologies and assumptions;
- (e) Consideration of anticipated future changes to site characteristics and of features that could have an impact on emergency arrangements and the ability to carry out emergency response actions for the facility.

## 4. DESIGN

### GENERAL

#### **Main safety functions for reprocessing facilities**

4.1. The requirements for design for a fuel reprocessing facility are established in NS-R-5 (Rev. 1) [1], section 6 and appendix IV, paras IV.2–IV.50. The requirements identify main safety functions, the loss of which may lead to releases of radioactive material or exposures having possible radiological consequences for workers, the public or the environment. The main safety functions are those designed for:

- (1) Prevention of criticality;
- (2) Confinement of radioactive material (including protection against internal exposure, removal of decay heat and dilution of gases from radiolysis);
- (3) Protection against external exposure.

Further guidance on the main safety functions is provided in paras 4.13–4.61.

#### **Specific engineering design guidance**

4.2. Owing to its expected long service life, substantial inventory of radioactive and radiotoxic materials, the potential for criticality, and the use of aggressive physical and chemical processes, the design of a reprocessing facility should be based upon the most rigorous application of the above requirements to a high hazard facility. Particular consideration should be given to the reuse and recycling of materials to reduce discharges and waste generation.

4.3. The protection of the public and the environment in normal operation relies on robust, efficient and effective facility design, particularly for the minimization of effluents and the predisposal or predischage treatment of effluents.

4.4. Requirements for the prevention and mitigation of accidents are established in GSR Part 3 [7], Requirement 15. For abnormal states, the protection of people and the environment relies mainly on the prevention of accidents and, if an accident occurs, the mitigation of its consequences by robust and fault tolerant design providing defence in depth in accordance with a graded approach. These provisions will be supplemented by on-site and off-site emergency arrangements

to protect human life, health, property and the environment in accordance with GSR Part 7 [11], as the fifth level of the defence in depth concept.

4.5. The following requirements and guidance apply:

- (a) Requirements for the confinement of radioactive material are established in NS-R-5 (Rev. 1) [1], paras 6.37–6.39, 6.52, 6.53 and appendix IV, paras IV.21–IV.25. In normal operation, internal exposure should be avoided by design, including static and dynamic barriers and adequate zoning. The need to rely on personal protection (personal protective equipment) should be minimized in accordance with the requirement for the optimization of protection and safety (see GSR Part 3 [7], Requirement 11).
- (b) Requirements for the removal of decay heat are established in NS-R-5 (Rev. 1) [1], para. 6.52 and appendix IV, paras IV.4–IV.6. In view of the decay heat generated, all thermal loads and processes should be given appropriate consideration in the design. Particular care should be paid to the provision of adequate cooling, passively if possible, in accident conditions.
- (c) Requirements for the need to address the generation of radiolytic hydrogen and other flammable or explosive gases and materials are established in NS-R-5 (Rev. 1) [1], paras 6.53, 6.54 and appendix IV, para. IV.33. In view of the widespread potential for the generation of radiolytic hydrogen, particular care should be given to the provision of adequate diluting airflow where applicable, or to alternative provisions for ensuring application of the concept of defence in depth, for example, catalytic recombiners. If possible, these provisions should function without the need for ventilation fans or compressors and in accident conditions.
- (d) Requirements for protection against external exposure are established in NS-R-5 (Rev. 1) [1], paras 6.40–6.42 and appendix IV, paras IV.27–IV.30. Owing to the radiation fields associated with high beta/gamma activity, alpha activity and neutron emissions, appropriate combinations of requirements for source limitation, shielding, distance and time are necessary for the protection of workers. Particular attention should be paid to provisions for maintenance in both design and operation.
- (e) Requirements for the prevention of criticality are established in NS-R-5 (Rev. 1) [1], paras 6.43–6.51 and appendix IV, paras IV.9–IV.20, and guidance is provided in Criticality Safety in the Handling of Fissile Material, IAEA Safety Standards Series No. SSG-27 [22]. All processes involving fissile material should be designed in such a way as to prevent criticality.

