IAEA Safety Standards

for protecting people and the environment

Safety of Nuclear Fuel Reprocessing Facilities

Specific Safety Guide

No. SSG-42

IAEA
International Atomic Energy Agency

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.

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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

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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[1] 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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[1] See also publications issued in the IAEA Nuclear Security Series.

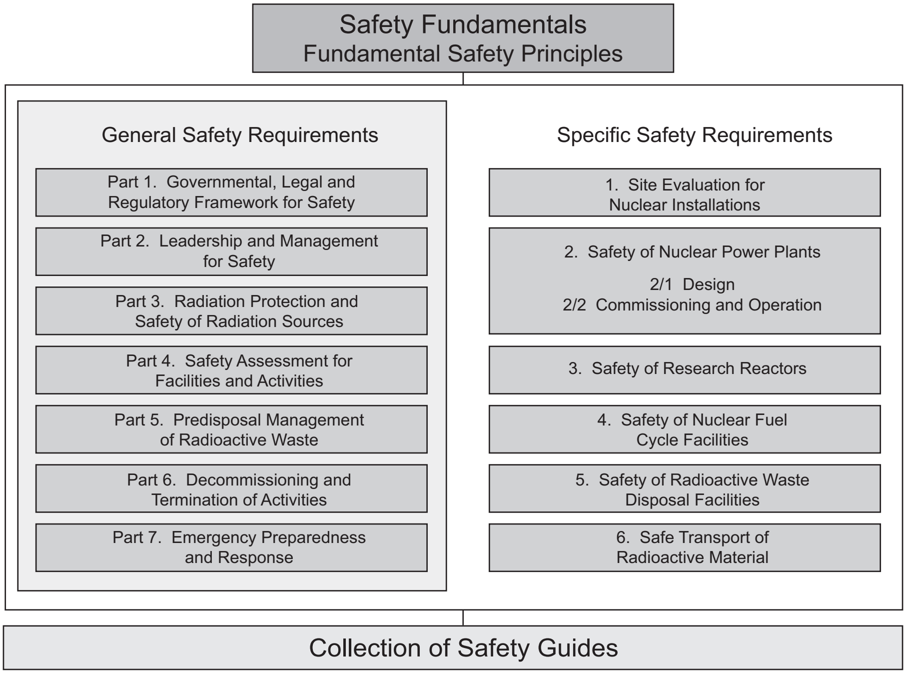

FIG. 1. The long term structure of the IAEA Safety Standards Series.

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

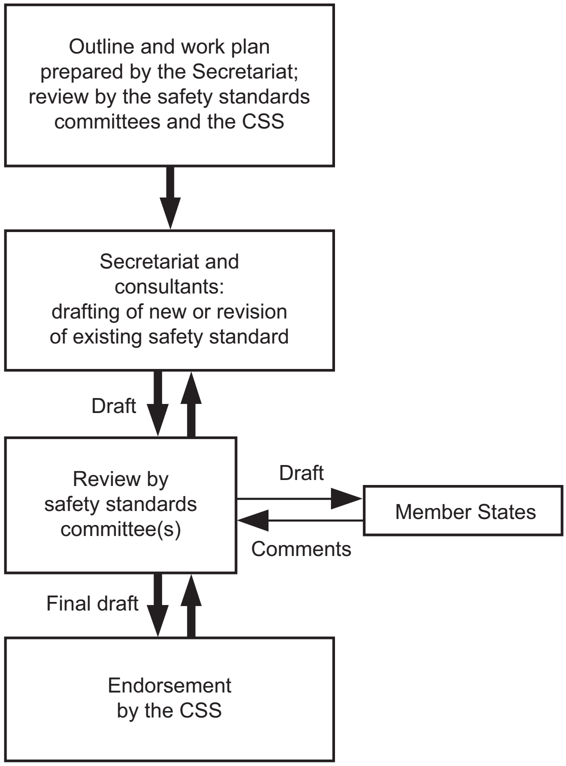

FIG. 2. The process for developing a new safety standard or revising an existing standard.

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[1] 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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[1] 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[2] or decladding[3] 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_2/PuO_2) 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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[2] Shearing involves cutting spent fuel into short lengths to allow its dissolution inside its metallic cladding.

[3] 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[4], 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

[4] 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[5] (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.

[5] 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[6].

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[7].

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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[6] 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.

[7] 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 predischarge 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[8], 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

[8] "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_{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[9]. 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.

[9] The critical value of a parameter is its value for $k_{eff} = 1$.

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[10] 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).
>
> …….
>
> "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

[10] 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[11], 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

[11] 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[12] 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[13] 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

[12] A firewall is an engineered feature specifically designed to prevent, limit or delay the spread of fire.

[13] 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[14] 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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[14] 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[15] and PuO_2 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_2, CH_4, organic nitrate or nitrites (red oils) and peroxides) or corrosive (e.g. Cl_2 and H_2O_2) 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

[15] 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 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, 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 guidance identified in para. 4.5, by use of the following elements, separately or in combination:

(a) Limiting the magnitude of the radiation source (where practicable) during operation and maintenance (e.g. by prior decontamination or washing before maintenance is carried out).
(b) Shielding the radiation source, including the use of temporary shielding.
(c) Distancing the radiation source from personnel (e.g. by means of the position of work stations and by remotely controlled operation).
(d) Limiting the exposure time of personnel (e.g. by means of automation of operation and alarmed dosimeters).
(e) Controlling access to areas where there is a risk of external exposure.
(f) Using personal radiation protection (torso shields and organ shields). For normal operation, the need for personal protective equipment is required to be minimized through careful design.

4.56. Optimization of protection and safety in design should also take into account operational constraints on maintenance staff. In addition, the use of time limitation as the main method of dose management should be minimized.

4.57. In high beta/gamma activity facility units, the design of shielding should consider both the strength and the location of the radiation source. In a medium or low activity facility, a combination of radiation source strength and location, exposure time and shielding should be considered for the protection of workers, for both whole body doses and doses to extremities. As a general guide, shielding should be designed to be as close as possible to the radiation source.

4.58. The need for maintenance, including examination, inspection and testing activities, should be considered in the design of equipment installed in highly active cells, with particular consideration given to radiation levels and contamination levels throughout the lifetime of the reprocessing facility (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.28).

(a) For the mechanical and electrical parts of units containing highly radioactive material, the design of the layout and of the equipment should allow for adequate remote maintenance (e.g. ‘master–slave’ manipulators).

(b) For transfers of liquids, non-mechanical means (e.g. air lift or jet lift with disentrainment capabilities[16], or fluidic devices as appropriate) should be preferred. Mechanical items, such as pumps and valves, should be designed for remote maintenance (e.g. by use of shielded equipment maintenance flasks[17]).

4.59. The radioactive inventories used in calculations for design and safety assessment should take into account depositions of material inside pipes and equipment, from processed materials and their daughter products. Examples of such depositions include particulates and coatings[18] of active material within pipes (sections containing highly radioactive material) and gloveboxes (americium). The potential for the accumulation of radioactive material in process equipment and secondary systems (e.g. ventilation ducting) in operation should be minimized by design, or provision should be made for its removal.

4.60. In a reprocessing facility, process control relies (in part) on analytical data from samples. In order to minimize occupational exposure, automatic and remote operation should be preferred for sampling devices, the sample transfer network to the laboratories and analytical laboratories (see NS-R-5 (Rev. 1) [1], para. 6.40).

4.61. Depending on national and international regulations and the safety assessment, the monitoring system for radiation protection should consist principally of the following:

(a) Fixed area monitors (for gamma and neutron radiation) and stationary ‘sniffers’[19] (for beta/gamma and alpha activity) to monitor air for purposes of access and/or evacuation;
(b) Mobile area monitors (for gamma and neutron radiation) and mobile sniffers (for beta/gamma and alpha activity) to monitor air for purposes of personnel protection, evacuation during maintenance and at barriers between normal access areas and controlled areas;
(c) Workers’ (personal) dosimeters consistent with the type(s) of radiation present.

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[16] An air lift or jet lift with disentrainment capabilities is a system or device for separating liquid from a motive air or steam with minimum carry-over (entrainment) of activity into the ventilation system.

[17] Such flasks are sometimes referred to as mobile equipment replacement casks.

[18] The phenomenon of such deposition is called ‘plate-out’ in some States.

[19] A sniffer is an air sampling point or device.

POSTULATED INITIATING EVENTS

Internal initiating events

Fire

4.62. The requirements for fire safety at a reprocessing facility are established in NS-R-5 (Rev. 1) [1], para. 6.55, and appendix IV, paras IV.33–IV.36. In a reprocessing facility, fire hazards are associated with the presence of:

(a) Flammable materials such as pyrophoric materials, solvents, reactive chemicals and electrical cabling;
(b) Potentially flammable materials such as polymeric neutron shielding (normally associated with gloveboxes) and process and operational waste (e.g. wipes and protective suits), including office waste.

4.63. Fire in a reprocessing facility can lead to the dispersion of radioactive and/or toxic materials by breaching the containment barriers. It can also cause a criticality accident by affecting the system(s) used for the control of criticality, by changing the dimensions of processing equipment, altering the moderating or reflecting conditions by the presence of firefighting media or fire suppression media, or destroying neutron decoupling devices.

Fire hazard analysis

4.64. Fire hazard analysis involves the systematic identification of the causes of fires, the assessment of the potential consequences of a fire and, where appropriate, the estimation of the probability of the occurrence of fires. Fire hazard analysis should consider, explicitly, potential external and internal fires, including fires involving nuclear material, both directly and indirectly.[20] Fire hazard analysis is used to assess the inventory of (flammable) fuels and ignition sources and to determine the appropriateness and adequacy of measures for fire protection. Computer modelling of fires should be used in support of the fire hazard analysis for complex and high hazard applications, as necessary. Fire hazard analyses can provide valuable information on which it is possible to base design decisions or

[20] In some States, fires involving nuclear materials (e.g. an actinide loaded solvent fire) and general (internal, conventional) fires (e.g. a control room fire caused by an electrical fault) are considered separately and explicitly in the safety assessment for additional clarity and to help to ensure all potential radiological and non-radiological hazards from both categories of fire are addressed adequately.

to identify weaknesses that might otherwise have gone undetected. Even if the likelihood of a fire occurring is low, it may have significant consequences with regard to nuclear safety and, as such, appropriate protective measures should be undertaken (e.g. delineating small fire compartment[21] areas) to prevent fires or to prevent the propagation of a fire.

4.65. The analysis of fire hazards should also include a systematic review of the provisions made for preventing, detecting, mitigating and fighting fires.

4.66. An important aspect of the fire hazard analysis for a reprocessing facility is the identification of areas of the facility that require special consideration (see NS-R-5 (Rev. 1) [1], para. 6.55). In particular, the fire hazard analysis should include the following:

(a) Areas where fissile material is processed and stored;
(b) Areas where radioactive material is processed and stored;
(c) Gloveboxes, especially those in which plutonium is processed;
(d) Workshops and laboratories in which flammable or combustible liquids and gas, solvents, resins and reactive chemicals are used and/or stored;
(e) Areas where pyrophoric metal powders are processed (e.g. uranium and zirconium from shearing or decladding);
(f) Areas with high fire loads, such as waste storage areas;
(g) Rooms housing systems and components important to safety (e.g. rooms housing last stage filters of the ventilation system and electrical switch rooms), whose degradation might have radiological consequences or consequences that are unacceptable in terms of criticality;
(h) Process control rooms and supplementary control rooms;
(i) Evacuation routes.

Fire prevention, detection and mitigation

4.67. Prevention is the most important aspect of fire protection. The reprocessing facility should be designed to limit fire risks through the incorporation of measures to ensure that fires do not occur and, if they do occur, to detect, limit and contain their spread. Measures for mitigation should be put in place to reduce to a minimum the consequences of fire in the event that a fire breaks out despite preventive measures.

[21] A room or suite of rooms within a firewall, possibly with separate fire detection and firefighting provisions, inventory controls and evacuation procedures.

4.68. To accomplish the dual aims of fire prevention and mitigation of the consequences of a fire, a number of general and specific measures should be taken, including the following:

(a) Minimization of the combustible load of individual areas, including the effects of fire-enhancing chemicals such as oxidizing agents;
(b) Segregation of the areas where non-radioactive hazardous material is stored from process areas;
(c) Installation of a fire detection system designed to allow the early detection and accurate identification of the location of any fire, rapid dissemination of information on the fire and, where installed, the activation of automatic devices for fire suppression;
(d) Selection of materials, including building materials, process and glovebox components and materials for penetrations, in accordance with their functional requirements and fire resistance ratings;
(e) Compartmentalization of buildings and ventilation ducts as far as possible to prevent the spreading of fires;
(f) Avoiding the use of flammable liquids or gases outside their flammability limits;
(g) Suppression or limitation of the number of possible ignition sources, such as open flames, welding or electrical sparks, and their segregation from combustible material;
(h) Insulation of hot or heated surfaces;
(i) Consistency of the fire extinguishing media with the requirements of other safety analyses, especially with the requirements for criticality control (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.17).

4.69. The design and control of ventilation systems for rooms, cells and gloveboxes should accomplish multiple aims in preventing and mitigating fire. The spread of fire should be limited while the dynamic containment system is maintained for as long as possible and the final stage of filtration is protected.

4.70. The design of the ventilation system should be given particular consideration with regard to fire prevention, including the following aspects:

(a) The accumulation of flammable dust or other materials should be limited.
(b) Means of removing or washing out inaccessible ventilation ducts should be provided.
(c) Ventilation ducts should be airtight and resistant to heat and corrosive products that might result from a fire.

(d) Ventilation ducts and filter units for dynamic containment should be of suitable design to ensure they do not constitute weak points in the fire protection system.
(e) Fire dampers should be mounted in the ventilation system, unless the likelihood of a widespread fire and fire propagation is acceptably low, and their effect on ventilation should be carefully considered.
(f) The fire resistance of the filter medium should be carefully considered and spark arrestors should be used to protect filters as necessary.
(g) The location of filters and fans should be carefully evaluated for its effect on their ability to perform during a fire.
(h) Careful consideration should be given to the potential need to reduce or stop ventilation flows in the event of a major fire to aid fire control.

4.71. Lines crossing the boundaries of compartments and firewalls (e.g. gas lines and process, electrical and instrument cables and lines) should be designed to ensure that fire does not spread.

4.72. Evacuation routes for fire and criticality events should be considered in the design in accordance with national regulations and the safety assessment. These should follow the same routes as far as possible consistent with the aim of reducing the number of different evacuation routes, where this does not impact significantly on fire safety or criticality safety.

Explosion

4.73. The requirements relating to explosion for a reprocessing facility are established in NS-R-5 (Rev. 1) [1], para. 6.54, and appendix IV, paras IV.33–IV.36. Explosions caused by explosive chemicals can cause a release of radioactive material. The potential for explosion can result from the use of chemical materials (e.g. organic solvents and reactants, hydrogen, hydrogen peroxide and nitric acid), degradation products, pyrophoric materials (e.g. zirconium or uranium particles), the chemical or radiochemical production of explosive materials (e.g. hydrogen and red oil) or the mixing of incompatible chemicals (e.g. strong acids and alkalines).

4.74. To prevent a release of radioactive material resulting from an explosion, in addition to the requirements of NS-R-5 (Rev. 1) [1], para. 6.54, the following provisions should be considered in the design:

(a) The need to maintain the separation of incompatible chemical materials in normal and abnormal situations (e.g. recovery of leaks);

(b) The control of parameters (e.g. concentration, temperature, pressure) to prevent situations leading to explosion;
(c) The use of blow-out panels to mitigate the effects of the explosion of non-radioactive materials;
(d) Limitations of the quantity or of the concentration of explosive material;
(e) Design of the ventilation systems to avoid the formation of an explosive atmosphere and/or to maintain the concentration of explosive gases below their lower explosive limit;
(f) Design of the equipment or structures to withstand the effects of an explosion;
(g) Where design options exist, the adoption of processes with a lower potential risk for fire or explosion.

4.75. Chemicals should be stored in well-ventilated locations or racks outside the process areas or laboratory areas.

Handling events

4.76. The requirements relating to handling events for a reprocessing facility are established in NS-R-5 (Rev. 1) [1], appendix IV, para. IV.42. Mechanical, electrical or human errors in the handling of radioactive or non-radioactive materials may result in the degradation of criticality controls, confinement, shielding, or other systems important to safety and associated controls, or in a reduction of defence in depth. A reprocessing facility should be designed to:

(a) Eliminate the need to lift loads where practicable, especially within the facility, by using track-guided transport or another stable means of transport;
(b) Limit the consequences of drops and collisions (e.g. by minimizing the heights of lifts, qualifying containers against the maximum drop, designing floors to withstand the impact of dropped loads and installing shock absorbing features and specifying safe travel paths);
(c) Minimize the failure frequency of mechanical handling systems (e.g. cranes and carts) by appropriate design[22], including control systems, with multiple fail-safe features (e.g. brakes, wire ropes, action on power loss and interlocks).

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[22] Some regulatory bodies have specific requirements for the design for ‘nuclear loads’ or ‘nuclear lifts’, e.g. requiring the use of multiroped cranes, or the maximum load to be a smaller fraction of the test load than for non-nuclear lifts.

These measures should be supported by ergonomic design, human factors analysis and the definition of appropriate administrative control measures.

Equipment failure

4.77. NS-R-5 (Rev. 1) [1] establishes the requirement to include equipment failure among the initiating events considered in the design of a reprocessing facility in paras 2.4, 6.8 and appendix IV, para. IV.37. The reprocessing facility should be designed to cope with the failure of equipment that would result in a degradation of confinement, shielding or criticality control or a reduction in defence in depth. As part of the design, the failure state of all structures, systems and components important to safety should be assessed and consideration should be given (in accordance with a graded approach) to the design or procurement of items that fail to a safe state. Where no fail-safe state can be defined, consideration should be given to ensuring that the functionality (safety function) of structures, systems and components important to safety is maintained (by redundancy, separation, diversity and independence, as necessary).

