20 February 2023

IAEA SAFETY STANDARDS

for protecting people and the environment

Step 8:

Soliciting comments by Member States

Safety of Nuclear Fuel Reprocessing Facilities

(Revision of SSG-42)

DRAFT SPECIFIC SAFETY GUIDE

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. Requirements for safety in all stages of the lifetime of a nuclear fuel cycle facility are established in IAEA Safety Standards Series No. SSR-4, Safety of Nuclear Fuel Cycle Facilities [1].

1.2. This Safety Guide provides specific recommendations on the safety of nuclear fuel reprocessing facilities (hereafter referred to as 'reprocessing 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. Reprocessing facilities may process or use large amounts of hazardous chemicals, which can be toxic, corrosive, combustible or explosive. Close attention needs to 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 need to be handled, processed, treated and stored safely, to optimize the levels of exposure of the public and workers, to minimize the amount of radioactive material discharged to the environment, and to limit the potential impact of an accident on workers, the public and the environment.

1.4. This Safety Guide supersedes IAEA Safety Standards Series No. 42, Safety of Nuclear Fuel Reprocessing Facilities[1].

OBJECTIVE

1.5. The objective of this Safety Guide is to provide recommendations on safety in the siting, design, construction, commissioning, operation, and preparation for decommissioning of reprocessing facilities to meet the requirements established in SSR-4 [1].

1.6. The recommendations in this Safety Guide are aimed primarily at operating organizations of reprocessing facilities, regulatory bodies, designers, and other relevant organizations.

SCOPE

1.7. The safety requirements applicable to nuclear fuel cycle facilities (i.e. facilities for uranium ore refining, conversion, enrichment, reconversion[2], storage of fissile material, fabrication of fuel including mixed oxide fuel, storage and reprocessing of spent fuel, associated conditioning and storage of waste, and facilities for the fuel cycle related research and development) are established in SSR-4 [1]. This Safety Guide provides recommendations on meeting these requirements for reprocessing facilities.

1.8. This Safety Guide covers facilities which use the PUREX process to reprocess fuels containing uranium and plutonium on a commercial scale. This Safety Guide does not specifically address reprocessing of thorium from fast breeder reactors or other advanced reactor systems (THOREX process, molten salt fuels, TRISO fuel) and partitioning of radionuclides other than uranium and plutonium (e.g. SANEX, GANEX, and UNEX processes) as there is insufficient experience of these processes and facilities at a commercial scale. However, the similarity between aqueous processes

---

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Fuel Reprocessing Facilities, Safety Standards Series No. SSG-42, Specific Safety Guides, 2017

2 Often called also 'deconversion'

allows for application of most of the recommendations in this Safety Guide, with suitable adjustments, to plants reprocessing other types of nuclear fuel.

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

(a) The handling and short term temporary storage of spent fuel;
(b) The dismantling, shearing[3] or decladding[4] and dissolution of spent fuel;
(c) The separation of uranium and plutonium from fission products and other trans-plutonium actinides;
(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 treatment and handling of the various waste streams.

1.10. The fuel reprocessing processes covered by this Safety Guide are a mixture of 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.

1.11. 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 insofar as all waste generated has to comply with the requirements established in SSR-4 [1] (see paras 6.94–6.99 and 9.102–9.108), and in IAEA Safety Standards Series No. GSR Part 5, Predisposal Management of Radioactive Waste [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.

1.12. The recommendations on ensuring criticality safety in a nuclear fuel reprocessing facility in this publication supplement the more detailed recommendations provided in IAEA Safety Standards Series No. SSG-27, Criticality Safety in the Handling of Fissile Material [3].

1.13. The implementation of safety requirements on the governmental, legal and regulatory framework and related to the regulatory oversight (e.g. requirements for the authorization process, regulatory inspection and regulatory enforcement) as established in IAEA Safety Standards Series No. GSR Part 1 (Rev.1), Governmental, Legal and Regulatory Framework for Safety [4] is not addressed in this Safety Guide.

1.14. This Safety Guide does not include nuclear security recommendations for a nuclear fuel reprocessing facility. Recommendations on nuclear security are provided in IAEA Nuclear Security Series No. 13, Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5) [5] and guidance is provided in IAEA Nuclear Security Series No. 27-G, Physical Protection of Nuclear Material and Nuclear Facilities (Implementation of INFCIRC/225/Revision 5) [6]. However, this Safety Guide includes recommendations on managing interfaces between safety, nuclear security and the State system for nuclear material accounting and control.

[3] Shearing involves cutting spent fuel into short lengths to allow its dissolution inside its metallic cladding.
[4] Decladding involves removing the metallic cladding of spent fuel prior to its dissolution.

STRUCTURE

1.15. Section 2 provides general safety recommendations for a reprocessing facility. Section 3 provides recommendations on the development of a management system for such a facility and the activities associated with it. Section 4 provides recommendations on the safety aspects to be considered in the evaluation and selection of a site to avoid or minimize any environmental impact of operations. Section 5 deals with safety in the design stage of a reprocessing facility: it provides recommendations on the safety analysis for operational states and accident conditions and presents the safety aspects of radioactive waste management in the facility and other design considerations. Section 6 provides recommendations on safety in the construction stage of a reprocessing facility, and Section 7 provides recommendations on safety in the commissioning stage. Section 8 deals with safety in the operation of a facility: it provides recommendations on the management of operation, maintenance and periodic testing, control of modifications, criticality control, radiation protection, industrial safety, the management of waste and effluents, and emergency preparedness and response. Section 9 provides recommendations on preparing for the decommissioning of a reprocessing facility.