- (f) Design requirements for provisions for decommissioning are established in NS-R-5 (Rev. 1) [1], paras 6.35, 6.36, and should be strictly implemented owing to the long operational lifetimes of reprocessing facilities, large throughput of radioactive and radiotoxic materials and the cumulative effects of modifications.

4.6. The Safety Requirements on the Decommissioning of Facilities, IAEA Safety Standards Series No. GSR Part 6 [23] establishes the general requirements for preparation for decommissioning and its supporting Safety Guide, Decommissioning of Nuclear Fuel Cycle Facilities, IAEA Safety Standards Series No. WS-G-2.4 [24], provides recommendations for preparation for decommissioning.

### **Other engineering design guidance**

4.7. The operating organization should develop (or should have already developed) a set of standardized designs and should set out conditions for their use in the design and modification of a reprocessing facility. Such standardized designs should be developed on the basis of proven experience and should be capable of being applied to a wide range of applications. For example, standardized designs should be applied to ensure the continuity and integrity of the containment, the ventilation of areas that could be contaminated and the transfer of highly active liquids, and to simplify the maintenance activities for the reprocessing facility. For each application of these standardized designs a thorough assessment should be made to verify that the conditions for the application are appropriate.

4.8. As reprocessing facilities have long operating lifetimes, provisions should be made to allow for anticipated in situ repair of major equipment, as far as reasonably achievable. Designers should consider allowing space for operation of remote repair equipment, and the generation and retention of three dimensional design data of the equipment and its location in hot cells.

## Design basis accidents and safety analysis

4.9. The definition of a design basis accident<sup>8</sup>, in the context of nuclear fuel cycle facilities, can be found in NS-R-5 (Rev. 1) [1], annex III, para. III–10. The safety requirements relating to design basis accidents are established in NS-R-5 (Rev. 1) [1], paras 6.4–6.9.

4.10. The specification of a design basis accident or design basis external event (or the equivalent) will depend on the design of the facility, its siting and national criteria. However, particular consideration should be given to the following hazards in the specification of design basis accidents for reprocessing facilities:

- (a) Loss of cooling;
- (b) Loss of electrical power;
- (c) Nuclear criticality accidents;
- (d) Fire (in particular in extraction units, plutonium gloveboxes and organic wastes);
- (e) Exothermic chemical reactions;
- (f) External events, including:
  - (i) Internal and external explosion;
  - (ii) Internal and external fire;
  - (iii) Dropped loads and associated handling events;
  - (iv) Natural phenomena (e.g. earthquake, flooding and tornadoes);
  - (v) Aircraft crashes.

Selected postulated initiating events are listed in annex I of NS-R-5 (Rev. 1) [1].

4.11. Reprocessing facilities are characterized by a wide diversity of radioactive materials distributed throughout the facility and by the number of potential events that could result in a release of radioactive material with the potential for public exposure. Therefore, the operational states and accident conditions for each process of the reprocessing facility should be assessed on a case-by-case basis (see NS-R-5 (Rev. 1) [1], para. 6.9 and annex III, paras III–10, III–11). If an event could simultaneously challenge several facilities at one site, the assessment

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<sup>8</sup> “In the context of fuel cycle facilities, a design basis accident is an accident against which a facility is designed according to established design criteria such that the consequences are kept within defined limits. These accidents are events against which design measures are taken when designing the facility. The design measures are intended to prevent an accident or to mitigate its consequences if it does occur.” (para. III–10 of NS-R-5 (Rev.1) [1]).

should address the implications at the site level in addition to the implications for each facility.

### **Structures, systems and components important to safety**

4.12. The likelihood of design basis accidents (or equivalent) should be minimized, and any associated radiological consequences should be controlled by means of structures, systems and components important to safety (see NS-R-5 (Rev. 1) [1], paras 6.4–6.9 and annex III). Annex II of this Safety Guide presents examples of structures, systems and components important to safety and representative events that may challenge the associated safety functions.