4.78. Special consideration should be given to the failure of computer systems, computerized control and software systems, in evaluating failure and fail-safe conditions, by application of appropriate national or international codes and standards.

Loss of support systems

4.79. The requirements for the loss of support systems[23] for a reprocessing facility are established in NS-R-5 (Rev. 1) [1], para. 6.28, and appendix IV, paras IV.40, IV.41.

4.80. The reprocessing facility should be designed to cope with potential short term and long term loss of support systems, such as the supply of electrical power, which may have consequences for safety. The loss of support systems should be considered both for individual items of equipment and for the facility as a whole, and, on multifacility sites, for the reprocessing facility's ancillary and

[23] Typical support systems in a reprocessing facility, including utilities, are: off-site and on-site electrical power systems, compressed air systems (instrument air and pneumatic power), systems for the supply of steam or cooling water, ventilation systems, emergency electrical power systems, uninterruptable power supply systems (instrument power), battery backup systems, reagent and chemical supply systems, inert gas supply systems and all other services and supplies the loss of which may have consequences for safety.

support facilities (e.g. waste treatment and storage facilities and other facilities on the site).

4.81. The electrical power supplies to the reprocessing facility should be of high reliability[24]. In the event of a loss of normal power, in accordance with the facility status and the requirements of the safety analysis, a robust emergency electrical power supply should be available to relevant structures, systems and components important to safety, including the following (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.41):

(a) Heat removal systems;
(b) The dilution system for hydrogen generated by radiolysis;
(c) (Some) exhaust fans of the dynamic containment system;
(d) Fire detection systems;
(e) Monitoring systems for radiation protection;
(f) Criticality alarm systems;
(g) Instrumentation and control associated with the above items;
(h) Lighting.

4.82. Consideration should be given to the need to provide emergency power for an extended period in the event of a major external event. The structures, systems and components important to safety, including selected monitoring and alarm systems and other services, that should be (and should remain) available in the event of a prolonged utilities outage should be identified.

4.83. The chronology for restoring electrical power to the reprocessing facility should be specified during design and should take account of the following:

(a) The ‘current power status’ (off, running on emergency supply, time to loss of backup power, etc.) of the items;
(b) The safety significance or priority of the item being restored to (normal) service;
(c) The interruptions of supply during switching operations;
(d) The initial power demand of items within the reprocessing facility and supply capabilities and capacity.

[24] Contributions to reliability include the use of diverse and redundant electric power sources, switching and connections, the design of power supplies to withstand external risks, and the use of uninterruptible power sources when necessary.

Emergency procedures for power recovery should also be developed during the design (see NS-R-5 (Rev. 1) [1], paras 4.2 and 4.21, and appendix IV, para. IV.41).

4.84. The assessments performed for the loss of electrical power supplies or other support services (e.g. cooling, radiolysis and ventilation) should be part of the overall safety assessment for the reprocessing facility (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.40).

4.85. The loss of general support supplies, such as compressed air for instrumentation and control, cooling water for process equipment, ventilation systems and inert gas supplies, may also have consequences for safety. In the design of a reprocessing facility, suitable measures to ensure such supplies or other means to ensure safety should be provided, including the following:

(a) In accordance with the safety assessment, the design of supply systems[25] should be of adequate reliability, with diversity and redundancy as necessary.
(b) The maximum period that a loss of support supplies can be sustained with acceptable levels of safety should be assessed for all supplies and considered in the design.
(c) For loss of air supply to pneumatically actuated valves, in accordance with the safety analysis, valves should be used that are designed to be fail-safe, as far as practicable.
(d) Loss of cooling water may result in the failure of components such as evaporator condensers, diesel generators and condensers or dehumidifiers in the ventilation system. Adequate backup capacity or independent, redundant supplies should be provided in the design.

Pipe or vessel leaks

4.86. The requirements relating to pipe and vessel leaks for a reprocessing facility are established in NS-R-5 (Rev. 1) [1], para. 6.17, and appendix IV, paras IV.16, IV.18, IV.27, IV.38, IV.39. The materials of the equipment of the reprocessing facility should be selected to cope as far as possible with the risk of corrosion due to the chemical and physical characteristics of the processed gases and liquids. The design of all containment barriers should include an adequate allowance for the combined effects of all degradation mechanisms, with

[25] Examples of supply systems include air reservoirs, uninterruptible power supplies and diverse cooling.

particular attention paid to both general and localized effects such as those due to corrosion, erosion, mechanical wear, temperature, thermal cycling, vibration, radiation and radiolysis.

4.87. Where cooling circuits are installed, especially in highly active systems, the effects of waterside corrosion, water chemistry, radiolysis (e.g. peroxide production) and stagnant coolant (no cooling required or a redundant cooling system) should be included in design considerations.

4.88. To fulfil requirements regarding confinement, any leaks from the first containment barriers should be collected and recovered (e.g. by means of drip trays or floor cladding and collecting sumps for active cells). When large volumes of highly active liquid waste are stored, a safety assessment should be made to determine the number of redundant tanks that need to be available in the event of failure of a waste storage vessel. See also NS-R-5 (Rev. 1) [1], appendix IV, para. IV.38.

4.89. The potential effects of corrosion on the dimensions of equipment containing fissile material should be taken into account in the criticality assessment (e.g. effects on the thickness of the walls of process vessels whose method of criticality control is geometry) (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.18). Consideration should also be given to the corrosion of support structures for fixed neutron absorbers and, where absorbers are in contact with the process medium, to corrosion of the absorber itself, e.g. the corrosion of packing in the condensers connected to evaporators. Where possible and in accordance with safety and technical requirements, process parameters should be optimized to give acceptable corrosion rates balanced with the need to ensure that waste is minimized and process performance and efficiency are enhanced. Examples of such parameters include the operating temperature of evaporators and specifications for the acceptable use of reagents or feeds recycled from facility effluents.

Internal flooding

4.90. The requirements relating to internal flooding for a reprocessing facility are established in NS-R-5 (Rev. 1) [1], appendix IV, paras IV.19 and IV.39. Flooding by process fluids (e.g. water, nitric acid) including utility feeds in the reprocessing facility may lead to the dispersion of radioactive material, changes in moderation and/or reflection conditions, the failure of electrically powered safety related devices, the failure of or false activation of alarms and trips, and the slowing or stopping of ventilation flows or fans. The design should address these issues, particularly the potential effect of a large leak on utility feeds and on instrumentation and control connections for structures, systems and components important to safety. Segregation of electrical services, instrumentation and control systems and their power supplies, and data and control cables from liquid and gaseous feeds should be strictly enforced as far as practicable. All floor penetrations and wall penetrations for electrical power supplies and supplies to instrumentation and control systems should be protected against liquid ingress. Where possible, electrical power supplies and cabling to instrumentation and control systems should be routed at high levels above potential flood levels. Particular care should be taken with the routing of steam and cooling water pipework owing to their potential to release large volumes of vapour or liquid.

4.91. Where vessels or pipes containing liquids pass through rooms containing fissile material, the criticality analysis should take into account the presence of the maximum credible amount of liquid within the considered room as well as the maximum credible amount of liquid that could flow from any connected rooms, vessels or pipework.

4.92. Walls (and floors if necessary) of rooms where flooding could occur should be designed to withstand the liquid load, and any equipment important to safety should not be affected by flooding. The dynamic effects of large leaks and the potential failure of any temporary 'dams' formed by equipment or internal structures should also be considered.

4.93. The potential hydraulic pressure and upthrust on large vessels, ducting and containment structures in the event of flooding should be considered in the design.

Use of hazardous chemicals

4.94. For a reprocessing facility, conservative assessments of chemical hazards[26] to workers and releases of hazardous chemicals to the environment should be made on the basis of standards used in the chemical industries and the requirements of national regulations, taking into account any potential for radiological or nuclear hazards. Where possible these chemicals should be chosen or used under physical conditions in which they are intrinsically safe, by design.

[26] Further guidance on hazardous chemicals is given in Refs [25, 26].

4.95. Based on the safety assessment, the design should take into account the effects of hazardous chemical releases from failures or damage of equipment that can lead to unsafe conditions at the reprocessing facility. The possibility of direct action of the chemicals involved (which may cause corrosion, dissolution and damage) and indirect actions (resulting in the evacuation of control rooms or toxic effects on workers) should be considered.

Use of non-atmospheric pressure equipment

4.96. As far as practicable, provisions for in-service testing of equipment installed in controlled areas and cells should be defined according to national requirements on pressurized and/or subatmospheric equipment[27]. If this is not possible, additional safety features should be specified at the design stage (e.g. oversizing with regard to pressure, increased safety margins, special justification for alternative testing regimes) and in operation (e.g. enhanced monitoring of process parameters). A specific safety assessment of any proposed alternative testing and operating regime should be made with the objective of demonstrating that the probability of failure and the consequences or risk, as appropriate, are consistent with the acceptance criteria for the facility. The potential consequences of an explosion, implosion or leak, including during testing, should be assessed, and complementary safety features should be identified to minimize potential consequences, in accordance with a defence in depth approach.

External initiating events

General

4.97. The reprocessing facility should be designed in accordance with the nature and severity of the external hazards, either natural or human induced, identified and evaluated in accordance with the provisions of NS-R-3 (Rev. 1) [14] and its associated Safety Guides (see para. 3.1 of this Safety Guide). The specific hazards for a reprocessing facility are identified in the following paragraphs under appropriate headings.

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[27] Most equipment in reprocessing plants operates at or close to atmospheric pressure; exceptions are evaporators operating at reduced pressures for safety reasons, possibly some equipment designed to resist potential violent or run-away reactions and service supplies (air, steam, etc.).

Earthquake

4.98. To ensure that the design provides the required degree of robustness, a detailed seismic assessment (see NS-R-3 (Rev. 1) [14] and SSG-9 [15]) should be made of the reprocessing facility design, including the following seismically induced events:

(a) Loss of cooling;
(b) Loss of support services, including utilities;
(c) Loss of containment functions (static and dynamic);
(d) Loss of safety functions for ensuring the return of the facility to a safe state and maintaining the facility in a safe state after an earthquake, including structural functions and functions for the prevention of other hazards (e.g. fire, explosion, load drop and flooding);
(e) The effect on criticality safety functions such as geometry and/or moderation of the following (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.44):
    — Deformation (geometry control);
    — Displacement (geometry control, fixed poisons);
    — Loss of material (geometry control, soluble poisons).

4.99. Supplementary control rooms or emergency control panels (paras 4.166, 4.167) should be accessible and operable by staff after a design basis earthquake.[28] Equipment required to maintain the reprocessing facility in a safe and stable state and to monitor the facility and environment should be tested (as far as practicable) and qualified using appropriate conservative methodologies, including the use of an earthquake simulation platform (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.45).

4.100. Depending on the reprocessing facility's site characteristics and location, as evaluated in the site assessment (Section 3), the effect of a tsunami induced by an earthquake and other extreme flooding events should be addressed in the facility design (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.46).

[28] Emergency control panels: where justified by the safety assessment, control or monitoring functions required during or after a design basis accident may not need to be located in a designated supplementary control room.

External fires and explosion

4.101. The design of the reprocessing facility should address external fire and explosion hazards as identified in the site evaluation (see Section 3 and paras 4.67–4.75 of this Safety Guide).

External toxic hazards

4.102. Toxic and asphyxiant hazards should also be assessed to verify that anticipated maximum gas concentrations meet acceptance criteria. It should also be ensured that external toxic or asphyxiant hazards would not adversely affect the control of the facility.

Extreme weather conditions

4.103. The reprocessing facility should be protected against extreme weather conditions as identified in the site evaluation (see Section 3) by means of appropriate design provisions. These should generally include the following (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.46):

(a) The ability to maintain the availability of cooling systems under extreme temperatures and other extreme conditions.
(b) The ability of structures important to safety to withstand extreme weather loads, with particular assessment of parts of the facility structure designed to provide containment with little or no shielding function (e.g. alpha active areas).
(c) Prevention of flooding of the facility.
(d) Safe shutdown of the facility in accordance with the operational limits and conditions, followed by maintaining the facility in a safe and stable state, where necessary.
(e) Keeping the groundwater level within acceptable limits during flooding.
(f) Events consequential to extreme weather conditions should also be considered in the design.

Tornadoes

4.104. The design of buildings and ventilation systems should comply with specific national regulations relating to hazards from tornadoes (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.46).

4.105. Tornadoes are capable of lifting and propelling large, heavy objects (e.g. automobiles or telegraph poles). The possibility of impacts of such missiles should be taken into consideration in the design stage for the facility, for both the initial impact and the effects of secondary fragments arising from collisions with concrete walls or from other forms of transfer of momentum (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.46).

Extreme temperatures

4.106. The potential duration of extreme low or high temperatures should be taken into account in the design of cooling systems and support systems, to prevent unacceptable effects such as the following:

(a) The freezing of cooling circuits (including cooling towers and outdoor actuators);
(b) The loss of efficiency of cooling circuits (hot weather);
(c) Adverse effects on a building's venting, heating and cooling systems, to avoid poor working conditions and excess humidity in the buildings and adverse effects on structures, systems and components important to safety.

Administrative actions to limit or mitigate the consequences of such events can only be relied upon if the operators have the necessary information, sufficient time to respond and the necessary equipment, e.g. portable air-conditioning (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.46).

Snowfall and ice storms

4.107. Snow and ice are generally taken into account as an additional load on the roofs of buildings and, in the case of 'glaze' ice, on, for example, vertical surfaces and utility cables and pipework. The flooding resulting from snow or ice accumulation and infiltration and the possibility that it could damage equipment important to safety (e.g. electrical systems) should be considered. The neutron reflecting or moderating effect of snow should be considered if relevant (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.46).

Floods

4.108. For extreme rainfall, attention should be focused on the stability of buildings (e.g. hydrostatic and dynamic effects), the water level and, where relevant, the potential for mudslides. Consideration should be given to the highest flood level historically recorded and to siting the facility above this flood level, at sufficient elevation and with sufficient margin to account for uncertainties (e.g. in postulated effects of global warming), to avoid major damage from flooding.

4.109. For flooding events, attention should be focused on potential leak paths (containment breaks) into active cells and structures, systems and components important to safety at risk of damage. In all cases, equipment containing fissile material should be designed to prevent any criticality accident. Gloveboxes should be designed to be resistant (undamaged and static) to the dynamic effects of flooding and all glovebox penetrations should be above any potential flood levels (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.46). Electrical systems, instrumentation and control systems, emergency power systems (batteries and power generation systems) and control rooms should be protected by design. Where necessary, the design should be such as to ensure continued operation of selected functions in extreme events (defence in depth).

Inundation events (of natural and human induced origin)

4.110. Measures for the protection of the facility against inundation events (dam burst, flash flood, storm surge, tidal wave, seiche, tsunami), including both static effects (floods) and dynamic effects (run-up and draw-down), will depend on the data collected during site evaluation for the area in which the facility is located. The design of buildings, electrical systems and instrumentation and control systems should comply with specific national regulations for these hazards (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.46), including the recommendations outlined in paras 4.108, 4.109. Particular attention should be given to the rapid onset of these events, the probable lack of warning and their potential for causing widespread damage, disruption of utility supplies and common cause failures both within the reprocessing facility and at other facilities on the site, locally and potentially region-wide, depending on the magnitude of the event.

Accidental aircraft crash or hazards from externally generated missiles

4.111. In accordance with the risk identified in the site evaluation (see Section 3), the reprocessing facility should be designed to withstand the design basis impact (see NS-R-5 (Rev. 1) [1], para. 5.5).

4.112. For evaluating the consequences of impact or the adequacy of the design to resist aircraft or secondary missile impacts, only realistic crash scenarios, rotating equipment scenarios or structural failure scenarios should be considered.

Such scenarios require knowledge of such factors as the possible angle of impact or the potential for fire and explosion due to the aviation fuel load. In general, fire cannot be ruled out following an aircraft crash. Therefore, specific requirements for fire protection and for emergency preparedness and response should be established and implemented as necessary.

Terrestrial and aquatic flora and fauna

4.113. The potential for a wide range of interactions with flora and fauna should be considered in the design of the reprocessing facility, including the potential for the restricting or blockage of cooling water and ventilation inlets and outlets, the effect of vermin on electrical and instrument cabling and their ingress into waste storage areas. Where physical control measures or, particularly, chemical control measures for flora and fauna are necessary, these should be subject to the same level of evaluation as any other chemical used in the process, in accordance with a graded approach based upon the risks.

INSTRUMENTATION AND CONTROL

Instrumentation and control systems important to safety

4.114. Instrumentation and control systems important to safety for normal operation should include systems for the following (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.47):

(a) Criticality control:
   — Depending on the method of criticality control, the control parameters should include mass, concentration, acidity, isotopic composition or fissile content and quantity of moderators as appropriate (see NS-R-5 (Rev. 1) [1], para. 6.45, and appendix IV, para. IV.11).
   — Specific control parameters required from criticality safety analyses where burnup credit is taken into account, such as burnup measurement for spent fuel assemblies and elements before shearing or decladding (see NS-R-5 (Rev. 1) [1], para. IV.15).
   — Specific control parameters required from criticality safety analyses where criticality control relies upon soluble poison, such as concentration measurements in reagent feeds (see NS-R-5 (Rev. 1) [1], para. IV.20).