1.16. 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.

2. HAZARDS IN NUCLEAR FUEL REPROCESSING FACILITIES

2.1. In a reprocessing facility, large amounts of fissile material, radioactive material and other hazardous materials are present, often in dispersible forms (e.g. solutions, powders and gases) and sometimes subjected to vigorous chemical and physical reactions. Reprocessing facilities have the potential for serious accidents that could result in a nuclear or radiological emergency. In reprocessing facilities the main hazards are potential nuclear criticality, loss of confinement and radiation exposure (both internal exposure and external exposure), fire, chemical and explosive hazards.

2.2. 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 are required to be designed and operated to minimize the impact of these effluents on the public and the environment as low as reasonably achievable: see para. 6.100 of SSR-4 [1]. The recycling of effluents should be considered, 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. To ensure 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.

2.3. Effluents and discharges are required to be managed by the addition of specific design features to remove and reduce levels of activity and amounts of toxic chemicals: see Requirement 25 of SSR-4 [1]. The operating organization of the reprocessing facility (and the operating organizations of any associated effluent treatment facilities) are required to monitor and record discharges: see para. 9.104 of SSR-4 [1]. As a minimum, they are required to comply with the limits on discharges authorized by the regulatory body (see para. 3.123 of IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [7]) and to optimize protection and safety: see Requirement 25 of SSR-4 [1]. Further recommendations on the management of radioactive effluents are provided in IAEA Safety Standards Series Nos SSG-41, Predisposal Management of Radioactive Waste from Nuclear Fuel Cycle Facilities [8], and GSG-9, Regulatory Control of Radioactive Discharges to the Environment [9]).

2.4. When periodic safety reviews are being performed, the records of previous discharges should be examined thoroughly to confirm that the existing 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. In reprocessing facilities, actinides and fission products in different chemical and aggregate forms are processed. The factors affecting the safety of a reprocessing facility include the following:

(a) The wide range and nature of radioactive inventories present at such facilities.
(b) The wide range and nature and quantities of process chemicals used in different forms with a potential for release through the barriers (filters, contamination of personnel, destruction of barriers) and their chemical reactions including radiation–chemical reactions.
(c) The range and nature of fissile material present being in contact with water in a soluble form and potentially concentrated in evaporation and precipitation processes, i.e. the potential for criticality in both liquid and solid systems.
(d) The presence of exothermic materials with high heat generation during the processing of spent nuclear fuel, which leads to the need to provide heat removal by active safety systems.
(e) The high complexity of the processes, which might lead to unpredictable changes in facility safety during or after modification of equipment;
(f) The need for proper monitoring and maintenance of systems important to safety is challenged by the presence of highly radioactive media, limited access and limited possibility to perform manual operations.
(g) 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. In particular, this involves application of the concept of defence in depth in accordance with Requirement 10 of SSR-4 [1].

2.7. In the design of a reprocessing facility, well-proven process technologies and engineering knowledge are required to be used: see Requirement 12 of SSR-4 [1]. Engineering solutions adopted to ensure the safety of the reprocessing facility are required be of high quality, proven by previous experience or, in accordance with a graded approach, by rigorous testing, research and development, and experience of operating prototypes: see paras 6.31–6.35 of SSR-4 [1]. This strategy should also be applied in the design of the reprocessing facility, including development and design of equipment, in construction of the facility, in operation, in carrying out modifications and in preparation for the decommissioning of the reprocessing facility, including any upgrades or modernization.

2.8. Owing to the anticipated long lifetime of industrial scale reprocessing facilities and in accordance with the specific mechanical, thermal, chemical, nuclear and radiation conditions of the processes in use, particular consideration is required to be given to the potential for ageing (and thus degradation) of structures, systems and components important to safety: see Requirement 32 of SSR-4 [1]. This should include the impacts of obsolescence, 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 are required to be taken into account: see para. 6.36 of SSR-4 [1]. Programmes are required be developed and implemented to detect and monitor ageing and degradation and corrosion processes see Requirement 60 of SSR-4 [1]. These should include provisions for monitoring, inspection, sampling, surveillance and testing, and specific design provisions and equipment for inaccessible structures, systems and components important to safety. To achieve the required lifetime of the facility, the design might need to include the provision of standby equipment or vessels. In some cases, spare cells or remote replacement system may be provided to allow the installation of new vessels.

2.9. The reliability of process equipment in a reprocessing facility 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 performed against unambiguous, established performance standards and expectations.

2.10. A combination of passive design features and active design features is more reliable than administrative controls (see para. 6.68 of SSR-4 [1]) and are therefore preferred in the design of reprocessing facilities 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].

2.11. When administrative controls are considered as an option at a reprocessing plant, 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 an automatic response action and relying on 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.

2.12. 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 should be of high quality and reliability. Adequate and reliable controls and appropriate instrumentation should be provided to maintain parameters 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 management system, including verification and validation of the software.