## **SAFETY FUNCTIONS**

### **Prevention of criticality**

#### *General*

4.13. The requirements for criticality prevention in reprocessing facilities are established in NS-R-5 (Rev. 1) [1], paras 6.43–6.51, and appendix IV, paras IV.9–IV.20, and general recommendations on criticality prevention are provided in SSG-27 [22].

4.14. Criticality hazards are required to be controlled by design as far as practicable (see NS-R-5 (Rev. 1) [1], para. 6.43 and appendix IV, para. IV.10). Where a credible hazard cannot be eliminated, the double contingency principle is the preferred approach for the prevention of criticality by means of design (see NS-R-5 (Rev. 1) [1], para. 6.45 and SSG-27 [22]).

4.15. Those system interfaces at which there is a change in the state of the fissile material or in the method of criticality control should be specifically assessed (see NS-R-5 (Rev. 1) [1], para. 6.48 and appendix IV, para. IV.14). Particular care should also be taken to assess all transitional, intermediate or temporary states that occur, or could reasonably be expected to occur, under all operational states and accident conditions.

4.16. When required by the safety analysis, the precipitation of fissile material within solutions should be prevented by, for example, the following methods:

- (a) The use of interlocks and the avoidance of any permanent physical connection from units containing reagents to the equipment in which fissile material is located;
- (b) The acidification of cooling loops for equipment containing solutions of nuclear material (to prevent precipitation in case of leakage from the cooling loop into the equipment) and consideration of the need for the cooling loops themselves to meet subcritical design requirements.

4.17. In a number of locations in a reprocessing facility, criticality safety for equipment containing fissile liquid is achieved by the geometry or shape of the containment. The overall design should provide for any potential leakage to a criticality safe (secondary) containment. This should drain or have an emptying route to criticality safe vessels, depending on the exact design. The evaluation of such designs should address the potential for such leaks to evaporate and crystallize or precipitate either at the leak site or on nearby hot vessels or lines, and should consider the need for:

- (a) Localized drip trays to recover and direct potential liquid leaks away from hot vessels to collection vessels of favourable geometry;
- (b) Level measurement devices or liquid detectors in the drip trays to provide additional protection;
- (c) Frequent inspections, continuous closed circuit television camera surveillance and adequate lighting.

4.18. The need for additional design provisions to detect leaks or similar abnormal occurrences involving liquids containing fissile solids (slurries) or solid (powder) transfer systems should also be carefully considered and appropriate criticality control measures should be put in place.

4.19. In accordance with the criticality safety analysis, instruments specifically intended to detect accumulations and inventories of fissile material should be installed where required. Such instruments should also be used to verify the fissile inventory of equipment during decommissioning.

### *Criticality safety assessment*

4.20. The aim of the criticality safety assessment, as required in NS-R-5 (Rev. 1) [1], appendix IV, para. IV.11, is to demonstrate that the design of equipment and the operating conditions in the reprocessing facility are such that the values of controlled parameters are always maintained in the subcritical range. Further guidance on criticality safety assessment is provided in SSG-27 [22].

4.21. The criticality safety assessment should include a criticality safety analysis, which should evaluate subcriticality for all operational states (i.e. normal operation and anticipated operational occurrences) and for design basis accidents. The criticality safety analysis should be used to identify hazards, both external and internal, and to determine the radiological consequences. The criticality safety analysis should involve the use of a conservative approach with account taken of the following:

- (a) Uncertainties in physical parameters, the possibility of optimum moderation conditions and the presence of non-homogeneous distributions of moderators and fissile material;
- (b) Anticipated operational occurrences and their combinations, if they cannot be shown to be independent;
- (c) Facility states that may result from internal and external hazards.