(b) Process control: the key safety related control systems of concern are those for:
   — Removing decay heat;
   — Diluting hydrogen due to radiolysis and other sources;
   — Monitoring liquid levels in vessels;
   — Controlling temperature and other conditions to prevent explosions.
(c) Fire detection systems.
(d) Glovebox controls and cell controls:
   — Monitoring the dynamic containment for cells and gloveboxes (see point (e), below);
   — Monitoring cell and glovebox sump levels (leak detection systems).
(e) Control of ventilation:
   — Monitoring and control of differential pressure to ensure that air in all areas of the reprocessing facility is flowing in the correct direction, i.e. towards areas that are more contaminated;
   — Monitoring ventilation (stack) flows for the monitoring of environmental discharges.
(f) Control of occupational radiation exposure:
   — Sensitive dosimeters with real time displays and/or alarms should be used to monitor occupational radiation doses.
   — Portable equipment and installed equipment should be used to monitor whole body exposures and exposures of the hands to gamma radiation and neutron emissions.
   — Continuous air monitors to detect airborne radioactive material should be installed as close as possible to working areas to ensure the early detection of any dispersion of airborne radioactive material.
   — Devices for detecting surface contamination should be installed or located close to the relevant working areas and also close to the exits of rooms in which relevant working areas are located.
   — Detectors and interlocks associated with engineered openings (i.e. access controls) should be used.
(g) Monitoring for control of liquid and gaseous discharges in accordance with para. 4.47 of this Safety Guide should include monitoring (operation of) the sample system for environmental discharges.

4.115. Instrumentation should be provided to monitor the variables and systems of the facility over their respective ranges for:

(1) Normal operation;
(2) Anticipated operational occurrences;

(3) Design basis accidents;
(4) Design extension conditions, as far as practicable.

The aim should be to ensure that adequate information can be obtained on the status of the facility and correct responses can be planned and taken in accordance with normal operating procedures, emergency procedures or accident management guidelines, as appropriate, for all facility states (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.47).

4.116. Adequate and reliable controls and appropriate instrumentation should be provided for monitoring and controlling all the main variables that can affect the safety of the process and the general conditions at the facility. These variables include radiation levels, airborne contamination conditions, effluent releases, criticality conditions, fire conditions and ventilation conditions. Instrumentation should also be provided for obtaining any other information about the facility necessary for its reliable and safe operation. Provision should be made for the automatic measurement and recording of relevant values of parameters important to safety (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.47).

4.117. According to the requirements of the safety analysis and any defence in depth consideration, instrumentation and control systems should incorporate redundancy and diversity to ensure an appropriate level of reliability and availability. This should include the requirement for a reliable and uninterruptable power supply to the instruments, as necessary.

Local instrumentation

4.118. In a reprocessing facility, many areas may be impossible or very difficult to access, with restricted working times due to high radiation levels and/or contamination levels. As far as possible, the need to access such areas to operate, view or maintain instruments, local indicators or control stations should be avoided. Where the location of instruments in such environments is unavoidable, separate enclosures or shielding should be used to protect instruments or personnel as appropriate (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.47).

Sample taking and analysis

4.119. The preference in reprocessing facilities should be for measurement by:

(1) In-line instruments;
(2) At-line instruments[29];
(3) Sampling with local analysis (e.g. checking the dilution of reagents from concentrated stock solutions to the concentration required by the process);
(4) Sampling with analysis at a distant laboratory, for example, at a central site laboratory.

4.120. In choosing the type of instrument to install the following factors should be considered:

(a) The availability of capable equipment and its precision, accuracy, reliability and stability;
(b) The availability of suitable points in the process including, for sampling and analyses important to safety, the following:
    — Diversity and redundancy considerations;
    — The requirement for assurance of the delivery and measurement of samples that are ‘representative and fresh’[30].
(c) Realistic calibration and testing options (e.g. in situ, on-line or off-line calibration and testing);
(d) The ergonomics of maintenance and replacement, including dose considerations and timeliness issues.

4.121. In a reprocessing facility, the safety of many chemical processes relies on the quality and timeliness of chemical and radiochemical analysis performed on samples taken from vessels and equipment at strategic points in the processes, e.g. measurement of plutonium concentration, plutonium isotopic composition or solution acidity. For such strategic sample points, all the aspects relating to the

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[29] At-line instruments are devices that remove a small sample or flow (proportional sampling) from a process flow or vessel for measurement rather than measuring in the bulk material directly.

[30] In this context ‘representative and fresh’ means that, where the main process or flow is not being measured directly, it has to be demonstrated (to the same reliability as specified for the system, structure or component by the safety assessment) that the sample is fully representative of the main flow in composition at the time of sampling and measurement (with allowable deviation as specified in the safety assessment) and is delivered to the point of measurement reliably.

quality of sample taking and labelling, its safe transfer to analytical laboratories, the quality of the measurements and their reporting to the facility operators should be documented and justified as part of the management system (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.47, and GSR Part 2 [4]). The use of bar-coding or similar systems that reduce the opportunity for error should be considered.

4.122. Occupational exposures and the possibility for human error should be analysed for sampling operations, and sampling systems should be automated where appropriate. The use of completely automated systems (from the request for sampling to the receipt of results) for frequent analytical measurements should be considered where beneficial to safety and for minimizing operational exposure. See NS-R-5 (Rev. 1) [1], para. 6.16, and appendix IV, para. IV.28.

Control systems

4.123. The recommendations in paras 2.10–2.13 apply to all control systems in a reprocessing facility. In particular, the hierarchy of design measures established in para. 6.6 of NS-R-5 (Rev. 1) [1] (application of passive design features, in preference to application of active design features, in preference to administrative controls (operator action)) should be applied in accordance with a graded approach and the available reaction time (grace period). Application of the defence in depth principle of avoiding challenges to safety features or safety controls should also be considered.

4.124. Appropriate information should be made available to workers for monitoring the actuation of, and facility response to, remote actions and automatic actions. The preference should be for independent indication showing, as far as practicable, the actual effect of an action, for example, a flowmeter showing a flow stopping or starting rather than merely a valve position indicator. As far as practical, all displays (instrument, computer, facility and process schematics and mimic displays) and all control rooms and control stations should follow good ergonomic practice. The layout of instrumentation and the presentation of information should provide workers with a clear and comprehensive view of the status and performance of the facility, to assist the operators in comprehending the facility status rapidly and correctly, in making informed decisions and in executing those decisions accurately.

4.125. Devices should be installed that provide, in an effective manner, visual and, as appropriate, audible indications of operational states that have deviated from normal conditions and that could affect safety. Specifically, information should be displayed in such a way that operators can easily determine if a facility is in a safe state and, if it is not, can readily determine the appropriate course of action to return the facility to a safe and stable state (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.47).

4.126. For radioactive material and important reagent transfers, in addition to any specific safety measures, the following measures should be applied, as far as practicable, to allow early detection of operational occurrences as part of defence in depth (see NS-R-5 (Rev. 1) [1], para. 2.7, and appendix IV, para. IV.47):

(1) The use of transfers by batch between units, buildings or facilities (see para. 4.47);
(2) Characterization of a batch before transfer;
(3) The use of an authorization procedure allowing the receiving installation to authorize the start of the transfer and to monitor the transfer process.

Where transfers are initiated automatically, especially if such transfers are frequent, consideration should be given to appropriate automatic means of detecting failures to start or stop transfers.

Control rooms

4.127. Control rooms should be provided to centralize the main data displays, controls and alarms for general conditions at the facility. Occupational exposure should be minimized by locating the control rooms in parts of the facility where the levels of radiation are low. For specific processes, it may be useful to have dedicated, local control rooms to allow the remote monitoring of operations, thereby reducing exposures and risks to operators. Particular consideration should be paid to identifying those events, both internal and external to control rooms, that may pose a direct threat to the workers, to the operation of the control room and to the control of the reprocessing facility itself (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.47).

CONSIDERATIONS RELATING TO HUMAN FACTORS

4.128. The facility should be designed for high reliability of human operator action. The requirements relating to the consideration of human factors are established in NS-R-5 (Rev. 1) [1], paras 6.15 and 6.16. Human factors should be considered at the design stage and should include:

(a) Ensuring that operators have awareness of the facility status and configuration;
(b) Possible effects on safety of human errors (with account taken of ease of intervention by the operator and the system tolerance of human error);
(c) The potential for occupational exposure.

4.129. In the design of the reprocessing facility, all work locations should be evaluated under normal facility states, including maintenance, and circumstances should be identified where and when human intervention is required under abnormal conditions and accident conditions. The aim should be to facilitate the workers' activities and ensure resistance to human error of safety functions and the structures, systems and components that support them during such interventions. This should include optimization of the design to prevent or reduce the likelihood of operator error (e.g. locked valves, segregation and grouping of controls, fault identification, logical displays and segregation of displays and alarms for processes and safety systems). Particular attention should be paid to situations in which, in accident conditions, operators need to make a rapid, accurate, fault tolerant identification of the problem, and select an appropriate response or action.

4.130. Experts in human factors and experienced operators should be involved from the earliest stages of the design. Aspects that should be considered include:

(a) Application of ergonomic requirements to the design of the workplace, considering the following aspects:
  — Good design of human–machine interfaces, e.g. well laid-out electronic control panels displaying all the necessary information and no more;
  — Reliability and ease of access and use for sampling systems;
  — The working environment, e.g. good accessibility to, and adequate space around, equipment, good lighting, including emergency lighting, and suitable finishes to surfaces to allow areas to be kept clean easily.
(b) Provision of fail-safe equipment and automatic control systems for accident sequences for which reliable and rapid protection is required;
(c) Allocation of function, considering the advantages and drawbacks of automatic action vs operator (i.e. manual) action in particular applications;
(d) Design provisions that accommodate and promote good task design and job organization, particularly during maintenance work when automated control systems may be disabled;

(e) Determination of the minimum safety staffing levels and combination of skills required during the most demanding occurrences by task analysis of operator responses;
(f) Consideration of the need for additional space and of access needs during the lifetime of the facility;
(g) Provision of dedicated storage locations for all special tools and equipment;
(h) Choice of location and clear, consistent and unambiguous labelling of equipment and utilities so as to facilitate maintenance, testing, cleaning and replacement;
(i) Minimization of the need to use additional means of personal protective equipment and, where it remains necessary, careful attention to the selection and design of such equipment.

4.131. Consideration should be given to providing computer-aided tools to assist operators in detecting, diagnosing and responding to events.

4.132. In the design and operation of gloveboxes, the following specific ergonomic considerations should be taken into account:

(a) In the design of equipment inside gloveboxes, account should be taken of the potential for conventional industrial hazards that may result in injuries to workers, including internal radiation exposure through cuts in the gloves and/or wounds on the operator's skin, and/or the possible failure of confinement.
(b) Ease of physical access to gloveboxes and adequate space and good visibility in the areas in which gloveboxes are located.
(c) Consideration of the requirements for the maintenance of glovebox seals and glovebox window seals, including the need for personal protective equipment during these operations.
(d) Careful consideration of the number and location of glove and posting ports[31] in relation to all the operating and maintenance activities within the glovebox.
(e) Consideration of employing mock-ups and conducting extensive testing of glovebox ergonomics at the manufacturer before finalizing the design.
(f) The potential for damage to gloves and the provisions for glove change, and, where applicable, filter changing.

[31] Posting ports are an engineered provision for the transfer of items into, out of and between gloveboxes.

SAFETY ANALYSIS

4.133. The safety analysis of the reprocessing facility should assess the variety of hazards and places where radioactive material is located (see NS-R-5 (Rev. 1) [1], paras 2.6, 2.10–2.12, 4.2, 4.24 and 6.2) to ensure a comprehensive risk assessment for the whole facility and all activities. Safety Assessment for Facilities and Activities, IAEA Safety Standards Series No. GSR Part 4 (Rev. 1) [27] requires that all credible postulated initiating events be assessed.

4.134. The list of hazards defined in NS-R-5 (Rev. 1) [1], annex III should be developed by identifying all postulated initiating events and the resulting event scenarios and by carrying out detailed analyses to define appropriate structures, systems and components important to safety and operational limits and conditions (see NS-R-5 (Rev. 1) [1], annex III, step 3.A).

4.135. For reprocessing facilities, the safety analysis should be performed iteratively with the development of the design (see NS-R-5 (Rev. 1) [1], annex III) with the objectives of achieving the following:

(a) That doses to workers and the public during operational states are within acceptable and operational limits for those states and consistent with the optimization of protection and safety[32] (see GSR Part 3 [7], Requirements 11 and 12);
(b) That the radiological and chemical consequences of design basis accidents (or equivalent) to the public are within the limits specified for accident conditions and consistent with the optimization of protection and safety (see GSR Part 3 [7]);
(c) The development of appropriate operational limits and conditions.

4.136. Bounding cases (see NS-R-5 (Rev. 1) [1], annex III, para. III–10) have limited application in reprocessing facilities, owing to the variety of equipment used, the materials handled and the processes employed. The approach should be used only where the accidents grouped together can be demonstrated by a thorough analysis to be within a representative bounding case. The use of such

[32] Optimization of protection (and safety) is the process of determining what level of protection and safety makes exposures, and the probability and magnitude of potential exposures, “as low as reasonably achievable, economic and social factors being taken into account” (ALARA), as required by the International Commission on Radiological Protection System of Radiological Protection (Ref. [9]). See also Fundamental Safety Principles, IAEA Safety Standards Series No. SF-1 [28], Principles 5 and 6.

bounding cases is nevertheless important in reducing unnecessary duplication of safety analyses and should be used when practicable and justified.

Safety analysis for operational states

Occupational exposure and exposure of the public

4.137. At the design stage of a new reprocessing facility, radiation doses to workers should be estimated early in the design process and should be iteratively re-calculated and refined as the design proceeds, as this maximizes opportunities for the optimization of protection and safety. A common initial approach is first to allocate an (estimated) internal dose based on engineering judgement and then to assess the provisions for external radiation protection (e.g. shielding and layout). The assessment of occupational external exposure should be carried out on the basis of conservative assumptions including the following:

(1) External exposure calculations using a bounding radiation source term established on the basis of:
   (i) The maximum inventory including activity, energy spectrum and neutron emission of all radioactive material;
   (ii) Accumulation factors (e.g. accounting for the deposition of radioactive material inside pipes and equipment).
(2) Two approaches are possible to assess external exposure (see NS-R-5 (Rev. 1) [1], paras 6.40 and 6.41):
   (i) The specification of a limit for dose that will allow any worker to be present without time constraints, and irrespective of the distance between the (shielded) radiation source and the worker; or
   (ii) Determination of the type of work activity to be performed by each worker, the time required for the work activity and the distance between the worker and the (shielded) radiation source.
(3) Calculations to determine the shielding requirements for case 2(i) or 2(ii), as appropriate.

4.138. The calculation of estimated dose to the public should include all the radiological contributions originating in the facility, i.e. external exposure through direct or indirect radiation (e.g. skyshine, cloud shine or ground shine[33]), and internal exposure through intake of radioactive material and doses received

[33] Skyshine is radiation reflected from the sky; the other forms of shine are defined in the IAEA Safety Glossary [9].

through the food chain as a result of authorized discharges of radioactive material. Where a range is calculated, the maximum values for each contribution should be used for the dose calculation. Conservative models and parameters should be used to estimate doses to the public. The dose should be estimated for the representative person(s).

Releases of hazardous chemical material

4.139. This Safety Guide addresses only those chemical hazards that can give rise to radiological hazards (see NS-R-5 (Rev. 1) [1], para. 2.2). Facility specific, realistic, robust (i.e. conservative) estimations of purely chemical hazards to workers and releases of hazardous chemicals to the environment should be performed, in accordance with the standards applied in the chemical industry (see NS-R-5 (Rev. 1) [1], paras 6.12, 6.30 and 6.54, and Refs [25, 26]).

Safety analysis for accident conditions

Methods and assumptions for safety analysis for accident conditions

4.140. The acceptance criteria associated with the accident analysis should be defined in accordance with GSR Part 4 (Rev. 1) [27], Requirement 16, and with respect to any national regulations and relevant criteria.

4.141. To estimate the on-site and off-site consequences of an accident, the range of physical processes that could lead to a release of radioactive material to the environment or to a loss of shielding should be considered in the accident analysis, and bounding cases[34] encompassing the worst consequences should be determined (see NS-R-5 (Rev. 1) [1], paras 2.6, 2.11, 2.12 and 4.24, and appendix IV, paras IV.11–IV.20).

4.142. Accident consequences should be assessed in accordance with the requirements established in GSR Part 4 (Rev. 1) [27] and with relevant parts of its supporting Safety Guides.

[34] Bounding cases (also called limiting cases or enveloping cases) are used for the estimation of consequences, see paras 4.136 and 4.161 in this Safety Guide.

Assessment of possible radiological or associated chemical consequences

4.143. Safety assessments should address the consequences associated with possible accidents. The main steps in the development and analysis of accident scenarios should include the following:

(a) Analysis of the actual site conditions (e.g. meteorological, geological and hydrogeological site conditions) and the conditions expected in the future.
(b) Identification of workers and members of the public who could possibly be affected by accidents, i.e. representative person(s) living in the vicinity of the facility.
(c) Specification of accident configurations, with the corresponding operating procedures and administrative controls for operations.
(d) Identification and analysis of conditions at the facility, including internal and external initiating events that could lead to a release of material or of energy with the potential for adverse effects, the timeframe for emissions and the exposure time, in accordance with reasonable scenarios.
(e) Specification of the structures, systems and components important to safety that are credited to reduce the likelihood of accidents and/or to mitigate their consequences. These structures, systems and components important to safety that are credited in the safety assessment should be qualified to perform their functions reliably in accident conditions.
(f) Characterization of the source term (material, mass, release rate, temperature, etc.).
(g) Identification and analysis of intra-facility transport pathways for material that is released.
(h) Identification and analysis of pathways by which material that is released could be dispersed in the environment.
(i) Quantification of the consequences for the representative person(s) identified in the safety assessment.

4.144. Analysis of the actual conditions at the site and the conditions expected in the future involves a review of the meteorological, geological and hydrological conditions at the site that may influence facility operations or may play a part in transporting material or transferring energy that is released from the facility (see NS-R-5 (Rev. 1) [1], section 5).

4.145. Environmental transport of material should be calculated using qualified codes and using data derived from qualified codes, with account taken of the meteorological and hydrological conditions at the site that would result in the highest exposure of the public.

4.146. The workers and members of the public (the representative person(s)) who may potentially be affected by an accident should be identified. The identification should involve a review of descriptions of the facility, of demographic information and of internal and external exposure pathways, such as patterns of food consumption.