2.13. A reprocessing facility should have alarm systems to initiate full or partial facility evacuation in the event of an emergency (e.g. criticality, fire or high radiation levels).

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

2.14. Ergonomic considerations should be applied to all aspects of the design and operation of the reprocessing facility. Careful consideration is required to be given to human factors in the design of control rooms, remote control stations and other work locations: see para. 6.108 of SSR-4 [1]. 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.

2.15. Utility supply services are necessary to ensure that the safety systems of the reprocessing facility remain operational 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.

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. The actions to be taken in such situations should be well defined in procedures, based on the findings of this analysis. These procedures should be executed in accordance with the nature and urgency of the risk involved. Such situations might include potential nuclear criticality sequences, and natural or human induced internal or external events. The subsequent recovery sequences should be similarly analysed, defined and executed, when necessary, in a timely manner; for example, the managed recovery or reduction of fissile material in a multi-stage contactor[6].

2.17. For a reprocessing facility to remain in a safe state (including when the reprocessing process is stopped and there is no movement or transfer of fissile material), the following systems should continue to operate:

(a) Active heat removal systems used to remove decay heat in storage areas or buffer tanks, in 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 related instrumentation and control systems including for radiation monitoring systems, static and dynamic confinement and utility supply systems important for safety;
(e) Systems ensuring confinement function;
(f) Criticality accident detection and alarm systems.

2.18. Reprocessing facilities are required to be designed to ensure the confinement of radioactive materials and associated harmful materials: see Requirement 7 of SSR-4 [1]. This may include level measurement systems within tanks and vessels, batch transfer accountancy systems to ensure that transfers made between vessels are completed and the installation of systems to detect and recover materials lost from primary containment (e.g. cell sumps and liquid transfer systems).

2.19. Reprocessing facilities might be designed to operate on a batch basis with discrete processes being undertaken with separate cells within a larger facility, or even within different facilities on the same site. In such cases the design should consider the buffer storage between these processes. The design should also ensure that the radioactive material transfers are undertaken safely and that the movement between separate stages is controlled.

[6] A contactor is a liquid–liquid extraction device such as pulsed column.

3. MANAGEMENT SYSTEM FOR NUCLEAR FUEL REPROCESSING FACILITIES

3.1. A documented management system that integrates the safety, health, environmental, security, quality, human-and-organizational-factors, societal and economic elements of the operating organization is required to be implemented by the operating organization in accordance with Requirement 4 of SSR-4 [1]. The integrated management system should be established early in the lifetime of a reprocessing facility, to ensure that safety measures are specified, implemented, monitored, audited, documented and periodically reviewed throughout the lifetime of the facility or the duration of the activity.

3.2. Requirements for the management system are established in IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [10]. Associated recommendations are provided in IAEA Safety Standards Series Nos GS-G-3.1, Application of the Management System for Facilities and Activities [11], GS-G-3.5, The Management System for Nuclear Installations [12], GSG-16, Leadership, Management System and Culture for Safety in Radioactive Waste Management [13], and TS-G-1.4, The Management System for the Safe Transport of Radioactive Material [14].

3.3. The management system is required to take into account the interfaces between safety and nuclear security: see para. 1.3 of GSR Part 2 [10]. Requirement 75 of SSR-4 [1] states:

> "**The interfaces between safety, security and the State system of accounting for, and control of, nuclear material shall be managed appropriately throughout the lifetime of the nuclear fuel cycle facility. Safety measures and security measures shall be established and implemented in a coordinated manner so that they do not compromise one another.**"

The activities for ensuring safety throughout the lifetime of a reprocessing facility involve different groups and interfaces with other areas such as those relating to nuclear security and to the State system for nuclear material accounting and control. Activities with such interfaces should be identified in the management system, coordinated, planned and conducted to ensure effective communication and clear assignment of responsibilities. Communications regarding safety and security should ensure that confidentiality of information is maintained. This includes the system of nuclear material accounting and control, for which information security should be coordinated in a manner ensuring that subcriticality is not compromised. Potential conflicts between the transparency of information related to safety matters and protection of the information for security reasons are required to be addressed: see para. 4.10 of GSR Part 2 [10].

3.4. In determining how the requirements of the management system for safety of a reprocessing facility are to be applied, a graded approach based on the relative importance to safety of each item or process is required to be used: see Requirement 7 and para. 4.15 of GSR Part 2 [10]. However, considering the significant hazards associated with a reprocessing facility, the potential for applying a graded approach is limited.

3.5. The management system is required to support the development and maintenance of a strong safety culture,: see Requirement 12 of GSR Part 2 [10]. This should also include all aspects of criticality safety. Special consideration should be given to all processes covered by the management system that are associated with handling plutonium. This includes transition to hot commissioning or assigning new staff to activities involving plutonium handling (see also para. 8.27 of SSR-4 [1]).