4.22. Computer codes used for criticality analysis should be qualified, validated and verified (i.e. compared with benchmarks to determine the effects of code bias and code uncertainties on the calculated effective multiplication factor  $k_{\text{eff}}$ ). Any codes should be used appropriately and within their applicable range with appropriate data libraries of nuclear reaction cross-sections. Detailed guidance is provided in SSG-27 [22], paras 4.20–4.25.

4.23. An alternative method of analysis is to specify, for physical parameters such as mass, volume, concentration and geometrical dimensions, a ‘safe value’ as a fraction of their critical value<sup>9</sup>. This safe value needs to take into account conservative (or worst case values) for other parameters, such as the optimum values for moderation or realistic minimum values for neutron poisons. The assessment has to demonstrate that each of the parameters will always be less than the numerical limits used in the calculation of the safe value under all normal, abnormal and design basis accident conditions.

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<sup>9</sup> The critical value of a parameter is its value for  $k_{\text{eff}} = 1$ .

### *Mitigatory measures*

4.24. The requirements to be applied in respect of criticality detection systems and associated provisions are established in NS-R-5 (Rev. 1) [1], para. 6.50.

4.25. The areas containing fissile material for which criticality alarm systems are necessary to initiate immediate evacuation<sup>10</sup> should be defined in accordance with the layout of the facility, the process at hand and national safety regulations and by the criticality safety analysis.

4.26. The need for additional shielding, remote operation and other design measures to mitigate the consequences of a criticality accident, if one does occur, should be assessed in accordance with the defence in depth requirements (see NS-R-5 (Rev. 1) [1], paras 2.4–2.8 and appendix IV, para. IV.29).

### **Confinement of radioactive material**

#### *Static and dynamic confinement*

4.27. The requirements for confinement for a reprocessing facility are established in NS-R-5 (Rev. 1) [1], para. 6.38 and appendix IV, paras IV.21–IV.25.

“Containment shall be the primary method for confinement against the spread of contamination. Confinement shall be provided by two complementary containment systems — static (e.g. physical barrier) and dynamic (e.g. ventilation).

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“The static containment shall have at least one static barrier between radioactive materials and operating areas (workers) and at least one additional static barrier between operating areas and the environment” (NS-R-5 (Rev. 1) [1], appendix IV, paras IV.21 and IV.22).

4.28. In a reprocessing facility (for most areas), three barriers (or more, as required by the safety analysis) should be provided, in accordance with a graded approach. The first static barrier normally consists of process equipment, vessels and pipes, or gloveboxes. The second static barrier normally consists of

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<sup>10</sup> The immediate activation of the alarm system is to minimize doses to workers in case of repeat or multiple criticality events.

cells around process equipment or, when gloveboxes are the first containment barrier, the rooms around the glovebox(es). The final static barrier is the building itself. The design of the static containment system should take into account openings between different confinement zones (e.g. doors, mechanisms, instruments and pipe penetrations). Such openings should be designed to ensure that confinement is maintained in all operational states, especially during maintenance (e.g. by the provision of permanent or temporary additional barriers) (see NS-R-5 (Rev. 1) [1], appendix IV, paras IV.22 and IV.28) and, as far as practicable, in accident conditions.

4.29. Each static barrier should be complemented by one or more dynamic containment systems, which should establish a cascade of pressure between the environment outside the building and the contaminated material inside the building, and across all static barriers within the building. The dynamic containment system should be designed to prevent the movement or diffusion of radioactive or toxic gases, vapours and airborne particulates through any openings in the barriers to areas of lower contamination or concentration of these materials. The design of the dynamic containment system should address, as far as practicable:

- (a) Operational states and accident conditions;
- (b) Maintenance, which may cause localized changes to conditions (e.g. opening access doors, removing access panels);
- (c) Where more than one ventilation system is used, protection in the event of a failure of a lower pressure (higher contamination) system, causing pressure differentials and airflows to be reversed;
- (d) The need to ensure that all static barriers, including any filters or other effluent control equipment, can withstand the maximum differential pressures and airflows generated by the system.