MANAGEMENT OF RADIOACTIVE WASTE

4.147. The general requirements for optimization of protection and safety for waste and effluent management and the formulation of a waste strategy are established in GSR Part 5 [2] with additional guidance provided in The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste, IAEA Safety Standards Series No. GSG-3 [29], Classification of Radioactive Waste, IAEA Safety Standards Series No. GSG-1 [30], SSG-41 [12] and The Management System for the Processing, Handling and Storage of Radioactive Waste, IAEA Safety Standards Series No. GS-G-3.3 [31]. Recommendations are provided in the following paragraphs on aspects that are particularly relevant or specific to reprocessing facilities.

4.148. The requirements and recommendations on facility design in the relevant IAEA standards (see GSR Part 5 [2] and SSG-41 [12]) apply fully to the waste streams (solid, liquid and gaseous) and effluents resulting from the operation of reprocessing facilities and from their eventual decommissioning. However, associated waste treatment and conditioning processes and facilities that are not integral to the reprocessing facility are excluded from the scope of this Safety Guide (see para. 1.8 of this Safety Guide and NS-R-5 (Rev. 1) [1], appendix IV).

4.149. For safety, environmental and economic reasons, an essential objective of radioactive waste management is to minimize (in both activity and volume) the generation of radioactive waste from reprocessing (see GSR Part 5 [2], Requirement 8 and SF-1 [28], Principle 7).

4.150. Owing to the nature and diversity of the composition of spent fuel (structural parts, spectrum of fission products, activation products and actinides) and to the chemical processes involved, the commissioning, operation and eventual decommissioning of a reprocessing facility result in waste with a wide variation in type, radiological characteristics, chemical composition and quantity. The designers of the reprocessing facility should try, as far as practicable, to ensure that all wastes anticipated to be generated throughout the lifetime of the facility have designated disposal routes. Where necessary and practicable, process options should be chosen or design provisions should be made to facilitate the disposal of such waste by existing routes. The identification of disposal routes should take into account not only the radionuclides present in the waste but also its chemical and physical characteristics (e.g. flammable or heat generating waste).

4.151. The recovery and recycling of reagents and chemicals, especially those that are contaminated, contributes significantly to the minimization of effluents and the maximization of process efficiency, as does the decontamination of process equipment for reuse or disposal. The design of the reprocessing facility should maximize such recovery, recycling and reuse to optimize protection and safety, with account taken of occupational exposure and technological constraints on the use of recycled materials. The design should include appropriate facilities for carrying out recovery and recycling and should include in the overall waste strategy consideration of the need for minimization of the secondary waste generated.

4.152. Where waste is intended for identified and existing disposal routes, the reprocessing facility designers should establish the waste characteristics for each route. Equipment and facilities should be provided (or existing equipment and facilities identified) for characterizing, pretreating, treating and transporting, as necessary, waste to the appropriate identified disposal route, interim storage location or further waste treatment facility.

4.153. For waste for which there is no identified disposal route, an integrated approach should be taken in the design that considers the optimization of protection and safety, local and national regulations and regulatory limits and the best available information for potential disposal routes in accordance with GSR Part 5 [2], paras 1.6 and 1.8 and Requirements 4 and 6. As disposal is the final step of radioactive waste management, any interim waste processing techniques and procedures applied should provide waste forms and waste packages compatible with the anticipated waste acceptance requirements for disposal; with care paid to the retrievability of waste intended for interim storage.

4.154. The design should accommodate, as far as practicable, provisions for the rerouting of effluents and waste to allow for the future use of emerging technologies, improved knowledge and experience, or regulatory changes. This applies particularly to gaseous and volatile waste from reprocessing facilities that pose particular challenges in both the capture and disposal of the waste.

4.155. The design should incorporate, or have provision to provide incrementally, sufficient intermediate waste storage capacity for the lifetime of the facility including, as necessary, decommissioning. This should include, in accordance with the safety assessment, the provision of spare capacity, as part of a defence in depth strategy, for example, in case of the failure of a waste storage tank.

MANAGEMENT OF GASEOUS AND LIQUID DISCHARGES

4.156. Facilities should be designed so that effluent discharge limits can be met in normal operation and accidental releases to the environment are prevented.

4.157. The activity of gaseous effluent discharged from a reprocessing facility should be reduced by process specific ventilation treatment systems. These should include, where necessary, equipment for reducing the discharges of radioiodine and other radioactive volatile or gaseous species. The final stage of treatment normally consists of dehumidification, spark arrestors and debris guards to protect filters, then filtration by a number of high efficiency particulate air (HEPA) filters in series.

4.158. Equipment for monitoring the status and performance of filters should be installed, including:

(a) Differential pressure gauges to identify the need for filter changes;
(b) Activity or gas concentration measurement devices and discharge flow measuring devices with continuous sampling;
(c) Test (aerosol) injection systems and the associated sampling and analysis equipment (filter efficiency).

4.159. Liquid effluents to be discharged to the environment should be treated to reduce the discharge of radioactive material and hazardous chemicals. The use of filters, ion exchange beds or other technologies should be considered where appropriate to optimize protection and safety. Analogous provisions to those in para. 4.158 should be made to allow the efficiency of these systems to be monitored.

4.160. The design and location of effluent discharge systems should be chosen to maximize the dilution and dispersal of discharged effluents (GSR Part 5 [2], para. 4.3) and to eliminate, as far as practicable, the discharge of particulates and insoluble liquid droplets that could compromise the intended dilution of effluents containing radioactive material.

EMERGENCY PREPAREDNESS AND RESPONSE

4.161. A comprehensive hazard assessment should be performed in accordance with Requirement 4 of GSR Part 7 [11] prior to commissioning. The results of the hazard assessment should provide a basis for identifying the emergency preparedness category relevant to the facility and the on-site areas and, as relevant, off-site areas where protective actions and other response actions may be warranted in case of a nuclear or radiological emergency. See GSR Part 7 [11] and Arrangements for Preparedness for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GS-G-2.1 [32].

4.162. The operating organization of the reprocessing facility should develop on-site emergency arrangements including an emergency plan that takes into account the identified hazards associated with the facility and the potential consequences (see NS-R-5 (Rev. 1) [1], para. 9.62, and GSR Part 7 [11]). The content, features and extent of the plan should be commensurate with the assessed hazards (paras 4.141–4.146). The plan should be coordinated and integrated with those of off-site response organizations (see GSR Part 7 [11]) and submitted to the regulatory body for approval.

4.163. The emergency plan should address and elaborate all the functions to be performed in an emergency response (see GSR Part 7 [11]) as well as the infrastructural elements (including training, drills and exercises) that are necessary to support these functions. Reference [33] provides an outline of emergency plans that may be used in the development of specific emergency plans for a reprocessing facility.

4.164. The design of the reprocessing facility should take into account the requirements for on-site infrastructure that is necessary for an effective emergency response (including the emergency response facilities, suitable escape routes and logistical support), as defined in GSR Part 7 [11] and elaborated in GS-G-2.1 [32]. The design should also take account of the need for on-site and off-site monitoring of releases and the environment in the event of an accident (see GSR Part 3 [7], GSR Part 7 [11] and GS-G-2.1 [32]).

4.165. The reprocessing facility should be capable of being brought to a safe and long term stable state, in which the availability of the necessary information on the status of the facility and monitoring information is maintained in and following abnormal conditions and accident conditions (see NS-R-5 (Rev. 1) [1], paras 2.6, 6.22–6.24, 9.26, and GSR Part 7 [11], para. 5.25). As far as practicable, the control room(s) should be designed and located to remain habitable during postulated emergencies (e.g. with separate ventilation and with a low calculated dose in case of a criticality event).

4.166. The safety analysis should identify those safety functions that should continue during and after events that may affect control rooms themselves, for example fire or externally generated releases of hazardous chemicals. Appropriately located supplementary control rooms or alternative arrangements, e.g. emergency control panels, should be provided for the safety functions identified by this analysis.

4.167. The need for infrastructure for off-site emergency response (e.g. emergency centres, medical facilities) should be considered in accordance with the site characteristics and the location of the reprocessing facility (see NS-R-5 (Rev. 1) [1], para. 9.63, and Requirement 24 of GSR Part 7 [11]).

5. CONSTRUCTION

5.1. General guidance on the construction and construction management of nuclear installations is provided in Construction for Nuclear Installations, IAEA Safety Standards Series No. SSG-38 [34].

5.2. A construction project for a fuel reprocessing facility will involve a large number of designers and contractors, over a considerable span of time, with the likelihood that design, construction and early commissioning will be taking place simultaneously in different sections of the facility. The operating organization should ensure that the relevant recommendations in SSG-38 [34] are followed, and that adequate procedures are put in place to minimize potential problems and deviations from the design intent as design and construction proceeds, as part of the management system.

5.3. The operating organization should consider minimizing the number of designers and contractors, as far as practicable, for consistency and standardization to support safe and effective operation and maintenance. Fewer external organizations (particularly fewer layers of subcontractors) will ease the process of control and communication between the operating organization and external designers and contractors. It will also facilitate the transfer of knowledge to the operating organization and allow the operating organization to benefit more effectively from the experience of external designers and contractors. This approach should be balanced by the need to use specialist designers for some design elements (e.g. criticality alarm systems), the need to make, where justified, safety improvements and other improvements using proprietary designs and equipment (see para. 2.8), and the need to have access to the necessary experts for reviews. In all cases, the management system should include provisions to ensure that the necessary information is transferred to the operating organization.

5.4. Reprocessing facilities are large and complex chemical and mechanical facilities, and, as such, modularized, standardized components should be used in their construction as far as practicable. In general, this approach will allow better control of quality and testing before delivery to site. This practice will also aid commissioning, operation, maintenance and decommissioning.

5.5. As recommended in SSG-38 [34], equipment should be tested and proven at manufacturers' workshops and/or on the site before its installation at the reprocessing facility, as far as possible. Testing and verification of specific structures, systems and components important to safety should be performed before construction and installation when appropriate (e.g. verification of shielding efficiency, testing of neutron decoupling devices, verification of geometry for criticality purposes and testing of welding), since this may not be possible or may be limited after installation.

5.6. The operating organization should put in place effective processes to prevent the installation of counterfeit, fraudulent or suspect items, as well as non-conforming or sub-standard components. Such items or components can have an impact on safety even years after commissioning of the facility (e.g. sub-standard stainless steel used for vessel construction).

5.7. The recommendations in SSG-38 [34] relevant to the care of installed equipment should also be strictly followed, particularly those with respect to the exclusion of foreign material[35] and the proper care of installed equipment.

[35] Foreign material can cause breakdowns, blockages or flow restrictions, either in situ or by displacement to a more restricted location (e.g. a pump, valve or ejector nozzle). Foreign material may also cause or promote corrosion by forming electrochemical cells or crevices or impeding heat transfer.

Existing facilities

5.8. Major construction work or refurbishment at an existing reprocessing facility presents a wide range of potential hazards to operating personnel, construction personnel, the public and the environment. The areas where such works are in progress should be isolated from other parts of the reprocessing facility in operation or already constructed, as far as practicable, to prevent negative effects on and from the operating part of the facility and possible events in either area (see Section 7 of this Safety Guide and SSG-38 [34]).

6. COMMISSIONING

6.1. This Safety Guide addresses only the commissioning of safety related aspects of reprocessing facilities. Demonstration of performance and optimization of processes, except in so far as these support the safety case, the structures, systems and components important to safety or the operational limits and conditions, are outside the scope of this Safety Guide. For fuel reprocessing facilities, the verification process established in section 8 of NS-R-5 (Rev. 1) [1] should be followed rigorously, owing to the high hazard potential and complexity of the facilities. Where possible, lessons from the commissioning and operation of similar reprocessing facilities should be sought out and applied.

6.2. The commissioning process, as established in section 8 of NS-R-5 (Rev. 1) [1], should be completed prior to the operation stage. Commissioning should be conducted, as far as practicable, as if the facility were fully operational. In particular, the requirements for good operational practices, housekeeping and access to supervised and controlled areas should be increasingly applied through commissioning.

6.3. The operating organization should make the best use of the commissioning stage to become completely familiar with the facility. It should also be an opportunity to develop a strong safety culture, including positive behaviours and attitudes, throughout the entire organization. In becoming familiar with the facility, consideration should be given to the full range of operations:

(a) Campaigns of fuel reprocessing;
(b) Startup and run-down periods;

(c) Work conducted between campaigns, including maintenance work, such as significant modifications and equipment repair and replacement projects that are not possible or too hazardous during normal operation;
(d) Emergency response.

6.4. Senior management[36] has responsibility for safety throughout the reprocessing facility. A safety committee, which should report to senior management, is required to be established at this stage (if one has not already been established) to provide advice on commissioning. The safety committee should consider the following:

(a) Any changes or modifications to the design required for, or as a result of, commissioning;
(b) The results of commissioning;
(c) The safety case of the facility;
(d) Any modifications to the safety case as a result of commissioning.

6.5. Prior to commissioning, the expected values for parameters important to safety to be measured during commissioning should be established. These values, along with any uncertainties in their determination, and maximum and minimum allowable variations (as appropriate), should determine the acceptability of commissioning results. Any measurements during commissioning that fall outside the acceptable range should be the subject of retest and safety reassessment if necessary.

6.6. During commissioning, operational limits and normal values for safety significant parameters should be confirmed as established in the safety assessment and should be validated where they are set by the regulatory body. In addition, any limits (margins) required owing to measurement precision or uncertainties and any acceptable variation in values (range) owing to facility transients or other small perturbations should also be validated and/or confirmed. Considerations in this area should include changing from one facility state to another (e.g. at the start and end of a campaign). Such limits and values may include the type, quantity and state of the fuel to be accepted (see para. 7.22).

[36] 'Senior management' means the person or persons who are accountable for meeting the terms established in the licence, and/or who direct, control and assess an organization at the highest level. Several different terms are used, including, for example: board of directors, chief executive officer (CEO), director general, executive team, plant manager, top manager, chief regulator, site vice-president, managing director and laboratory director.

These limits and values should be embedded in any instructions relating to safety, including emergency instructions.

6.7. Where necessary (and in accordance with a graded approach[37]), commissioning tests should be repeated a sufficient number of times under varying conditions, to verify their reproducibility. Particular attention should be applied to the detection, control and exclusion of foreign material, examples of which include spent welding rods, waste building materials and general debris. Such material may be inadvertently introduced during construction and one of the objectives of the commissioning process is to confirm that all such foreign material has been removed, while enhancing controls to limit any further introduction. See para. 6.15.

6.8. Commissioning typically requires the use of temporary works (such as utility supplies, supports for items and access openings in building structures) or devices (temporary electrical or instrument supplies and connections to allow the testing of items in isolation or the injection of test signals). The operating organization:

(a) Should establish suitable controls over the use of temporary works and devices, including the use of the modification process as required;
(b) Should appoint an individual with responsibility for overseeing the application of the controls and a process for registering and approving the introduction of such works and devices.

The controls should include a process for verification that all such temporary works and devices have either been removed at the end of commissioning or are properly approved to remain in place (as a modification) and included in the safety case for operation.

6.9. The procedures and training of personnel that support these non-routine activities often necessitate the temporary removal or reduction of protective barriers (both physical barriers and administrative barriers) and the bypassing of trip and control systems including those associated with structures, systems and components important to safety. The operating organization should introduce controls as described in para. 6.8 to control these activities and all such procedures

[37] In commissioning, grading should be applied in accordance with the potential hazard or risk associated with the item being commissioned (or temporarily modified) failing to deliver its safety function on demand at any time in its anticipated operational (qualified) life.

should be included in the management system as for all operational procedures. Particular care should be taken to ensure that all temporary procedures are withdrawn as soon as no longer necessary and that none remain in place at the end of commissioning.

6.10. Where inactive simulants or temporary reagent supplies are introduced for commissioning purposes, care should be taken that they have identical characteristics (for achieving the commissioning purpose) to material to be used during operations as far as practicable. If the characteristics are not identical, before approval for use, the effect of any differences should be analysed to determine the potential effects of any constituents or contaminants that might affect the integrity of the facility over its lifetime. This analysis should also identify any effects on the validity of commissioning results arising from these differences. Similar controls should be introduced to ensure that readily available supplies are not substituted in place of the specified facility feeds, e.g. normal, potable water for demineralized water, unless a full evaluation of the potential effects has been made.

6.11. Some stages of commissioning may require regulatory approval in accordance with national regulations, both prior to starting and at completion. The regulatory body should define hold points and witness points commensurate with the complexity and potential hazard of the activity and facility, as appropriate, to ensure proper inspection during commissioning. The purpose of these hold points should be principally to verify compliance with regulatory requirements and licence conditions. The operating organization should establish and maintain effective communications with the regulatory body, to ensure full understanding of the regulatory requirements and to maintain compliance with those requirements.

6.12. The commissioning programme may vary according to national practices. Nevertheless, the following activities should be performed, as a minimum:

(a) Confirmation of the performance of the shielding and the performance of the containment or confinement;
(b) Demonstration of the availability of the criticality detection and alarm systems;
(c) Emergency drills and exercises to confirm that emergency plans and arrangements are adequate and deliverable;

(d) Demonstration and confirmation of the satisfactory training and assessment of personnel;
(e) Demonstration of the availability of other detection and alarm systems (e.g. fire detection and alarm system).

6.13. Clear communications between management, supervisors and workers and between and within different shifts of workers under normal and abnormal circumstances and with the relevant emergency services is a vital component of overall facility safety. Commissioning provides the opportunity not only to commission and exercise these lines of communication and associated equipment, but also to become familiar with their use. Personnel should be trained in the use of a range of human performance techniques to aid communication (e.g. use of a phonetic alphabet, three-way communications, pre-job briefings, post-job reviews, a questioning attitude and peer review). Commissioning should also be used to develop a standard format for logbooks and shift handover procedures, to train personnel in their use and to assess the use of such standard formats and procedures.

COMMISSIONING PROGRAMME

6.14. Because of the complexity and size of reprocessing facilities, it may be appropriate to commission the facility in a section-by-section manner. If this is the case, the operating organization should ensure that sections already commissioned are suitably maintained and that the knowledge and experience gained during the commissioning of each section is retained.