3.6. In accordance with paras 4.15–4.23 of SSR-4 [1], the management system is required to address four functional areas: management responsibility; resource management; process implementation; and measurement, assessment, evaluation and improvement. In general:

(a) Management responsibility includes the support and commitment of management necessary to achieve the safety objectives of the operating organization in such a manner that safety is not compromised by other priorities.
(b) Resource management includes the measures necessary to ensure that the resources essential to the implementation of safety strategy and the achievement of the safety objectives of the operating organization are identified and made available.
(c) Process implementation includes the activities and tasks necessary to achieve the safety goals of the organization.
(d) Measurement, assessment, evaluation and improvement provides an indication of the effectiveness of management processes and work performance compared with objectives or benchmarks; it is through measurement and assessment that opportunities for improvement can be identified.

MANAGEMENT RESPONSIBILITY FOR A REPROCESSING FACILITY

3.7. The prime responsibility for safety, including criticality safety, rests with the operating organization: see Requirement 2 of SSR-4 [1]. As required by para 3.1 of GSR Part 2 [10], the senior management of a reprocessing facility is required to demonstrate leadership for and commitment to safety. In accordance with para. 4.11 of GSR Part 2 [10], the management system for a reprocessing facility is required to clearly specify the following:

(a) A description of the organizational structure;
(b) Functional responsibilities;
(c) Levels of authority.

3.8. The documentation of the management system is required to describe the interactions among the individuals managing, performing and assessing the adequacy of the processes and activities important to safety: see para. 4.16 of GSR Part 2 [10]. The documentation should also cover other management measures, including planning, scheduling and resource allocation (see para. 9.9 of SSR-4 [1]).

3.9. Paragraph 4.15 of SSR-4 [1] states:

> “the management system shall include provisions for ensuring effective communication and clear assignment of responsibilities, in which accountabilities are unambiguously assigned to individual roles within the organization and to suppliers, to ensure that processes and activities important to safety are controlled and performed in a manner that ensures that safety objectives are achieved.”

The management system should include arrangements for empowering relevant personnel to stop unsafe operations at the reprocessing facility.

3.10. The operating organization is required to ensure that safety assessments and analyses are conducted, documented and updated: see Requirement 5 of SSR-4 [1]. Detailed requirements for safety assessment are established in IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), Safety Assessment for Facilities and Activities [15].

3.11. In accordance with para. 4.2 (d) of SSR-4 [1], the operating organization is required to audit all safety related matters on a regular basis. This includes the examination of arrangements for emergency preparedness and response at the reprocessing facility, such as emergency communications, evacuation routes including their signage. Audits should be performed also by the nuclear criticality safety staff who performed the safety assessments to confirm that the data used and the implementation of criticality safety measures are correct. Audits should be performed by personnel who are independent of those that performed the safety assessments or conducted the safety activities. The data from audits should be documented and submitted for management review and for action, if necessary.

RESOURCE MANAGEMENT FOR A REPROCESSING FACILITY

3.12. The senior management of the operating organization is required to determine the competences and resources (both human and financial) for the safe operation of a reprocessing facility: see Requirement 9 of GSR Part 2 [10]. They are also required to ensure that suitable training is conducted: see para. 4.23 of GSR part 2 [10]. The management of the operating organization should also undertake the following:

(a) Prepare and issue specifications and procedures on safety related activities and operations;
(b) Support the performance of safety assessments of modifications;
(c) Have frequent personal contact with personnel, including observing work in progress.

3.13. Senior management are also required to determine the minimum staffing of the facility[7]: see para. 9.15 of SSR-4 [1]. This should include succession planning and retention of corporate knowledge.

3.14. Requirement 58 of SSR-4 [1] states that "**The operating organization shall ensure that all activities that may affect safety are performed by suitably qualified and competent persons**." In accordance with paras 9.39–9.47 of SSR-4 [1], the operating organization is required to ensure that these personnel receive training and refresher training at suitable intervals, appropriate to their level of responsibility. In particular, personnel involved in activities with fissile material (both uranium and plutonium), radioactive material including waste and with chemicals should understand the nature of the hazard posed by these materials and how the risks are controlled by the established safety measures, operational limits and conditions, and operating procedures.

3.15. Requirement 11 of GSR Part 2 [10] states:

> "**The organization shall put in place arrangements with vendors, contractors and suppliers for specifying, monitoring and managing the supply to it of items, products and services that may influence safety.**"

In accordance with paras 4.33–4.36 of GSR Part 2 [10], the management system for a reprocessing facility is required to include arrangements for procurement.

3.16. In accordance with para. 4.16(b) of SSR-4 [1], the operating organization is required to ensure that suppliers of items and resources important to safety have an effective management system. To meet these requirements, the operating organization should conduct audits of the management systems of the suppliers.

PROCESS IMPLEMENTATION FOR THE MANAGEMENT SYSTEM FOR A REPROCESSING FACILITY

3.17. Requirement 63 of SSR-4 [1] states:

[7] Including for situations where a large number of personnel might be unavailable, such as during an epidemic or other event affecting an area where personnel live.

“**Operating procedures shall be developed that apply comprehensively for normal operation, anticipated operational occurrences and accident conditions, in accordance with the policy of the operating organization and the requirements of the regulatory body.**”

3.18. Paragraph 9.66 of SSR-4 [1] states that “Operating procedures shall be developed for all safety related operations that may be conducted over the entire lifetime of the facility.” The operating procedures should specify all parameters at the reprocessing facility which are intended to be controlled and the criteria that should be fulfilled.