4.30. The reprocessing facility should be designed to retain and detect promptly any leakage of liquids from process equipment, vessels and pipes and to recover the volume of liquid to the primary containment (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.38). This is particularly important for both design and operation, where the first static barrier provides other safety functions, e.g. favourable geometry for criticality avoidance or exclusion of air for flammable liquids. Great care should be taken when dealing with spills or leaks from liquid streams with high fissile content and effects such as crystallization due to cooling or evaporation of leaked liquors should be considered. The chemical compatibility of liquid streams should also be considered in the design.

4.31. Particular consideration should be given to those sections of the reprocessing facility handling solids (powders) with radioactive, fissile and other hazardous properties. Design for the detection of leaks and of accumulations of leaked powders and for their return to containment or to the process is particularly challenging, and care should be taken to ensure this equipment is based upon well-proven designs and subject to rigorous qualification. In either case, commissioning should rigorously test the effectiveness of the design solutions. As far as practicable, considering both risk and the optimization of protection and safety, operator intervention should be avoided.

4.32. The ventilation system should include, as a minimum, both a ventilation system for the building (cells and rooms) and a ventilation system for process equipment (e.g. vessels contained in a cell).

4.33. The assessment and design of the building's ventilation system (see NS-R-5 (Rev. 1) [1], appendix IV, paras IV.23–IV.25) including redundant sub-systems<sup>11</sup>, filtration equipment and other discharge control equipment, should take account of:

- (a) The type and design of static barriers (cells, gloveboxes and building);
- (b) The classification of areas according to the hazards they contain;
- (c) The nature of potential airborne contamination (i.e. the predicted or actual normal levels of airborne contamination);
- (d) The levels of surface contamination and the risks of additional contamination;
- (e) Requirements for maintenance.

4.34. The process ventilation system creates the lowest pressure within the facility and collects and then treats most of the radioactive vapours, radioactive gases and particulates generated by the processes. Careful attention should be paid to the need to install effective washing, draining and collection systems to reduce the buildup of contamination and radioactive material and to facilitate future decommissioning.

4.35. All filtration stages of the ventilation systems that require testing should be designed in accordance with relevant standards, such as those of the International

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<sup>11</sup> Redundant sub-systems may be provided to ensure continuous availability during, for example, maintenance or filter changes.

Organization for Standardization (ISO) (see also NS-R-5 (Rev. 1) [1], appendix IV, para. IV.25).

4.36. For the portions of the process involving powders, primary filters should be located as close to the source of contamination as practical (e.g. near the gloveboxes), to minimize the potential buildup of powders in the ventilation ducts. Particular care should be taken to avoid accumulations of fissile material in powder form at junctions and connections in ventilation ducts that may be of less favourable geometry (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.25).

4.37. On-line fans and standby fans should be provided in accordance with the results of the safety assessment. Alarm systems should be installed to alert operators to system malfunctions resulting in high or low differential pressures.

4.38. Fire dampers to prevent the propagation of a fire through ventilation ducts and to maintain the integrity of firewalls<sup>12</sup> should be installed, unless the likelihood of a fire spreading or the consequences of such a fire are acceptably low (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.36).

#### *Protection of workers*

4.39. The static barriers (at least one is required between radioactive material and working areas) normally protect workers from internal and external exposure. Their design should be specified to ensure their integrity and effectiveness and, where appropriate, to facilitate maintenance. Their design specifications should include, for example, weld specifications, selection of materials, leaktightness, including specification of penetration seals for electrical and mechanical penetrations, and the ability to withstand seismic loads (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.21).