6.15. The likelihood or risk of any modification to commissioned structures, systems and components important to safety from subsequent construction and installation work should be considered. Reassurance or verification testing of (commissioned) structures, systems and components important to safety should be included in the commissioning programme, to the extent that such retesting is practicable.

6.16. The safety committee should provide advice on the safety of arrangements for controlling such section-by-section commissioning and the arrangements for communications between the commissioning team and other groups in the facility. The safety committee should also advise on whether any structures, systems and components important to safety and their support systems tested earlier in the programme require reassurance testing prior to the next stage of commissioning (as a check on arrangements in para. 6.15). This may also apply to recently commissioned sections if there is a significant delay in proceeding to the next stage of commissioning, owing to, for example, the need for modifications or for revision of the safety case.

6.17. Consideration should be given to the need to sequence the commissioning so that facilities required to support the section being commissioned are able to provide such support at the appropriate time (or, if not, that suitable alternative arrangements are made). This should involve considerations of ‘upstream’[38] sections of the facility (including supplies of utilities such as electrical power, steam, reagents, cooling water and compressed air), ‘downstream’[39] sections of the facility (including waste treatment, aqueous and aerial discharges, and environmental monitoring) and ‘support’[40] sections of the facility (including automatic sampling benches, the sample transfer network and analytical laboratories). The safety committee should provide advice on the safety of arrangements for any such sequencing, particularly with respect to any environmental issues if downstream sections of the facility are not available.

COMMISSIONING STAGES

6.18. For a reprocessing facility, the commissioning is required to be divided into a number of distinct stages, according to the objectives to be achieved. Typically, this may involve four stages, which are described below.

Stage 1: Construction testing

6.19. For some structures, systems and components important to safety, where verification of compliance may not be possible after construction and installation is complete, testing should take place during construction and installation. A representative of the operating organization should observe this testing and the outcome should be reported with the first stage of commissioning. Examples of typical items for construction testing include seismically qualified supports or restraints, homogeneity of walls (shielding or barrier), pipe welding, vessels and

[38] Upstream sections are parts of the fuel cycle facility or site that provide feeds (reagent, utilities, etc.) to the section being commissioned.

[39] Downstream sections are parts of the fuel cycle facility or site that accept products or waste from the section being commissioned.

[40] Support sections are parts of the facility ancillary to the section being commissioned but which are necessary to allow or monitor its operation.

other passive structures, systems and components important to safety. In many cases this should involve both direct observation of activities, including testing, and the examination of quality control records for procurement, installation, testing and, where relevant, maintenance.

6.20. When the direct testing of safety functions is not possible in practice, alternative methods of adequately demonstrating the performance of systems, structures and components important to safety should be undertaken in agreement with the national authority, before later stages of commissioning commence. Such methods may include the verification and audit of materials or suppliers' training records. This further emphasizes the importance of an effective integrated management system.

6.21. Testing of other structures, systems and components may be performed at this stage, in accordance with national requirements.

6.22. Further recommendations are provided in relevant sections of SSG-38 [34].

Stage 2: Inactive or 'cold processing' commissioning

6.23. At this stage, the facility's systems are systematically tested; both individual items of equipment and the systems in their entirety are tested. As much verification and testing as practicable should be carried out because of the relative ease of taking corrective actions at this stage, unimpeded by the introduction of radioactive material.

6.24. In this stage, operators should take the opportunity to further develop and finalize the operational documentation and to learn the details of the systems. Such operational documentation should include procedures relating to the operation and maintenance of the facility and those relevant to any anticipated operational occurrences, including emergencies.

6.25. The completion of inactive commissioning also provides the last opportunity to examine the facility under inactive conditions. This is a valuable opportunity to simulate transients or the complete failure of support systems, e.g. ventilation, electrical power, steam, cooling water and compressed air systems. Such tests and simulations should be used to improve the responses available by comparing the outcomes and responses to those identified in calculations of simulated events.

6.26. This is also a final opportunity to ensure that all required maintenance can be completed once the facility is active. This is particularly applicable to all hot cells and items of equipment that can be maintained only by remote means. As maintenance is known to be a major contributor to worker doses in reprocessing facilities, the opportunity should also be taken to verify active maintenance procedures and controls, enhance the arrangements for the control of doses and identify any aids necessary to simplify or speed up maintenance.

6.27. Reprocessing facilities are complex facilities and, to avoid any potential errors, rooms, pieces of equipment, systems, components, cables and pipes should be given clear, consistent and unambiguous labelling. Training materials and operational documentation should be checked for consistency with such labelling and finalized during inactive commissioning.

6.28. Particular attention should also be paid to confirming that all physical connections have been made as expected. This should involve confirmation that all process lines, service connections and utility lines start and end in the expected places and that they follow the expected routes, as defined in the design documentation. Exceptions that occur should be assessed for their safety consequences and should then either be corrected or accepted, with suitable approvals and updating of documentation.

Stage 3: Trace active or uranium commissioning

6.29. Natural or depleted uranium should be used[41] at this stage, to avoid criticality risks, to minimize doses due to occupational exposure and to limit possible needs for decontamination. This stage provides the opportunity to initiate the control regimes that will be necessary during active commissioning, when fission products and fissile material are introduced. Safety tests performed at this commissioning stage should mainly be devoted to confinement checking. This should include: (i) checking for airborne radioactive material; (ii) smear checks on surfaces; and (iii) checking for gaseous discharges and liquid releases. Unexpected accumulations of material should also be checked for.

6.30. For the timely protection of workers, all monitoring equipment (both fixed and mobile) and personal dosimetry should be operational with supporting administrative arrangements when radioactive material is introduced into the facility.

[41] In some States, the use of natural or depleted uranium may require regulatory approval.

6.31. This stage should also be used to provide some measurable verification of parameters that had previously been calculated only theoretically (particularly discharges). The use of tracers[42] should also be considered to enhance or allow such verification.

6.32. Prior to active commissioning, emergency arrangements (on-site and off-site) should be put in place, including procedures, training, sufficient numbers of trained personnel, emergency drills and exercises. Capabilities should be demonstrated on and off the site, e.g. by simulated, large scale public warning and evacuation exercises (see GSR Part 7 [11]).

Stage 4: Active or 'hot processing' commissioning

6.33. Regulatory permission to operate the facility is generally issued to the operating organization before the start of this stage. In this case, 'hot processing' commissioning will be performed under the safety procedures and organization of the operating organization as for a fully operational facility.

6.34. The regime of safety requirements valid for the operational stage of the facility should be applied during active commissioning, in full, as far as defined and applicable. The safety regime should not be suspended or modified unless a safety assessment has been made and any approval required by the regulatory body has been granted.

6.35. The full requirements of the operational radiation protection programme should also be implemented (if not already in place), including personnel monitoring.

6.36. Compared to inactive commissioning, active commissioning requires major changes in the facility control arrangements and staff skills, for example those relating to confinement, criticality, cooling and radiation. The management of the facility should ensure that both the facility and the workers are fully ready for the change to active commissioning before it is implemented. The safety culture should be enhanced at this stage, to contribute further to safe operation.

[42] Tracers are small quantities of very low active (or inactive) materials that mimic the behaviour of the operational material and are used to determine process parameters.

6.37. This stage enables the process to be progressively brought into full operation by steadily increasing both the quantity and activity of the spent fuel fed into the facility, as far as such an incremental approach is practicable.

6.38. This stage provides further measurable verification of parameters that had previously only been calculated, in particular radiation levels, airborne activity levels, environmental discharges and external and internal exposure of workers. The feedback from such measurable verification should be used to inform corrective actions and to update the assumptions in any estimates and calculations.

COMMISSIONING REPORT

6.39. The requirements for a commissioning report[43] are established in NS-R-5 (Rev. 1) [1], appendix IV, para. IV.57.

6.40. A commissioning report should be prepared for each stage of commissioning. The objective of the commissioning report is to provide a comprehensive record of the commissioning stage completed and to provide evidence of both the facility's and the operating organization's readiness to proceed safely to the next stage of commissioning.

6.41. The commissioning report should describe the safety commissioning tests carried out to demonstrate the facility's compliance with the design, the design intent and the safety assessment, or should summarize the necessary corrective actions. Such corrective actions may include making changes to the safety case, adding or changing safety features and work practices. All such changes should be treated as modifications. If commissioning tests are brought forward from subsequent stages to the reported stage or put back to a subsequent stage, this should also be described and justified in the commissioning report for the reported stage.

6.42. The commissioning report should include a review of the results of facility radiation and contamination surveys, sampling and analytical measurements, particularly those relating to waste, effluent and environmental discharges.

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[43] In some States, the format and content of a commissioning report may be defined by the regulatory body.

6.43. To demonstrate the operating organization’s readiness, the commissioning report should also describe the following:

(a) The numbers, specialities, training, development and assessment of the facility staff, including managers;
(b) The development of the management system for the facility and the necessary procedures and instructions;
(c) Internal and external dose data, aggregated by work group, summarizing any dose investigations carried out;
(d) Audits and summaries of feedback from the operating organization and of feedback from workers on facility activities such as:
    — The organization of activities and tasks;
    — Briefings, procedures, work methods, ergonomics and human factors in general and in relation to specific activities;
    — Equipment and tools;
    — Support activities (such as radiation and contamination surveys, decontamination, the use of personal protective equipment and responses to issues arising during tasks);
    — Emergency drills and exercises;
    — Safety culture.

6.44. Any incidents or events that have occurred during the commissioning stage should also be summarized in the commissioning report and any learning from experience should be identified. Consideration should be given to using the guidelines of the IAEA/NEA Fuel Incident Notification and Analysis System [35] to categorize and analyse events.

6.45. Detailed findings from commissioning, including the results of all tests, calibrations and inspections, may be provided in supporting documents, but the commissioning report should list all structures, systems and components important to safety and operational limits and conditions commissioned and tested, including surveillance and maintenance activities. In addition, any assumptions or data relating to the safety assessment that had to be confirmed during plant commissioning should be reported.

6.46. The safety committee should review the commissioning report, which should be made subject to approval by senior management in accordance with the management system. The commissioning report should then be submitted to the regulatory body, as required by national regulations.

7. OPERATION

ORGANIZATION OF REPROCESSING FACILITIES

7.1. Given the large scale and complexity of fuel reprocessing facilities, there is a particular need for rigorous control, planning and coordination of the work to be undertaken in the facility, whether for operation, routine maintenance, non-routine maintenance — such as may be conducted between fuel reprocessing campaigns — and projects (modifications). The operating organization and the management system of the reprocessing facility should provide for this need, through a consistent and systematic method of approving, planning and coordinating such work. Provision of accurate and timely information to all those involved should be a further characteristic of the management system. Section 4 of NS-R-5 (Rev. 1) [1] establishes the requirements for the organization of reprocessing facilities.

7.2. The requirements for staff training and minimum staffing are established in NS-R-5 (Rev. 1) [1], paras 4.10, 8.4, 9.8–9.14, 9.52, 9.53 and 9.59, and appendix IV, para. IV.67.

7.3. Suitable arrangements should be made to gather, assess and propagate any lessons learned during the commissioning stage of the facility and, on an ongoing basis, during the operations stage. Similar arrangements should be put in place to adopt lessons learned from other organizations that operate reprocessing facilities or other hazardous facilities (e.g. chemical plants).

7.4. Round the clock continuity of organization should be provided in order to ensure that the appropriate authority is always present on the site, with appropriate access to suitably qualified and experienced personnel, whether on the site or available to be called in, commensurate with the grace time for manual intervention. This should include operations personnel, engineering personnel, radiation protection personnel, emergency management personnel and other personnel as necessary.

7.5. The operating organization:

(a) Should establish and maintain appropriate interfaces (in particular, the application of communication procedures in the field) between:
   — Shift staff and day operations staff (especially maintenance personnel and radiation protection personnel) within the reprocessing facility, as

reprocessing facilities typically operate on a 24 hours per day, 365 days a year basis even when not processing material;
- The reprocessing facility and other site facilities, particularly waste treatment facilities and utility supplies that are closely coupled to the reprocessing facility, for example, to ensure the effective management of the timing, quality (content) and quantity of transfers, to confirm the storage capacity available for receiving transfers and to ensure that facility operators have the latest information on the continuity of utility supplies;
- The reprocessing facility and the organizational unit responsible for on-site transport of radioactive material, if any;
- The reprocessing facility and any organization engaged to make modifications to the facility (e.g. projects to improve throughput or to provide additional capacity);
- The reprocessing facility and wider emergency services involved in emergency response functions at the reprocessing facility (see NS-R-5 (Rev. 1) [1], paras 9.62–9.67);

(b) Should review periodically the operational management structure, training, experience and expertise of reprocessing facility staff (individually and collectively) to ensure that, as far as practicable, sufficient knowledge and experience is available at all times. This analysis should include all reasonably foreseeable circumstances including staff absences. The requirement in NS-R-5 (Rev. 1) [1], para. 9.19, for control of organizational change should be extended to include key safety personnel and other posts, based on this analysis.

7.6. The safety committee(s) in a reprocessing facility, as defined in NS-R-5 (Rev. 1) [1], para. 9.15, should be developed from the safety committee established for commissioning. Its function should be specified in the management system, it should be adequately staffed and it should include diverse expertise and have appropriate independence from the direct line management of the operating organization.

QUALIFICATION AND TRAINING OF PERSONNEL

7.7. The safety requirements for the qualification and training of facility personnel are established in NS-R-5 (Rev. 1) [1], paras 9.8–9.13. Further guidance can be found in GS-G-3.1 [6], paras 4.6–4.25.

7.8. The safety risks and hazards for operators, maintenance staff and other personnel, such as the decontamination team, should be carefully considered when establishing the training programme. In particular, all staff handling fissile material, including waste containing fissile material, should have a sound understanding of criticality safety and the relevant physical phenomena.

7.9. The need for training all levels of management should be considered. Personnel involved in the management and operation of the facility should understand the complexity and the range of hazards present at the reprocessing facility at a level of detail consistent with their level of responsibility.

7.10. Comprehensive training should cover both automatic operations and manual operations. Dedicated training facilities should be established as necessary, with the training emphasis on activities according to their potential safety consequences.

7.11. For manual activities, training should include, but not be limited to, the following:

(a) Use of master–slave manipulators and other remote equipment (in highly active areas);
(b) Maintenance, cleaning activities and project activities that may involve intervention in the active parts of the facility and/or changes to the facility configuration;
(c) Sampling of materials from the facility;
(d) Work within gloveboxes, glove changes and glovebox posting activities;
(e) Decontamination, preparation of work areas, erection and dismantling of temporary enclosures and waste handling;
(f) Procedures for breaching barriers, self-monitoring and the use of personal protective equipment;
(g) Responses to be taken in situations that are outside normal operation (including emergency response actions).

7.12. For automatic modes of operation, training should include, but not be limited to, the following:

(a) Comprehensive training for the control room;
(b) The response to alarms;
(c) Alertness to the possibility of errors in automatic and remote systems;
(d) Alertness to unexpected changes (or lack of changes) in key parameters;

(e) The particular differences in operation that may occur during the ramp-up and ramp-down of a campaign;
(f) Responses to be taken in situations that are outside normal operation (including emergency response actions).

FACILITY OPERATION

Operational documentation

7.13. For reprocessing facilities, the requirements for operating instructions established in NS-R-5 (Rev. 1) [1], paras 9.21–9.27, should be strictly adhered to.

7.14. In order to ensure that, under normal circumstances, the reprocessing facility operates well within its operational limits and conditions, a set of operational sub-limits should be defined at lower levels by the operating organization. The margins should be derived from the design considerations and from experience of operating the facility (both during commissioning and subsequently). The objective should be to maximize the safety margin while minimizing breaches of the sub-limits.

7.15. Authority to make operating decisions should be assigned to management at suitable levels in accordance with the operational limits and conditions, the operational sub-limits and the potential safety implications of the decision. The management system should specify the authority and responsibilities at each management level and, where necessary, of individual post holders. If a sub-limit or an operational limit or condition is exceeded, the appropriate level of management should be informed (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.63). The circumstances that require immediate decisions or responses for safety reasons should be defined, as far as practicable, in procedures following guidance provided by the management system. The appropriate shift staff or day staff should be trained and authorized to make the necessary decisions in accordance with these procedures.

7.16. Any excursion outside the set of operational sub-limits should be adequately investigated by the operating organization and the lessons learned should be applied to prevent a recurrence. As required by national regulations, the regulatory body should be notified in a timely manner of such excursions and any immediate actions taken and should be kept informed of the subsequent investigations and their outcome.

7.17. Operational documentation should be prepared that lists all the limits and conditions that apply to the facility, and defines the procedures to restore the process to a state within the limits and sub-limits (see NS-R-5 (Rev. 1) [1], paras 9.22 and 9.26). Annex II gives examples of parameters that can be used for defining operational limits and conditions.

7.18. All limits and conditions should be clearly identified in procedures and in directly relevant procedural steps. In particular, procedures and procedural steps relevant to operational limits and conditions should be highlighted in a consistent manner. Provision should be made in the management system to ensure that such identification and highlighting is carried out comprehensively and consistently. Consideration should be given to classifying procedures in accordance with their safety significance (i.e. using a graded approach).

7.19. Operating procedures should be developed to control process operations directly. To maximize the benefit of the robust design of a reprocessing facility, operating procedures should be user-friendly and accurate, and should cover all operational states, including ramp-up and ramp-down. Procedures for non-operational conditions, abnormal states and accident conditions should also be put in place. Operators should be fully trained and assessed, using simulations or exercises where appropriate, in these procedures.

7.20. The documents prepared should also systematically link to the safety case and operational limits and conditions, either directly or through interface documents, to ensure that safety requirements are fully met through the instructions. Records of operation should be capable of demonstrating compliance with safety instructions and operational limits and conditions at all times.