3.19. The management system of a reprocessing facility should include management for criticality safety. Further recommendations on the management system for criticality safety are provided in SSG-27 [3].

3.20. Any proposed modification to an existing reprocessing facility, or a proposal for introduction of new activities, are required to be assessed for their implications on existing safety measures and appropriately approved prior to implementation: see para. 9.56 of SSR-4 [1]. Modifications of safety significance are required to be subjected to safety assessment and regulatory review and, where necessary, they are required to be authorized by the regulatory body before they are implemented: see para. 9.57(h) and 9.59 of SSR-4 [1]. The facility or activity documentation is required to be updated to reflect modifications: see paras 9.57(f) and (g) of SSR-4 [1]. The operating personnel, including supervisors, should receive adequate training on the modifications.

MEASUREMENT, ASSESSMENT, EVALUATION AND IMPROVEMENT OF THE MANAGEMENT SYSTEM FOR A REPROCESSING FACILITY

3.21. Requirement 13 of GSR Part 2 [10] states:

“**The effectiveness of the management system shall be measured, assessed and improved to enhance safety performance, including minimizing the occurrence of problems relating to safety.**”

3.22. The audits performed by the operating organization (see para. 3.11), as well as proper control of modifications to facilities and activities (see para. 3.20) are particularly important for ensuring subcriticality. The results of audits are required to be evaluated by the operating organization and corrective actions to be taken where necessary: see para. 4.2(d) of SSR-4 [1].

3.23. Deviation from operational limits and conditions, deviations from operating procedures and unforeseen changes in process conditions that could affect criticality safety are required to be reported and promptly investigated by the operating organization, and the operating organization is required to inform the regulatory body: see paras 9.34, 9.35 and 9.84 of SSR-4 [1]. The depth and extent of the investigation should be proportionate to the safety significance of the event, in accordance with a graded approach. The investigation should cover the following:

(a) An analysis of the causes of the deviation to identify lessons and to determine and implement corrective actions to prevent a recurrence;
(b) An analysis of the operation of the facility or conduct of the activity including an analysis of human factors;
(c) A review of the safety assessment and analyses that were previously performed, including the safety measures that were originally established.

3.24. Requirement 73 of SSR-4 [1] states that "**The operating organization shall establish a programme to learn from events at the facility and events at other nuclear fuel cycle facilities and in the nuclear industry worldwide.**". Recommendations on operating experience programmes are provided in IAEA Safety Standards Series No. SSG-50, Operating Experience Feedback for Nuclear Installations [16].

VERIFICATION OF SAFETY AT A REPROCESSING FACILITY

3.25. In accordance with Requirement 5 of SSR-4 [1], the safety of a reprocessing facility is required to be assessed in the safety analysis and verified by periodic safety reviews. The operating organization should ensure that these periodic safety reviews of the facility form an integral part of the organization's management system.

3.26. Requirement 6 of SSR-4 [1] states that "**An independent safety committee (or an advisory group) shall be established to advise the management of the operating organization on all safety aspects of the nuclear fuel cycle facility.**" The safety committee of a reprocessing facility should have members, or access to, suitably qualified and experienced persons in relevant areas, including human factors, criticality safety as well as radiation protection. Such experts should be available to the facility at all times during commissioning and operation including modifications of the facility.

4. SITE EVALUATION FOR NUCLEAR FUEL REPROCESSING FACILITIES

4.1. Requirements for site evaluation for reprocessing facilities are provided in IAEA Safety Standards Series No. SSR-1, Site Evaluation for Nuclear Installations [17] and recommendations are provided in associated Safety Guides, such as IAEA Safety Standards Series No. SSG-35, Site Survey and Site Selection for Nuclear Installations [18].

4.2. The site evaluation process for a reprocessing facility will depend on a large number of variables. At the earliest stage of planning of a facility, a list of potential hazards due to external events (e.g. earthquakes, accidental aircraft crashes, fires, nearby chemical hazards and explosions, floods, extreme weather conditions) is required to be developed, the relevant hazard evaluated and the design basis for the facility carefully determined: see section 5 of SSR-4 [1]. In addition, the radiological risk posed by the facility to workers, the public and the environment in both normal operation and accident conditions is required to be evaluated: see Requirement 12 of SSR-1 [17].

4.3. The scope of the site evaluation for a reprocessing facility is established in Requirement 3 of SSR-1 [17] and Requirement 11 and paras 5.1–5.14 of SSR-4 [1] and should also reflect the specific hazards listed in Section 2 of this Safety Guide.

4.4. In the siting of a reprocessing facility, 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 the following:
    (i) Waste processing and storage (for all stages of the facility's lifetime);
    (ii) The reliable provision of utility supply services;

(iii) 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 IAEA Safety Standards Series No. GSR Part 7, Preparedness and Response for a Nuclear or Radiological Emergency [19], including the following:
   (i) The provision of off-site supplies in the event of an emergency (including diversity of electrical power and water supplies);
   (ii) Arrangements for access by off-site emergency services to the site;
   (iii) The implementation of emergency arrangements for the evacuation of site personnel and, as appropriate, the surrounding population from affected areas.