4.40. For items that need to be regularly maintained or accessed (such as sampling stations and pumps), consideration should be given to their installation in shielded bulges<sup>13</sup> or gloveboxes, adjacent to the process cells where they are required, depending upon the radiation type and level of the material being processed. Such an approach will reduce the local radioactive inventory and allow for special

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<sup>12</sup> A firewall is an engineered feature specifically designed to prevent, limit or delay the spread of fire.

<sup>13</sup> A bulge is typically a shielded, stainless steel, windowless, glovebox type enclosure with mechanically sealed openings to allow for the remote removal of items into a shielded transport flask via a shielded docking port.

washing or decontamination features. The provision of such features should be balanced against the need to obtain representative samples (for example, by short sample lines) and the additional waste at decommissioning.

4.41. Where easily dispersible radioactive material is processed and a loss of containment with the potential for contamination or ingestion is a major risk, gloveboxes are often the preferred design solution. Gloveboxes are welded stainless steel enclosures with windows (of suitable materials), arranged either singly or in interconnected groups. Access to equipment inside a glovebox is through holes (ports) fitted with gloves that maintain the containment barrier. Seals on glovebox windows should be capable of being tested for leaktightness in operation and gloves should be replaceable without breaking containment. A negative pressure should be maintained inside the glovebox.

4.42. For normal operation, the requirement to minimize the use of personal protective respiratory equipment should be achieved mainly by the careful design of the static and dynamic containment systems (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.21) and location of reliable devices for the immediate detection of low levels of airborne radioactive material. Careful consideration should also be given to the need to distinguish naturally occurring radioactive species (e.g. radon) from other radionuclides.

4.43. At the design stage, provision should be made for the installation of equipment for monitoring airborne radioactive material (see NS-R-5 (Rev. 1) [1], para. 6.39). The system design and the location of monitoring points should be chosen with account taken of the following factors:

- (a) The most likely locations of workers;
- (b) Airflows and air movement within the facility;
- (c) Evacuation zoning and evacuation routes;
- (d) The use of mobile units for temporary controlled areas, e.g. for maintenance.

4.44. To avoid the inadvertent spread of contamination by personnel, control points with personnel contamination monitoring equipment for workers (for exposed skin surfaces, clothing and working suits) should be located at the exit airlocks and barriers from areas that could be contaminated. These should be located close to workplaces with contamination hazards, to the extent practicable (see NS-R-5 (Rev. 1) [1], para. 6.42).

4.45. As far as practicable, tools and equipment should not be transferred routinely through air locks or across barriers. Where such transfers are

unavoidable, the provisions of para. 4.44 apply to the monitoring of the tools and equipment. Consideration should be given in design to the provision of specific storage locations for lightly contaminated tools and equipment. More heavily contaminated items should be decontaminated for reuse or sent to an appropriate waste route.

### *Protection of the public and the environment*

4.46. To the extent required by safety analyses, all engineered discharge points from the ventilation system should be provided with equipment for the reduction of airborne activity. Such equipment should be designed to provide protection in normal operation, anticipated operational occurrences and accident conditions. As far as practicable, the final stage of treatment should be located close to the point at which gaseous discharge to the environment occurs.

4.47. In accordance with national requirements and the authorized limits for discharges, and to ensure optimization of protection and safety, the design should also provide measures for the uninterrupted monitoring and control of the discharge from the stack exhaust(s) and for monitoring of the environment around the facility (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.32, and GSR Part 3 [7], Requirements 14 and 32). Where practicable, batch-wise transfers should be used for sending liquid process effluents to the appropriate treatment facilities, to ensure the prevention of leaks. Equipment should be provided for monitoring for the loss of any containment barrier (e.g. detection of airborne activity and detection of liquid levels and sampling in cell sumps<sup>14</sup> and collection vessels).

4.48. Detailed recommendations for the treatment and monitoring of radioactive liquid effluents are outside the scope of this Safety Guide, but similar considerations to those for airborne discharges (paras 4.46, 4.47) apply to liquid discharge points and to the sampling of liquid effluent discharges and their dispersion in the environment.