Specific provisions

7.21. The development and maintenance of a feed programme (see NS-R-5 (Rev. 1) [1], appendix IV, para. IV.58) is important to safety in a reprocessing facility. The operating organization should allocate responsibilities within the organization for the feed programme, establish clear procedures that specify how the feed programme should be managed and establish provisions for independent verification.

7.22. Reprocessing facilities are generally designed to accept a specific range of fuel types with given characteristics such as a specific range of burnup. The feed programme should take into account fuel parameters (e.g. burnup, irradiation data, initial enrichment and duration of cooling following discharge from the reactor) and safety related constraints at the facility.

7.23. Process control at a reprocessing facility generally relies on a combination of instrument readings and analytical data from samples. Analytical instruments and methods should be used in accordance with the provisions of the management system and should be subject to suitable calibration and verification. The activities relating to obtaining and analysing data from samples should be managed and conducted to minimize doses to workers and any wastes generated should be managed in accordance with established procedures. Decisions that are based on sample analysis should take proper account of the accuracy of the sampling process, the analytical methods used and, where relevant, the delay between sampling and the result being available.

7.24. Following the batch transfer of process liquids and wastes, as far as practicable, operators should confirm that the volume transferred from the sending vessel corresponds to the volume received (see paras 4.47 and 4.126).

7.25. Operation of a reprocessing facility is often divided into campaigns (driven by operational, commercial or safety related constraints) and inter-campaign periods (for modifications to equipment, performing maintenance and purposes of nuclear material accounting and control). It is safer to carry out maintenance during inter-campaign periods but increased intervention results in higher contamination and dose risks. Intensive maintenance periods often require the use of less experienced personnel. The operating organization should take action to address the specific risks of intensive maintenance during inter-campaign periods, which may include specific training, the allocation of more experienced workers to teams of less experienced personnel and additional supervision of work.

7.26. The management system should include provision for a programme of internal audits whose purpose, among other aspects, is to confirm periodically that the facility is being operated in accordance with operating procedures (including the facility's operational limits and conditions, safety case and licence conditions). Suitably qualified and experienced persons should carry out such audits and consideration should be given to using personnel who are independent of the direct line management. See also NS-R-5 (Rev. 1) [1], para. 9.71.

7.27. Operator walk-arounds, including walk-arounds by senior management, should be specified and scheduled with the aim of ensuring that, as far as practicable, all areas of the facility are subject to regular surveillance. Particular attention should be paid to the recording, evaluating and reporting of abnormal conditions. This programme of walk-arounds should include a suitable level of independence (for example, including personnel from other facilities on the site or off the site). Examples of aspects to be observed should include the following:

(a) Local instrument readings and visual indications relevant to liquid levels or leaks, including sump levels, and to containment and ventilation failure;
(b) That safety checks have been completed within the specified range of dates (e.g. on access equipment[44], lifting equipment, fire extinguishers and electrical equipment);
(c) Conditions at access points to supervised and controlled areas;
(d) The number and condition of areas where access is temporarily restricted (radiation areas or contamination areas);
(e) The availability and functioning of personal dosimeters;
(f) The accumulation of waste;
(g) The proper storage of materials and equipment;
(h) The ready availability of emergency equipment.

Exclusion of foreign material

7.28. Suitable controls should be established to ensure, as far as is practicable, that foreign material is excluded from the process. These controls should build upon those developed during commissioning and are particularly relevant for maintenance activities and for the supply and delivery of process reagents.

Maintenance, calibration, periodic testing and inspection

Maintenance, periodic testing and inspection

7.29. As reprocessing facilities are large and complex facilities, maintenance should be coordinated and managed to ensure that unanticipated interactions, either with operation or between two maintenance activities, will not result in negative safety consequences.

7.30. The management system should ensure that all maintenance activities are reviewed for evidence of reliability and performance issues. Higher risk, complex or extended maintenance tasks should be regularly reviewed to benefit

[44] Examples of access equipment are ladders, scaffolding, access platforms and powered access equipment (hydraulic platforms).

from lessons learned and for optimization of protection and safety. The safety committee should routinely review maintenance reports generated for the most significant structures, systems and components important to safety and any other significant findings with consideration of their implications for facility safety.

7.31. Prior to any maintenance activities, consideration should be given to radiological checks of the work areas, the need for decontamination and the need for periodic surveys during the period of maintenance and before return to service.

7.32. Maintenance (and any preparatory operations) that involves temporary changes to confinement and/or shielding should always be thoroughly analysed beforehand, including any temporary or transient stages, to ensure that contamination and doses will be acceptable. The analysis should specify appropriate compensatory measures, where possible, and monitoring requirements (see paras 7.70, 7.71).

7.33. During maintenance, isolation between the equipment being maintained and the plant in operation or other facilities with a radioactive inventory should be ensured as far as practicable.

7.34. Hands-on maintenance should be performed after equipment drain down and washout or decontamination, as far as practicable, with the objective of removing radioactive material and reducing radiation risks and contamination risks.

7.35. For maintenance tasks with high anticipated doses or dose risk, consideration should be given to provision of mock-up and/or electronic models of the area, or other training methods, to develop familiarity with the task, develop operator aids and allow work techniques to be optimized, including through the development of 'stand-off' tools where practicable.

Calibration

7.36. The accurate and timely calibration of equipment is important for the safe operation of a reprocessing facility. Calibration procedures and standards should cover equipment used by facilities and by organizations that support the reprocessing facility, such as analytical laboratories, suppliers of radiation protection equipment and reagent suppliers. The operating organization should satisfy itself that such externally supplied or located equipment is properly calibrated at all times. Where necessary, traceability to national or international standards should be provided.

7.37. The frequency of calibration and periodic testing of instrumentation important to safety, i.e. part of the structures, systems and components important to safety (including instrumentation located in analytical laboratories), should be defined (from the safety analyses) in the operational limits and conditions.

CONTROL OF MODIFICATIONS

7.38. The management system for a reprocessing facility should include a standard process for all modifications (see NS-R-5 (Rev. 1) [1], para. 9.35). The process should use a modification control form or equivalent management tool. The operating organization should prepare procedural guidelines and provide training to ensure that the responsible personnel have the necessary training and authority to ensure that modification projects are carefully considered. The safety of modifications should be assessed for potential hazards during installation (e.g. the hazards associated with non-routine lifting with cranes), commissioning and operation. Decision making relating to modifications should be conservative.

7.39. The modification control form should contain (or have appended) a description of what the modification is and why it is being made. The modification control form should be used to identify all the aspects of safety that may be affected by the modification (including procedures and emergency arrangements). The modification control form should demonstrate that adequate and sufficient safety provisions are in place to control the potential hazards both during and after the modification, with any temporary or transient stages being clearly identified and assessed. The modification control form should also identify any (potential) need for the revision or renewal of a licence by the regulatory body.

7.40. Modification control forms should be scrutinized by and be subject to approval by qualified and experienced persons to verify that the arguments used to demonstrate safety are suitably robust. This should be considered particularly important if the modification could have an effect on the exposure of workers or the public, on the environment or on criticality safety. The depth of the safety arguments and the degree of scrutiny to which they are subjected should be commensurate with the safety significance (potential hazard) of the modification (a graded approach). Review of modification control forms should be carried out by the safety committee (or an equivalent committee), which should have suitable expertise and should be able to independently examine the proposal. Suitable records should be kept of their recommendations. Senior management of the reprocessing facility should grant specific personnel the responsibility for the approval and control of modifications. Such authorizations should be regularly reviewed and either withdrawn or confirmed as still valid, as appropriate.

7.41. The modification control form should also specify which documentation and training will need to be updated because of the modification (e.g. training plans, specifications, safety assessment, notes, drawings, engineering flow diagrams, process instrumentation diagrams and operating procedures).

7.42. Procedures for the control of documentation and training should be put in place to ensure that, where necessary and as specified in the modification control form:

- Training has been given and assessed.
- Documentation has been changed before the modification is commissioned.
- All changes in (the remaining) documentation and training requirements are completed within a reasonable period following the modification.

7.43. The modification control form should specify the functional checks (commissioning checks) that are required before the modified system may be declared fully operational again.

7.44. The modifications made to a facility should be reviewed on a regular basis to ensure that the combined effects of a number of modifications with minor safety significance do not have unforeseen effects on the overall safety of the facility. This should be part of (or additional to) periodic safety review or an equivalent process.

7.45. No modifications affecting operational limits and conditions or structures, systems and components important to safety should be put into operation unless all the requirements specified on the modification control form are confirmed to be in place and the required number of operators have been trained in their use, including their maintenance.

CRITICALITY CONTROL DURING OPERATION

7.46. The requirements for criticality safety in a reprocessing facility are established in NS-R-5 (Rev. 1) [1], paras 9.49–9.53, and appendix IV, paras IV.66–IV.76, and general recommendations are provided in SSG-27 [22]. The procedures and measures for controlling criticality hazards should be strictly applied.

7.47. Operational aspects of the control of criticality hazards in a reprocessing facility should include the following:

(a) Rigid adherence to the predetermined feed programme;
(b) Watchfulness for unexpected changes in conditions that could increase the risk of a criticality accident;
(c) Training of personnel in the factors affecting criticality as well as in facility procedures relating to the avoidance and control of criticality;
(d) Management of moderating materials, particularly hydrogenated materials;
(e) Management of mass in transfers of fissile material, where mass control is used;
(f) Reliable methods for detecting the onset of any of the deviations from normal conditions, particularly those parameters relied upon for the avoidance of criticality;
(g) Periodic calibration or testing of systems for the control of criticality hazards;
(h) Evacuation drills to prepare for the occurrence of a criticality and/or the actuation of a criticality alarm.

7.48. For each reprocessing campaign, before starting to feed fuel to the dissolver, the settings of criticality alarm parameters should be checked and changed if necessary, depending on the feed programme of the campaign. The feed programme should be supported by appropriate fuel monitoring instruments, as far as possible, and by administrative controls, to confirm that the fuel characteristics match the feed programme. All software used to support calculations for the feed programme should be suitably validated and verified.

7.49. When burnup credit is used in the criticality safety analysis, appropriate burnup measurements are required and care should be taken to allow for the associated measurement uncertainties; see paras 4.114 and 7.22 in this Safety Guide.

7.50. In chemical cycles, particular care should be given in the control and monitoring of those stages of the process where fissile material is concentrated or may become concentrated (e.g. by evaporation, liquid–liquid extraction, or other means such as precipitation or crystallization). A specific concern for reprocessing facilities is the creation of plutonium polymers, which can arise from hydrolysis in high plutonium and low acid concentration conditions in solution. This can potentially lead to precipitation and local high concentrations of plutonium (in contactor stages), resulting in the retention of plutonium in the contactor and/or the loss of plutonium to uranium product streams or waste streams, with implications for criticality and/or internal doses.

7.51. If identified by the safety analysis, the following issues should be addressed in facility procedures:

(a) Isolation, often by means of disconnection of and/or suitable locking devices on water or other reagent wash lines;
(b) Normal and allowable fissile concentration(s);
(c) The feed setting and the control of flows of reagents (solvent and aqueous);
(d) The conditioning of fissile solutions (for example, by heating or cooling) according to the facility flowsheet (the technical basis).

These requirements should be supported by appropriate alarm settings on the instruments used for monitoring the feeds and solutions.

7.52. Where there are any uncertainties in the characteristics of fissile material, conservative values should be used for parameters such as fissile content and isotopic composition. Particular issues may be encountered when carrying out maintenance work and during inter-campaign periods when material and residues from different campaigns may become mixed.

7.53. In some situations, the requirements for criticality avoidance and conservative decision making may make it necessary to halt the transfer of fissile material in accordance with the operational limits and conditions, while the situation is assessed and recovery is planned. The loss of a reagent feed to a separation process is one example of such a situation. As far as possible, all such situations should have been anticipated, assessed and included within appropriate procedures, including step-by-step recovery procedures to return the facility to a safe and stable state. Nevertheless, criticality staff should be involved in all such decisions and should subsequently analyse the event for feedback and learning.

RADIATION PROTECTION

7.54. The requirements for radiation protection in operation are established in NS-R-5 (Rev. 1) [1], paras 9.36–9.45, and appendix IV, paras IV.77, IV.78 and GSR Part 3 [7]; recommendations are provided in GSG-7 [8]. The operating organization should have a policy to optimize protection and safety, and is required to ensure doses are below national dose limits and within any dose constraints set by the operating organization. The policy should address the minimization of exposure to radiation by all available physical means and by administrative arrangements, including the use of time and distance during operations and maintenance activities.

7.55. The operational radiation protection programme should take into account the large inventories, the variety of sources, the complexity and the size of the reprocessing facility.

7.56. The operational radiation protection programme should include provisions for detecting changes in the radiation status (e.g. hot spots, slow incremental increases or reductions in radiation or contamination levels) of equipment (e.g. pipes, vessels, drip trays and filters) or rooms (e.g. contaminated deposits and increase of airborne activity), including by means of monitoring of effluents or environmental monitoring. It should also ensure prompt definition of the problem and the identification and implementation of timely corrective and/or mitigatory actions.

7.57. Workplace monitoring for purposes of radiation protection inside and outside the reprocessing facility buildings should be complemented by regular, routine monitoring by trained personnel. This should be organized to provide, as far as practicable, regular workplace monitoring of the whole reprocessing facility site. Particular attention should be paid to the recording, labelling or posting where necessary, evaluating and reporting of abnormal radiation levels or abnormal situations. The frequency of workplace monitoring should be related to the relative risk of radiation or contamination in the individual areas. Radiation protection personnel should consider assigning a frequency for monitoring of each facility area based upon easily identified boundaries. The use of photographs or drawings of the area or equipment should be considered for reporting the findings.

7.58. Radiation protection personnel should be part of the decision making processes associated with the application of the requirements for minimization of exposure (e.g. for the early detection and mitigation of hot spots) and proper housekeeping (e.g. waste segregation, packaging and removal).

Protection against exposure

7.59. Protection against internal and external exposure should be provided during all operations including maintenance. Limitation of exposure time, the use of additional shielding and remote operations and the use of mock-ups should be considered, as necessary, for personnel training and optimization of complex or high dose tasks, to minimize exposure times and exposure rates and to minimize risks.

7.60. A high standard of housekeeping should be maintained within the facility. Cleaning techniques that do not cause airborne contamination should be used. Waste arising from maintenance or similar interventions should be segregated by type (i.e. disposal route), collected and directed to interim storage or disposal as appropriate, in a timely manner.[45]

7.61. Regular contamination surveys of facility areas and equipment should be carried out to confirm the adequacy of facility cleaning programmes. Prompt investigations should be carried out following increased radiation or contamination levels. Performing additional cleaning and providing additional shielding could result in additional radiation exposure that should be balanced against the normal exposure from routine operations.

7.62. To aid operators in assessing the risk of any task and in setting the frequency of routine contamination or radiation surveys (rounds), consideration should be given to assigning facility areas a contamination and/or radiation classification. The class assigned should be based initially on the classification used in the facility design and should be developed on advice from radiation protection personnel, as necessary. Such contamination zones and the boundaries between them should be regularly checked and adjusted to match current conditions or other actions taken. Continuous air monitoring should be carried out to alert facility operators if levels of airborne radioactive material exceed predetermined action levels. The action levels should be set as near as possible to the level normal for the area. Mobile air samplers should be used near sources of contamination and at the boundaries of contamination zones as necessary, e.g. during maintenance or other operations,

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[45] Allowing waste (including industrial waste material that is suspected to contain radioactive material) to accumulate in work areas contributes to worker doses, both directly as sources and indirectly by impeding work progress. This can cause delays and complicate the identification of (new) sources of contamination, particularly airborne contamination. It can also lead to action levels for decontamination being raised (owing to an increase in background levels of radiation).

when there is a risk of contamination spreading. Prompt investigation should be carried out in response to readings of high levels of airborne radioactive material.

7.63. Newly identified contamination zones should be delineated, with proper posting and barriers provided where these are required by facility procedures. Temporary confinement should be used to accommodate higher levels of contamination (e.g. a temporary enclosure with contamination check at entry points and a dedicated, local ventilation system). A register should be maintained of such contamination zones, barriers and enclosures.

7.64. The register of temporary contamination zones should be reviewed regularly by an appropriate level of management. The objective should be to reduce the number of temporary contamination zones either by decontamination or, where possible, by the elimination of the root cause, which may necessitate modifications to the facility or its procedures.

7.65. Good communications between operators, radiation protection personnel, maintenance staff and senior management should be established and maintained to ensure timely corrective actions.

7.66. Personnel should be trained to adopt the correct behaviour during operational states, for example, training on general requirements and local radiation protection requirements.

7.67. Personnel should be trained in the use of dosimeters and personal protective equipment (e.g. lead gloves and apron), including dressing and undressing, and in self-monitoring. Personal protective equipment should be maintained in good condition, periodically inspected and kept readily available.

7.68. Personnel and equipment should be checked for contamination and should be decontaminated, if necessary, prior to their leaving contamination zones.

7.69. Careful consideration should be given to the possible combination of radiological hazards and industrial hazards (e.g. oxygen deficiency, heat stress). Particular attention should be paid to the balance of risks and benefits associated with the use of personal protective equipment, especially air-fed systems.

Intrusive maintenance

7.70. Intrusive maintenance[46] is considered a normal or regular occurrence in reprocessing facilities. The procedures for such work should include the following:

(a) The estimation, prior to the work starting, of expected doses for all staff (including decontamination workers);
(b) Preparatory activities to minimize individual and collective doses for all staff, including:
  — The identification of specific risks due to the intrusive maintenance;
  — Operations to minimize the radiation source (inventory), e.g. flushing out and rinsing of parts of the process;
  — Consideration of the use of mock-ups, remote devices, additional shielding or personal protective equipment, monitoring devices and dosimeters;
  — The identification of relevant procedures within the work permit, including procedures for meeting requirements for protection of individuals and the staff as a whole, e.g. personal protective equipment, monitoring devices and dosimeters, and time and dose limitations;
(c) The measurement of doses during the work:
  — If doses (or dose rates) are significantly higher than anticipated, consideration should be given to withdrawing personnel to re-evaluate the work.
(d) The use of feedback to identify possible improvements:
  — For extended maintenance activities, feedback should be applied to the ongoing task.