(d) External hazards that might particularly affect parts of a reprocessing facility, including:
   (i) Flooding, possibly leading to nuclear criticality, water penetration through openings in static barriers or damage to vulnerable items such as gloveboxes[8];
   (ii) Earthquakes, possibly affecting containment structures for spent fuel, highly active liquids or fissile materials;
   (iii) Human induced hazards.

(e) Combined hazards and hazard interactions between the facilities on the same site.

4.5. SSR-1 [17] and section 5 of SSR-4 [1] establish the requirements for site evaluation for new facilities and for existing facilities and allow the use of a graded approach. A reprocessing facility should be considered to be a facility with a high hazard potential. This should be taken into consideration when applying a graded approach to the implementation of the requirements of SSR-4 [1] to the facility. In addition, for reprocessing facilities, care should be taken and an adequate review and justification should be made for any graded application of the requirements for site evaluation. Particular attention should be paid to the following throughout the lifetime of the reprocessing facility:

(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 take mitigatory actions on the site and perform emergency response actions for the facility on the site and off the site.

4.6. The population density and population distribution in the vicinity of a reprocessing facility are required to be considered in the site evaluation process to minimize any possible health consequences for people in the event of a release of radioactive material and hazardous chemicals: see Requirements 4 and 12 of SSR-1 [17]. Also, in accordance with Requirement 25 and paras 6.1–6.7 of SSR-1 [17], the

[8] 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.

dispersion in air and water of radioactive material released from the reprocessing facility are required to be assessed taking into account the orography, land cover and meteorological features of the region. The environmental impact from the facility under all facility states is required to be evaluated (see para. 5.4 of SSR-4 [1]) and should meet the applicable site evaluation criteria.

4.7. Security advice is required to be taken into account in the selection of a site for a reprocessing facility: see para. 11.4 of SSR-4 [1]. Considering the presence of plutonium in the facility, special attention should be given to the management of the interface between safety and nuclear security during site evaluation (Requirement 75 of SSR-4 [1]). The selection of a site should take into account both safety and security aspects and should be facilitated by experts from both safety and security.

4.8. Even if an existing nuclear site is used for a reprocessing facility, the site evaluation should be performed using a similar process as that for the siting of a new facility at a new site: see paras 3.24–3.27 of SSG-35 [18].

4.9. The operating organization should maintain a full record of the decisions taken on the selection of a site for a reprocessing facility and the reasons behind those decisions.

4.10. The site characteristics are required to be reviewed periodically for their adequacy and persistent applicability during the lifetime of a reprocessing facility: see paras 5.13 and 5.14 of SSR-4 [1]. Any changes to these characteristics which might require safety reassessment are required to be identified and evaluated. This includes the case of an increase in the reprocessing capacity beyond the original design basis.

5. DESIGN OF NUCLEAR FUEL REPROCESSING FACILITIES

MAIN SAFETY FUNCTIONS AT A REPROCESSING FACILITY

5.1. Requirement 7 of SSR-4 [1] states:

> "**The design shall be such that the following main safety functions are met for all facility states of the nuclear fuel cycle facility:**
>
> **(a) Confinement and cooling of radioactive material and associated harmful materials;**
> **(b) Protection against radiation exposure;**
> **(c) Maintaining subcriticality of fissile material.**"

All these safety functions are applicable to reprocessing facilities.

5.2. Owing to its expected long service life, the substantial inventory of high toxicity radioactive material, 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 relevant safety requirements to a high hazard facility. Particular consideration should be given to the reuse and recycling of materials to reduce discharges and waste generation (see also para. 2.2).

5.3. Requirements for the confinement radioactive material are established in Requirement 35 and paras 6.123–6.128 of SSR-4 [1]. In normal operation, internal exposure should be avoided by design, including static and dynamic barriers and adequate zoning. The need to rely on personal protective equipment is required to be minimized: see para. 3.93 of GSR Part 3 [7].

5.4. Requirements for heat removal are established in Requirement 39 and paras 6.157 – 6.159 of SSR-4 [1]. 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.

5.5. Requirements for the need to address the generation of radiolytic hydrogen and other flammable or explosive gases and materials are established in paras 6.160 and 6.161 of SSR-4 [1]. In view of the widespread potential in reprocessing facilities for the generation of radiolytic hydrogen, particular care should be given to the provision of an 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, including in accident conditions.

5.6. Requirements for protection against external exposure in the design of reprocessing facilities are established in Requirement 36 and paras 6.129–6.134 of SSR-4 [1]. Owing to the radiation fields associated with high beta/gamma activity, alpha activity and neutron emissions, an appropriate combination of source limitation, shielding, distance and time are necessary for the protection of workers in reprocessing facilities. Particular attention in both design and operation should be paid to provisions for maintenance (see Requirements 26 and 65 of SSR-4 [1]).

5.7. The requirements on maintaining subcriticality are established in Requirement 38 and paras 6.138–6.156 of SSR-4 [1]. Recommendations on the design of a reprocessing facility to ensure subcriticality are provided in section 3 of SSG-27 [3].

Design basis and safety analysis for a reprocessing facility

5.8. A design basis accident is a postulated accident leading to accident conditions for which a facility is designed in accordance with established design criteria and conservative methodology, and for which releases of radioactive material are kept within acceptable limits [1].