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<sup>14</sup> A cell sump is a designed 'low point' in a (normally stainless steel lined) cell base to collect any liquid arising from leakage or overflow.

### *Design for cooling and the removal of decay heat*

4.49. Radioactive decay heat, exothermic chemical reactions (e.g. neutralization of acidic or alkaline solution), physical heating and cooling, and evaporation processes may result in the following:

- (a) Boiling of solutions;
- (b) Changes of state (e.g. melting, concentration, crystallization and changes in water content) relevant to radiological or criticality safety;
- (c) Transition to auto-catalytic chemical reactions (e.g. the formation of potentially explosive red oil) or other accelerated chemical reactions and fires;
- (d) Destruction of components of containment barriers;
- (e) Degradation of radiation protection shielding;
- (f) Degradation of neutron absorbers or neutron decoupling devices.

Cooling systems should be designed to prevent uncontrolled releases of radioactive material to the environment, exposure of workers and the public, and criticality accidents, particularly in storage vessels for highly active liquid waste<sup>15</sup> and PuO<sub>2</sub> containers, (see NS-R-5 (Rev. 1) [1], appendix IV, paras IV.4 and IV.6).

4.50. The safety analysis is required to define the cooling capacity necessary to remove heat from radioactive decay and chemical reactions. The analysis is also required to specify the availability and reliability of cooling systems and the corresponding need for emergency power supplies. See NS-R-5 (Rev. 1) [1], appendix IV, paras IV.4, IV.5. Where practicable, passive cooling should be considered in the design.

### *Prevention of hazardous concentration levels of gases from radiolysis and other hazardous explosive or flammable materials*

4.51. Radiolysis in water (including cooling water) or in organic materials may result in the production and buildup of degradation products. Such products may be flammable or explosive (e.g. H<sub>2</sub>, CH<sub>4</sub>, organic nitrate or nitrites (red oils) and peroxides) or corrosive (e.g. Cl<sub>2</sub> and H<sub>2</sub>O<sub>2</sub>) and may damage containment barriers. As far as practicable, dilution systems (air or inert gas) should be provided to prevent explosive gaseous mixtures and the subsequent loss of confinement

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<sup>15</sup> Highly active liquid waste is also referred to as high level liquid waste.

resulting from radiolysis in vessels. For product containers and other systems, the design should take into account the potential for corrosion and gas (pressure) production (e.g. from  $\text{PuO}_2$  powder or from plutonium contaminated waste) (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.33).

4.52. Unstable products and exothermic chemical reactions may result in explosion and loss of confinement. The relevant guidance in international and national standards and international experience should be taken into account in the process and the facility design when developing design requirements and specifications with the objective of preventing the buildup of explosive substances. The design should ensure that process parameters are monitored and provided with alarm systems and that inventories are minimized in order to prevent chemical explosions (e.g. red oils in evaporators,  $\text{HN}_3$  in extraction cycles) (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.33).

4.53. Pyrophoric metals (uranium and zirconium particles from fuel shearing or cladding removal) may cause fire or explosion. The design of the facility should avoid their unexpected accumulation and should provide an inert environment as necessary (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.33).

4.54. To ensure that hazardous or incompatible mixtures of materials cannot occur in leak collection systems and overflow collection systems, all relevant factors, including the following, should be fully evaluated in the design assessment:

- (a) The routing of overflow systems designed to prevent uncontrolled leaks;
- (b) Drip trays for the collection of leaks and their drain routes;
- (c) Collecting vessels;
- (d) Recovery routes;
- (e) The potential for any system passing through a cell to leak into a cell sump;
- (f) The potential for any inactive services and reagent feeds to overflow or leak in working areas.

### **Protection against external exposure**

4.55. The aim of protection against external radiation exposure is to maintain doses below the limits established in GSR Part 3 [7], schedule III, paras III.1 and III.2, to optimize protection and safety and to meet the requirements and