7.71. Procedures that address the following aspects should be developed and applied according to level of risk[47]:

(a) A temporary controlled area should be created that includes the work area. Depending on the assessed risk, this may include, as necessary:

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[46] Intrusive maintenance is maintenance involving a significant reduction in shielding, the breaking of static containment or a significant reduction of dynamic containment, or a combination of these.

[47] Where the level of risk is difficult to determine (e.g. for new tasks or initial breaking of containment following a fault), the precautions taken should initially be cautious, based on the assessed hazard and operational experience, until the risk assessment can be reviewed in the light of new data.

— An enclosure[48] with a temporary ventilation system with filtration and/or exhaust to the facility's ventilation system;
— Barriers with appropriate additional radiation and/or airborne contamination monitors.

(b) Personal protective equipment (e.g. respirators, over-suits), as specified, should be provided at the entry points and used when dealing with any release of radioactive material.

(c) In accordance with the assessed risk, a dedicated trained person, usually the radiation protection officer, should be present at the work place to monitor the radiological conditions and other safety related conditions; this individual should have the authority to halt the work and withdraw personnel in case of unacceptable risk (e.g. oxygen deficiency, if air-fed equipment is in use). This dedicated individual should also provide assistance to the maintenance staff in putting on, taking off and monitoring personal protective equipment.

These recommendations are applicable when the normal containment barrier is to be reduced or removed as part of a maintenance or modification activity.

Monitoring of occupational exposure

7.72. There should be appropriate provisions for the measurement of radiation and contamination to ensure compliance with regulatory and operational limits controlling doses to individuals. Instrumentation should be provided, where appropriate, to give prompt, reliable and accurate indications of airborne radiation and direct radiation in normal operation and accident conditions.

7.73. Doses to personnel should be estimated in advance and should be monitored during work activities, using suitably located devices and/or personal dosimeters (preferably alarmed) where appropriate.

[48] An enclosure is a (usually temporary) combination of a static barrier (containment) supplemented by a dynamic barrier (ventilation) with appropriate entry facilities, completely enclosing (boxing in) a work area and sealed, as far as practical, to local surfaces (walls, floors, etc.) to limit and minimize the spread of contamination. Where possible, enclosures should be modular with a rigid or heavy duty plastic outer 'skin' (that is resistant to damage) and a lighter weight (thinner), easily de-contaminable, inner skin to allow for maximum recycling and reuse and to minimize waste volumes. In some States, the inner skin is called a 'tent' or 'greenhouse'.

7.74. The extent and type of workplace monitoring should be commensurate with the expected level of airborne activity, contamination and radiation type, and the potential for these to change.

7.75. Personal dosimeters should be used as necessary, with, where available, alarms set for both cumulative dose and dose rate.

7.76. The selection and use of personal dosimeters and mobile radiation detectors should be adapted to the expected spectrum of radiation energies (alpha, beta/gamma or neutron) and the physical states (solid, liquid and/or gaseous forms) of radioactive material.

7.77. Equipment for monitoring local dose rates and individual doses and airborne activity for reprocessing facilities should include, as necessary, the following:

(a) Film dosimeters, solid trace detectors or electronic beta/gamma and neutron dosimeters, criticality 'lockets' or belts, TLDs (thermoluminescent dosimeters) and indium foil criticality event detectors;
(b) TLD extremity dosimeters (e.g. to measure doses to fingers);
(c) Mobile airborne activity monitors with immediate, local alarms (for maintenance work areas, tents and temporary enclosures and air locks);
(d) Mobile air samplers for low level monitoring.

7.78. The methodology for assessing doses due to internal exposure should be based on in vivo and in vitro monitoring, supplemented by the timely collection of data from air sampling in the workplace, in combination with worker occupancy data. Where necessary, the relationship between fixed detectors and individual doses should be verified by the use of personal air samplers in sampling campaigns of, preferably, limited duration.

7.79. In the event of abnormal radiation or contamination being detected in a room or area, checks of the staff that had been present in the area should be carried out and the appropriate decontamination or medical intervention should be implemented in accordance with the results. The details of such interventions are outside the scope of this Safety Guide.

7.80. In addition to personal monitoring and workplace monitoring, routine in vivo monitoring and biological sampling should be implemented in accordance with national regulations. The effects of hazardous chemicals and the radiological effects should be taken into account in monitoring programmes as necessary.

7.81. Further guidance on occupational radiation protection and the assessment of internal and external exposure to radiation can be found in GSG-7 [8].

MANAGEMENT OF FIRE SAFETY, CHEMICAL SAFETY AND INDUSTRIAL SAFETY

7.82. The potential for fire or exposure to chemical and other industrial hazards is significant for reprocessing facilities owing to their size and complexity, the nature of the materials processed and stored and the processes used.

7.83. The list of conventional non-nuclear hazards found in reprocessing facilities is extensive and could include the following:

(a) Conventional hazardous chemicals in the process or in storage;
(b) Electrical works;
(c) Fire and explosion;
(d) Superheated water and steam;
(e) Asphyxiation;
(f) Dropped loads;
(g) Falls from elevated working places;
(h) Noise;
(i) Dust.

Chemical hazards

7.84. Reprocessing facilities should be designed and operated to protect workers from the hazards associated with the use of strong acids and hazardous chemicals. Particular attention should be given to all processes at elevated temperatures and to the hazards associated with the use of organic solvents in the extraction stages.

7.85. In the reprocessing facility and analytical laboratories, the use of chemical reagents should be controlled by written procedures to prevent explosion, fire, toxicity and hazardous chemical interactions. These procedures should identify the nature and quantities of authorized chemicals. Where necessary, eye protection and local ventilation should be specified and provided. Consideration should be given to the need for breathing apparatus, equipment for dealing with chemical spills and suitable protective wear for chemical emergencies.

7.86. Chemicals should be stored in well-aerated locations or dedicated, secure storage arrays outside the process or laboratories, preferably in low occupancy areas. Containers used to store chemicals should be clearly marked, including the potential hazards that the chemical poses.

7.87. Personnel should be informed about the chemical hazards that exist. Operators should be properly trained with respect to the hazards associated with the process chemicals in order to adequately identify and respond to the problems that may lead to chemical accidents.

7.88. As required by national regulations, a health surveillance programme should be set up for routinely monitoring the health of workers who may be exposed to harmful chemicals.

Fire and explosion hazards

7.89. Flammable, combustible, explosive and strongly oxidizing materials are used in reprocessing facilities (e.g. some organic solvents in the extraction stage, and nitric acid and other materials and reagents throughout the process). Emergency systems and arrangements to prevent, minimize and detect the hazards associated with such materials should be properly maintained, and regularly exercised, to ensure that a rapid response can be deployed to any incident and its impact can be minimized.

7.90. To minimize the fire hazard of pyrophoric metals (zirconium or uranium particles), shearing hot cells and other locations where such materials could accumulate should be monitored, periodically checked and cleaned in accordance with procedures. In some cases, routine flushing out (i.e. high flow rate washing) of equipment may be necessary.

7.91. The procedures and training for responses to fires in areas containing fissile material should pay particular attention to the prevention of a criticality and preventing any unacceptable reduction of criticality safety margins.

7.92. The work permit and facility procedures and instructions should include an adequate assessment of and, as necessary, a check-sheet on the potential radiological consequences of fires resulting from activities that involve potential ignition sources, e.g. welding, and should define the precautions necessary for performing such work.

7.93. The prevention and control of waste material accumulations (contaminated material and 'clean' material) should be rigorously enforced to minimize the fire load (fire potential) in all areas of the reprocessing facility. Auditing for waste accumulations should be an important element in all routine inspection and surveillance activities by all levels of personnel. Periodic inspections by fire safety professionals should be part of the audit programme.

7.94. To ensure the efficiency and operability of fire protection systems, suitable procedures, training and drills should be implemented, including the following:

(a) Periodic testing, inspection and maintenance of the devices associated with fire protection systems (fire detectors, extinguishers and fire dampers);
(b) General and detailed (location specific) instructions and related training for firefighters;
(c) Firefighting plans;
(d) Fire drills, including the involvement of off-site emergency services;
(e) Training for operating staff and emergency teams.

MANAGEMENT OF RADIOACTIVE WASTE

7.95. A strategy for the management of radioactive waste should be established by the operating organization (see paras 4.147–4.155). The strategy should be implemented on the site of the reprocessing facility in accordance with the types of waste to be processed and the national waste management policy and strategy.

7.96. Waste minimization should be an important objective for managers and for workers at the reprocessing facility. As part of the management system, an integrated waste management plan and supporting procedures should be developed, implemented, regularly reviewed and updated as necessary. All facility personnel should be trained in the waste management hierarchy (namely: eliminate, reduce, reuse, recycle and dispose), the requirements of the waste management plan and the relevant procedures. Waste minimization targets should be set and regularly reviewed and a system for continuous improvement (minimization of waste volumes and waste activity in relation to work carried out) should be put in place (see NS-R-5 (Rev. 1) [1] paras 9.54–9.56).

7.97. All waste is required to be treated and stored in accordance with pre-established criteria and the national waste classification scheme. Waste management is required to take into consideration both on-site and off-site storage capacity, as well as disposal options and available disposal facilities. Every effort should be made to characterize the waste as fully as possible, especially waste without a recognized disposal route. Where a disposal facility is in operation, waste characterization should be performed in such a way that compliance with the waste acceptance requirements can be demonstrated. The available information characterizing the waste is required to be held in secure and recoverable archives (see NS-R-5 (Rev. 1) [1], appendix IV, paras IV.80 and IV.82).

7.98. Operational arrangements should be such that the generation of radioactive waste is avoided or the radioactive waste generated is reduced to a practical minimum (by reducing the generation of secondary waste and by the reuse, recycling and decontamination of materials). Trends in the generation of radioactive waste should be monitored and the effectiveness of the waste reduction and minimization measures applied should be demonstrated. Equipment, tools and consumable material entering hot cells, shielded boxes and gloveboxes should be minimized as far as practicable.

7.99. The accumulation of radioactive waste on the site should be minimized, as far as practicable. All accumulated waste should be stored in dedicated storage facilities that are designed and operated to standards equivalent to those of the reprocessing facility itself.

7.100. Any waste generated at a reprocessing facility should be characterized by physical, chemical and radiological properties to allow its subsequent optimum management, i.e. appropriate pretreatment, treatment, conditioning and selection or determination of an interim storage or disposal route. To the extent possible, the management of waste should ensure that all waste will meet the specifications for existing interim storage and/or disposal routes. Particular care should be taken to segregate waste containing fissile material and ensure criticality safety for such waste.

7.101. Consideration should be given to segregating solid waste according to its origin, which can be indicative of its potential radioactive 'fingerprint'[49] and thus can provide information on routes for processing, storage and disposal. The radioactive fingerprint, in conjunction with rapid, limited, local radiometric measurements (e.g. total beta/gamma activity), should be used as sorting criteria at the location where the waste is generated. This permits rapid segregation of the waste and the choice of appropriate waste handling techniques, and should be considered in relation to optimizing protection and safety both in the initial handling of the waste and in the subsequent detailed characterization and, if

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[49] The radioactive fingerprint is the mixture of radioactive nuclides and their ratios that characterize the waste. The radioactive fingerprint may be estimated from the material processed in the area and then confirmed during initial operation of the facility.

necessary, the sorting of the waste in dedicated waste handling areas. Remote or automatic equipment should be used to the extent possible.

7.102. The collection and further processing of the waste (i.e. pretreatment, treatment and conditioning) is required to be organized according to pre-established criteria, and procedures should be defined to meet the requirements for established or planned routes for storage and disposal.

7.103. Facility decontamination methods should be adopted that minimize the generation of primary and secondary waste and facilitate the subsequent treatment of the waste, e.g. by ensuring the compatibility of decontamination chemicals with available waste treatment routes.

7.104. As far as reasonably achievable, decontamination should be used for reducing and/or minimizing the environmental impact and maximizing the recovery of nuclear material. Decontamination of alpha contaminated (e.g. plutonium) waste should be as complete as economically practicable to reduce and/or minimize the impact of long lived emitters on the environment, provided recovery routes are available for the decontamination waste stream.

7.105. Clearance procedures for waste should be provided in accordance with national regulations. These procedures should be used as fully as practicable to minimize the volumes of material going to active disposal routes and thus the size of disposal facility necessary.

7.106. Information about the radioactive waste that is necessary for its safe management and eventual disposal now and in the future should be collected, recorded and preserved in accordance with the management system (see GS-G-3.3 [31]).

Effluent management

7.107. Reprocessing facilities usually have a number of discharge points corresponding either separately or collectively to the specific authorized discharges. The operating organization should establish an appropriate management structure to operate and control each of these discharge points as well as the overall discharges.

7.108. For reprocessing facilities, discharge streams should be measured where possible before discharge or, where not, in real time at the point of discharge. When used, sampling devices and procedures should provide representative and timely results corresponding to the actual flows or batch releases to the environment.

7.109. The operating organization should ensure that all discharges are minimized and are within authorized limits. The personnel involved should have the authority to shut down processes and facilities, subject to safety considerations, when they have reason to believe that these aims may not be met.

7.110. The operating organization should establish a list of performance indicators to assist in the monitoring and review of the programmes for minimization of discharges. The indicators should be related to maximum upper limits, e.g. monthly goals for discharges to the environment.

7.111. Periodic estimates of the impact on the public (the representative person(s)) should be made using data on effluent releases and standard models agreed with the national authorities. Environmental monitoring may also be necessary to verify the impact of discharges and any releases on the public and on the surrounding area, to identify any trends and to assess total public exposure.

Gaseous discharges

7.112. Radioactive gaseous discharges should be treated, as appropriate, by dedicated off-gas treatment systems and by means of HEPA filters.

7.113. After a filter change, the change procedure should be verified to ensure that filters are correctly seated. Changed filters should be tested to ensure that they provide (at least) the removal efficiency used or assumed in the safety analyses.

7.114. The efficiency of the last stage of filtration before stack release (or as otherwise required by the safety analysis) should be tested as defined in the operational limits and conditions.

Liquid discharges

7.115. All liquids collected from the site of the reprocessing facility (e.g. surface and underground water near buildings and process effluents) that have to be discharged into the environment should be assessed and managed in accordance with authorizations.

7.116. The liquid effluent system (i.e. collection and discharge pipework, temporary storage if any) should be correctly operated, and its effectiveness should be maintained as part of the reprocessing facility.

7.117. Authorizations for liquid discharges from a reprocessing facility usually specify an annual quantity of particular radionuclides and if necessary, the physical and chemical characteristics of the effluent. They may also prescribe further conditions designed to minimize the environmental impact, e.g. discharge at high tide, or above a minimum river flow. Operational procedures should be implemented to meet the requirements of the authorization.

7.118. Where allowed by its design, the reprocessing facility should be operated in a manner that accommodates batch-wise discharges, which permits verification of the necessary parameters by sampling and timely analysis prior to discharge.

EMERGENCY PREPAREDNESS AND RESPONSE

7.119. The scale, complexity and the level of potential hazards of reprocessing facilities mean that arrangements for emergency preparedness (for protecting workers, the public and the environment in the event of an accidental release) and maintaining and updating the emergency plan are particularly important. The requirements are established in NS-R-5 (Rev. 1) [1], paras 9.62–9.67 and GSR Part 7 [11], and recommendations are provided in GS-G-2.1 [32] and Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GSG-2 [36]). These are elaborated in paras 4.161 to 4.167 of this Safety Guide, since their application begins before active operations commence.

7.120. The operating organization is required to carry out regular emergency exercises, some of which should involve off-site resources[50], to check the adequacy of the emergency arrangements, including the training and preparedness of on-site and off-site personnel and services including communications.

7.121. The emergency arrangements are required to be periodically reviewed and updated (see GSR Part 7 [11] and GS-G-2.1 [32]), with account taken of any lessons learned from operating experience at the facility and at similar

[50] Even for small facilities, off-site resources may be called upon to provide public reassurance and for on-site response to localized events.

facilities, emergency exercises, modifications, periodic safety reviews, emerging knowledge and changes to regulatory requirements.

8. PREPARATION FOR DECOMMISSIONING

8.1. Recommendations for the decommissioning of nuclear fuel cycle facilities are provided in WS-G-2.4 [24] based on the requirements established in GSR Part 6 [23] that include the following:

(a) The initial decommissioning strategy is required to be selected in accordance with the national policy on the management of radioactive waste.
(b) The decommissioning strategy, the decommissioning plan and the supporting safety assessment (appropriate to the development stage of the decommissioning strategy and plan) are required to be produced early in the design stage.
(c) Decommissioning is required to be included in the optimization of protection and safety by iteration of the facility design, the decommissioning strategy and plan and the safety assessment.
(d) Adequate financial resources are required to be identified and allocated to carry out decommissioning, including the management of the resulting radioactive waste.

8.2. The developed decommissioning plan and the safety assessment should be periodically reviewed and updated throughout the reprocessing facility's commissioning and operation stages (see GSR Part 6 [23], Requirements 8 and 10) to take account of new information and emerging technologies to ensure that:

(a) The (updated) decommissioning plan is realistic and can be carried out safely.
(b) Updated provisions are made for adequate resources and their availability, when needed.
(c) The radioactive waste anticipated remains compatible with available (or planned) interim storage capacities and disposal considering its transport and treatment.

8.3. The reprocessing facility should be sited, designed, constructed and operated (maintained and modified) to facilitate eventual decommissioning, as far as practicable. Owing to their size, complexity and the diverse waste arising during operation and decommissioning, particular care should be taken that the following aspects are addressed throughout the lifetime of the reprocessing facility:

(a) Design features to facilitate decommissioning (e.g. measures to minimize contamination penetrating into the structures and installed provisions for decontamination);
(b) Physical and procedural methods to prevent the spread of contamination;
(c) Consideration of the implications for decommissioning when modifications to the facility and experiments at the facility are proposed;
(d) Identification of practicable changes to the facility design to facilitate or accelerate decommissioning;
(e) Comprehensive preparation of records for all significant activities and events at all stages of the facility's lifetime, archived in a secure and readily retrievable form and indexed in a documented, logical and consistent manner;
(f) Minimizing the eventual generation of radioactive waste during decommissioning.