5.9. Requirements relating to the design basis for items important to safety and for the design basis analysis for a nuclear fuel cycle facility are established in Requirements 14 and 20 of SSR-4 [1], respectively.

5.10. The specification of the design basis will depend on the potential radiological hazard associated with the facility, and will need to comply with design requirements as well as siting and other regulatory requirements. Consideration should be given to all internal hazards and external hazards selected in the site evaluation phase and associated with the design basis for a reprocessing facility. These hazards typically include internal and external explosions (in particular hydrogen explosions), internal and external fires, dropped loads and handling errors, earthquakes, extreme meteorological phenomena (in particular flooding and tornadoes), accidental aircraft crashes and other applicable external hazards as defined in the site evaluation report. A list of postulated initiating events to be considered for nuclear fuel cycle facilities is provided in the Appendix of SSR-4 [1].

5.11. Reprocessing facilities are characterized by a wide diversity of radioactive and chemical materials distributed throughout the facility and by the number of potential initiating events that might 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 paras 6.65–6.66 of SSR-4 [1]). If an event could simultaneously challenge several facilities at one site, the assessment is required to address the implications at the site level in addition to the implications for each facility: see para. 6.61 of SSR-4 [1].

Structures, systems and components important to safety at a reprocessing facility

5.12. Paragraph 6.21(e) of SSR-4 [1] states:

> "The design of the nuclear fuel cycle facility…Shall provide for structures, systems and components and procedures to control the course of and, as far as practicable, to limit the consequences of failures and deviations from normal operation that exceed the capability of safety systems."

Annex II of this Safety Guide presents examples of structures, systems and components important to safety and representative events that could challenge the associated safety functions.

Cooling of radioactive material at a reprocessing facility

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

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

5.14. Cooling systems are required to be designed to prevent uncontrolled releases of radioactive material to the environment, the exposure of workers and the public, and criticality accidents, particularly with regard to storage vessels for highly active liquid waste[9] and PuO_2 containers: see paras 6.157–6.159 of SSR-4 [1]. Cooling may also be used to control corrosion rates in aggressive environments.

5.15. The cooling capacity necessary to remove heat from radioactive decay and chemical reactions should be defined by the design and is required to be confirmed by the safety analysis: see Requirement 39 of SSR-4 [1]. The safety analysis is also required to specify the availability and reliability of cooling systems and the corresponding need for emergency power supplies (see paras 6.187–6.189 of SSR-4 [1]). 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 at a reprocessing facility

5.16. Requirement 40 of SSR-4 [1] states:

[9] Highly active liquid waste is also referred to as high level liquid waste.

“**The design shall include features to control reactive, flammable, corrosive and pyrophoric materials and mixtures used or produced in the processing of radioactive material.**”

5.17. The production and build-up of degradation products might result from radiolysis in water (including cooling water) or in organic materials, or from chemical reactions (interaction of active metals with water). Such products may be flammable or explosive (e.g. H_2, CH_4 or other hydrocarbons, organic nitrate or nitrites (red oils) and peroxides) or corrosive (e.g. Cl_2, H_2O_2) and might 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 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.

5.18. Unstable products and exothermic chemical reactions might result in explosion and loss of confinement. National and international codes and standards are required to be taken into account in the facility design: see para. 6.8 of SSR-4 [1]. Such codes and standards, together with international experience, should be taken into account when developing design requirements and specifications to prevent the build-up of explosive substances. The design is required to ensure that process parameters are monitored (see Requirement 43 of SSR-4 [1]) and should include suitable alarm systems and ensure that inventories are minimized in order to prevent chemical explosions (e.g. red oils in evaporators, HN_3 in extraction cycles, ion exchange resins). See also Requirement 41 and paras 6.162–6.167 of SSR-4 [1].

5.19. Pyrophoric metals (e.g. uranium and zirconium particles from fuel shearing or cladding removal) can cause fire or explosion. The design of the facility should avoid their unexpected accumulation and should provide an inert environment, as necessary.

5.20. 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:

(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;
(g) Leak detection and collection in radioactive liquid transfer systems, in particular in buried transfer systems;
(h) The potential for system overpressure.

Confinement of radioactive material at a reprocessing facility

5.21. To meet Requirement 35 of SSR-4 [1] in a reprocessing facility, three barriers (or more, as determined 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 cells around process equipment or, when gloveboxes are the first containment barrier, the rooms around the glovebox(es). The third static barrier is the building itself. The design of the static containment system should consider openings between the 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) and, as far as practicable, in accident conditions.

5.22. Each static barrier in a reprocessing facility should be complemented by one or more dynamic containment systems, which should establish a cascade of pressure between the environment outside the building and air that might contain 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 the following, as far as applicable:

(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, including increasing the filter resistance during operation and considering conservative assumptions regarding the meteorological conditions.

5.23. 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. 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 due to self-heating should be considered. The chemical compatibility of liquid streams should also be considered in the design.

5.24. Particular consideration should be given to those parts of the reprocessing facility that handle 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 the risk and the optimization of protection and safety, the need for operator intervention should be avoided.

5.25. The ventilation system (see para. 6.126 of SSR-4 [1]) 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). The ventilation system may also include an off-gas cleaning system.