8.4. General requirements in the event of decommissioning being significantly delayed after a reprocessing facility has permanently shut down or has been shut down suddenly (e.g. as a result of a severe process failure or accident) are established in GSR Part 6 [23] and include the potential need to revise the decommissioning strategy, the decommissioning plan and the safety assessment.

8.5. For any period between a planned or unplanned shutdown and prior to decommissioning starting, safety measures should be implemented to maintain the reprocessing facility in a safe and stable state, including measures to prevent criticality, the spread of contamination and fire, and to maintain appropriate radiological monitoring. The need to revise the safety assessment for the facility in its shutdown state should be considered. The application of knowledge management methods to retain the knowledge and experience of operators in a durable and retrievable form should also be considered. Wherever practicable, hazardous and corrosive materials should be removed from process equipment to safe storage locations before the reprocessing facility is placed into a prolonged shutdown state.

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Annex I

MAIN PROCESS ROUTES AT A REPROCESSING FACILITY

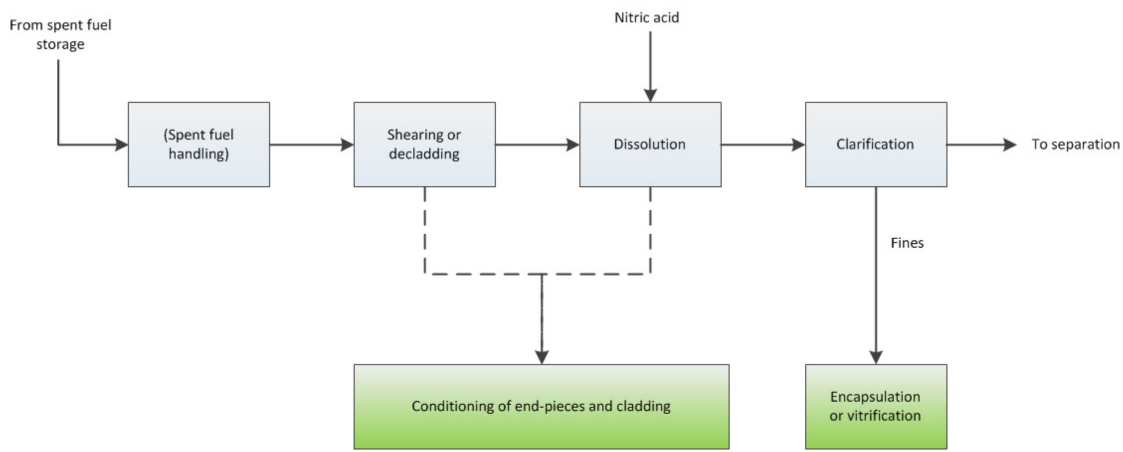

FIG. I–1. Main process routes at the head end of a reprocessing facility.

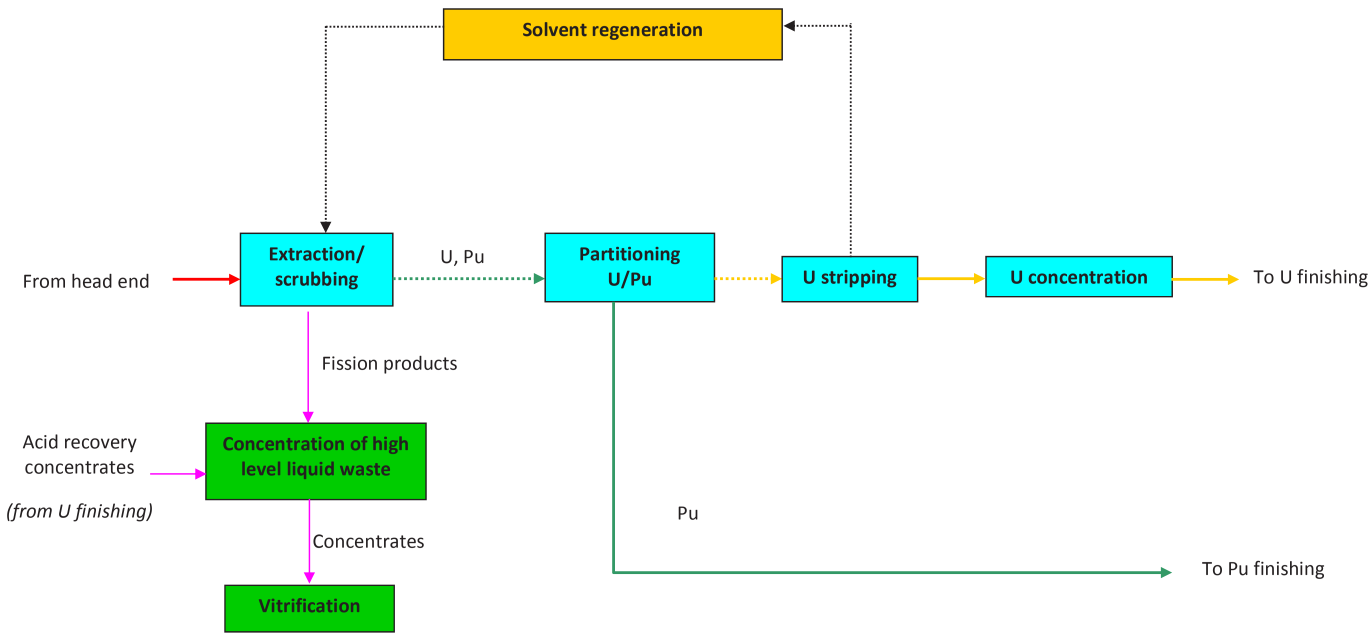

FIG. I–2. Separation of uranium and plutonium at a reprocessing facility.

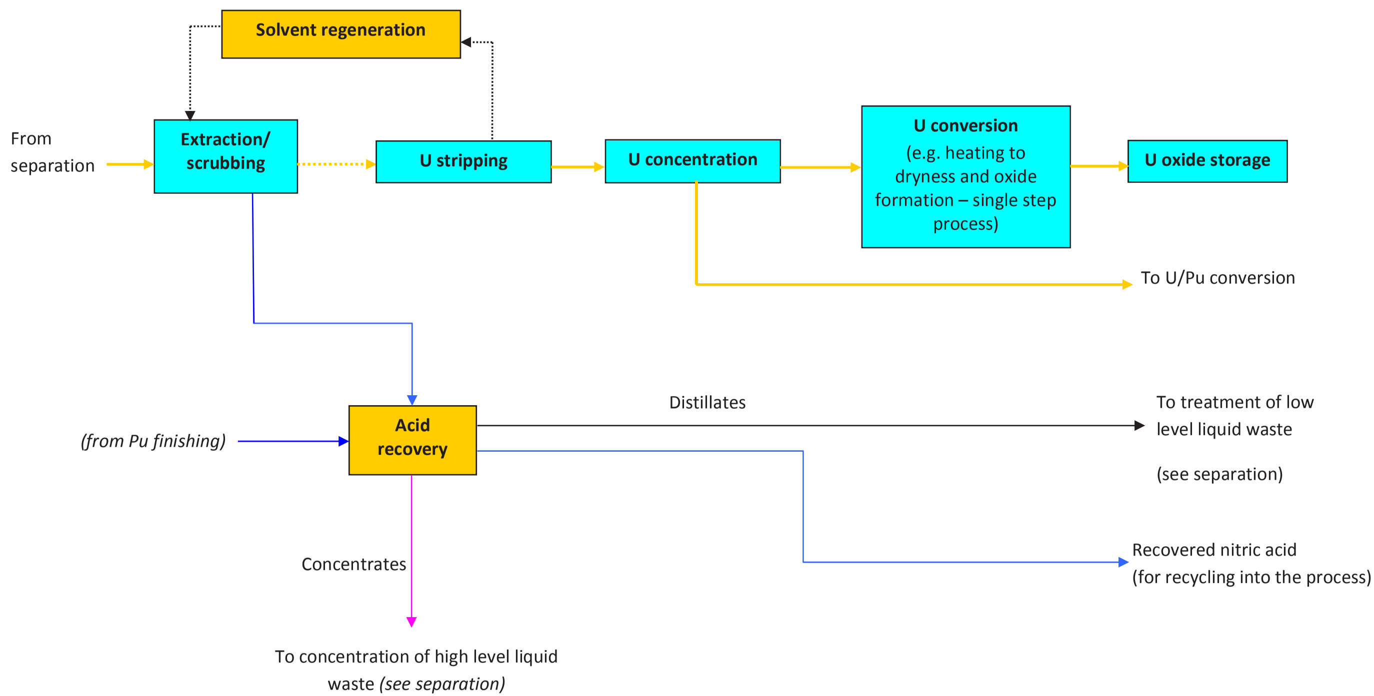

FIG. I–3. Uranium finishing at a reprocessing facility.

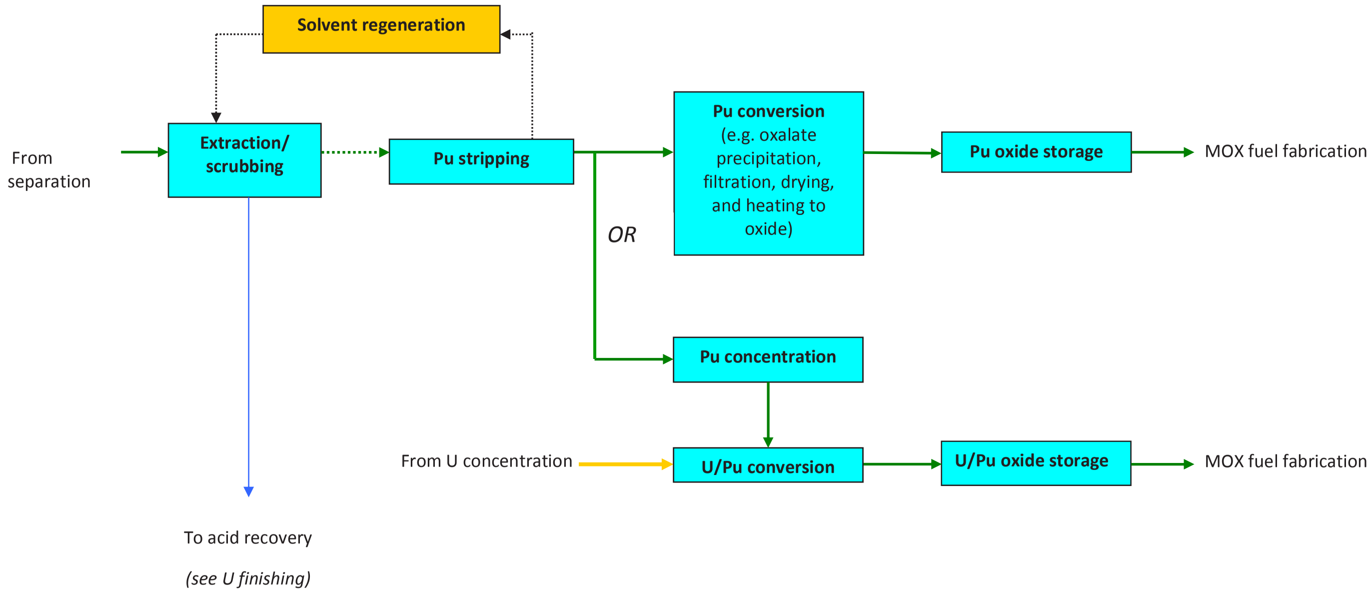

FIG. I–4. *Plutonium finishing at a reprocessing facility.*

Annex II

STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY

POSSIBLE CHALLENGES TO SAFETY FUNCTIONS AND EXAMPLES OF PARAMETERS FOR DEFINING OPERATIONAL LIMITS AND CONDITIONS FOR REPROCESSING FACILITIES

Main safety functions:

(1) Prevention of criticality;

(2) Confinement of radioactive material:

- (2(a)). Integrity of barriers;
- (2(b)). Cooling and the removal of decay heat;
- (2(c)). Prevention of radiolysis and of generation of other hazardous explosive or flammable materials.

(3) Protection against external radiation exposure.

TABLE II–1. HEAD END PROCESS (see Fig. I–1)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Feeding	Camera, detector	Safety concerns in the process	1, 2 and 3	Identification of the fuel assembly (feed programme)
	Spent fuel burnup measurement system	Criticality event	1	Burnup value
Shearing and decladding	Shearing machine	Zirconium fire	2c	Cleanness of the shearing machine (accumulation of material)
		Criticality event	1	
Dissolution	(See the process area ‘Vessel’)		2	
	Measurement systems for temperature, density and acidity of the solution	Criticality event	1	Temperature, density, acidity
	System for control of solution poisoning (if required)	Criticality event	1	Neutron poison concentration
Clarification	(See the process area ‘Vessel’)		3	
	Analytical measurement system	Criticality event in the final storage vessel	1	Hydrogen/plutonium ratio
	Filter cleaning/centrifuge cleaning systems	Potential release of radioactive material	2b	Cleaning system parameters

TABLE II–1. HEAD END PROCESS (see Fig. I–1) (cont.)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Conditioning of hulls and end pieces	Measurement system for fissile material of contents in hulls	Non-acceptance by the hulls conditioning facility	1	Residual fissile material
Vessel	Vessels containing radioactive solution	Leakage of active solution	2a	Detection of leakage (level measurement/sampling in drip trays or sumps, contamination measurements in cells and rooms)
	Cooling supply system (if any)	Overheating/boiling/crystallization/corrosion	2b	Flow rate of cooling water, temperature of active solution
	Heating supply system (if any)	Overheating/boiling/crystallization/corrosion	2a, 2b, 2c	Flow rate of heating fluid, temperature of active solution
	Supply system in air for dilution of radiolysis gases (if any)	Explosion (hydrogen)	2c	Flow rate of diluting air for dilution
	Level measurement system	Overflowing	2a	Leakage (and safety issues in downstream process)
	Pressure measurement system (where necessary)	Vessel failure	2a	Leakage

TABLE II–1. HEAD END PROCESS (see Fig. I–1) (cont.)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Vessel (cont.)	System for measurement of parameters relating to criticality control (if necessary)	Criticality event	1	Specific operational limits and conditions

TABLE II–2. SEPARATION PROCESS (see Fig. I–2)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Extraction/ scrubbing	(See the process area ‘Vessel’ in Table II–1)		3	
	Temperature control system	Fire (organic material)	2a	Solution temperature in mixer settlers or columns
	Organics content measurement system	Loss of defence in depth for downstream process	2a	Diluent/solvent ratio
	Reagent feeding system	Leakage of plutonium with fission products	1	Reagent flow rate
Uranium/ plutonium partitioning	Temperature control system	Fire (organic material)	2a	Solution temperature in mixer settlers or columns
	Organics content measurement system	Loss of defence in depth for downstream process	2a	Diluent/solvent ratio
	Reagent feeding system	Leakage of plutonium with uranium	1	Reagent flow rate
	System for neutron measurement at the column	Criticality event (prevention)	1	Neutron measurement along the column

TABLE II–2. SEPARATION PROCESS (see Fig. I–2) (cont.)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Uranium/ plutonium partitioning	Criticality event detection system	Criticality event (mitigation)	1	Criticality alarm system
Stripping/ concentration of uranium	Temperature control system	Explosion (red oil)	2c	Temperature
	Process parameters control system	Explosion (red oil)	2c	Administrative controls
Solvent regeneration	Temperature control system	Explosion (hydrazine) Fire (organic material)	2c	Temperature
	Analytical measurement system	Explosion (hydrazine) Fire (organic material)	2c, 2a	Administrative controls
High level liquid waste concentration	(See the process area ‘Vessel’ in Table II–1)		3	
	Temperature control system	Explosion (red oil)	2c	Temperature
	Control system for the destruction of nitrates	Overpressure	2c	Administrative controls

TABLE II–3. URANIUM PRODUCT TREATMENT PROCESS (see Fig. I–3)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Uranium extraction/ scrubbing	Temperature control system	Fire (organic material)	2a	Temperature
	Process parameters control system	Fire (organic material)	2a	Administrative controls
Uranium stripping	Temperature control system	Fire (organic material)	2a	Temperature
	Process parameters control system	Fire (organic material)	2a	Administrative controls
Uranium concentration	Temperature control system	Explosion (red oil)	2c	Temperature
	Process parameters control system	Explosion (red oil)	2c	Administrative controls
Uranium concentration	(See the process area 'Vessel' in Table II–1)		3	
Uranium oxide storage	(See the process area 'Vessel' in Table II–1)		3	
Solvent regeneration	Temperature control system	Fire (organic material)	2a	Temperature
	Analytical measurement system	Fire (organic material)	2a	Administrative controls

TABLE II–3. URANIUM PRODUCT TREATMENT PROCESS (see Fig. I–3) (cont.)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Acid recovery	Temperature control system	Explosion (red oil)	2c	Temperature
	Process parameters control system	Explosion (red oil)	2c	Administrative controls

TABLE II–4. PLUTONIUM PRODUCT TREATMENT PROCESS (see Fig. I–4)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Plutonium extraction / scrubbing / stripping	(See the process area ‘Vessel’ in Table II–1)		1, 3	
	Temperature control system	Fire (organic material)	2a	Temperature
	Process parameters control system	Fire (organic material)	2a	Administrative controls
Plutonium concentration	Process parameters control system	Criticality	1	
Plutonium conversion	Process parameters control system	Criticality	1	Temperature
Plutonium oxide storage	Control system for thermal criteria for storage	Potential release of radioactive material	2a	Temperature, ventilation flowrate
	Storage rack	Criticality	1	Geometry (design, commissioning)
Solvent regeneration	Temperature control system	Fire (organic material)	2a	Temperature
	Analytical measurement system	Fire (organic material)	2a	Administrative controls

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