5.26. The assessment and design of the building's ventilation system including redundant sub-systems[10], 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 in accordance with the hazards they contain;

[10] Redundant sub-systems may be provided to ensure continuous availability during, for example, maintenance or filter changes.

(c) The nature of potential airborne contamination (i.e. the predicted or actual levels of airborne contamination);
(d) The levels of surface contamination and the risks of additional contamination;
(e) Requirements for maintenance.

5.27. The process ventilation system creates the lowest pressure within a reprocessing 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 radioactive material and to facilitate future decommissioning.

5.28. All filtration stages of the ventilation systems that require testing should be designed in accordance with relevant standards, such as those of the International Organization for Standardization (ISO).

5.29. 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 might be of less favourable geometry.

5.30. The potential for the failure of a fully loaded filter in the ventilation system of a reprocessing facility should be considered. Additional standby fans and filters should be provided as specified in the safety analysis. These should be capable of maintaining ventilation during filter changing. Fans should be supplied with emergency power such that, in the case of a loss of electrical power, the standby ventilation system will begin operation within an acceptable period of time. The safety analysis should indicate what period of delay may exist between the loss of the primary ventilation system and initiation of the standby ventilation; this may define an operational limit or condition. Local monitoring and alarm systems should be installed to alert operating personnel to system malfunctions resulting in high or low flows or differential pressures.

5.31. On-line fans and standby fans should be provided in accordance with the results of the safety assessment. When required by the safety assessment (e.g. near the gloveboxes), alarm systems should be installed to alert operating personnel to system malfunctions resulting in high or low differential pressures.

5.32. Fire dampers to prevent the propagation of a fire through ventilation ducts and to maintain the integrity of firewalls[11] should be installed, unless the likelihood of a fire spreading or the consequences of such a fire are acceptably low (see para. 6.162 of SSR-4 [1]).

Protection of workers

5.33. Requirements on the design of reprocessing facilities to ensure radiation protection are established in Requirement 8 of SSR-4 [1].

5.34. The static barriers (at least one is required between radioactive material and working areas) normally protect workers from internal exposure and external exposure (see paras 6.123–6.125 of SSR-4 [1]). The design of such barriers should be specified to ensure their integrity and effectiveness and, where appropriate, to facilitate maintenance. Their design specifications should include, for example,

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

weld specifications, selection of materials, leaktightness, including specification of penetration seals for electrical and mechanical penetrations, and the ability to withstand seismic loads.

5.35. For items that need to be regularly maintained or accessed (such as sampling stations and pumps), consideration should be given to installing them in shielded bulges[12] or gloveboxes, adjacent to the process cells where they are needed, depending upon the radiation type and level of the material being processed. Such an approach will reduce the local inventory of radioactive material and allow for special 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.

5.36. 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. 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.

5.37. For normal operation, the need for the use of respiratory protective equipment should be minimized through careful design of the static and dynamic containment systems in the reprocessing facility and of devices for the immediate detection of low quantities of airborne radioactive material. Respiratory protective equipment should be used during normal operation only as a complementary means of protection in addition to existing barriers (see also paras 9.100–9.101 of SSR-4 [1]). Careful consideration should also be given to the need to distinguish naturally occurring radionuclides (e.g. radon) from artificial radionuclides.

5.38. The design of a reprocessing facility is required to include equipment for real-time monitoring airborne radioactive material: see para. 6.120 of SSR-4 [1]. 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 monitoring equipment for temporary controlled areas, e.g. for maintenance.

5.39. To avoid the inadvertent spread of contamination within the reprocessing facility, control points with personnel contamination monitoring equipment (for exposed skin surfaces, clothing and protective clothing) is required to be located at the exit airlocks and barriers from areas that could be contaminated: see para. 6.121 of SSR-4 [1].

5.40. As far as practicable, tools and equipment should not be transferred routinely through air locks or across barriers. Where such transfers are unavoidable, such items should be monitored for contamination. Consideration should be given in the 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.

[12] 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.

Protection of the public and the environment

5.41. Paragraph 3.9(e) of GSR Part 3 [7] states:

> "Any person or organization applying for authorization…Shall, as required by the regulatory body, have an appropriate prospective assessment made for radiological environmental impacts, commensurate with the radiation risks associated with the facility or activity".

Recommendations on performing an environmental impact assessment are provided in IAEA Safety Standards Series No. GSG-10, Prospective Radiological Environmental Impact Assessment for Facilities and Activities [20].

5.42. To the extent prescribed by safety analyses, all engineered discharge points from the ventilation system for a reprocessing facility should be provided with equipment for the reduction of airborne radioactivity. 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. Volatile gases, which cannot be filtered, should be addressed by appropriate engineered measures designed to retain, as far as practicable, any radioactivity within the system.

5.43. 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 Requirement 25 and paras 6.100–6.104 of SSR-4 [1], and Requirements 14 and 32 of GSR Part 3 [7]). 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[13] and collection vessels).

Protection against external exposure at a reprocessing facility

5.44. The aim of protection against external radiation exposure is to maintain doses below the limits established in schedule III of GSR Part 3 [7], and to optimize protection and safety (see paras 2.7 and 6.6 of SSR-4 [1]), by use of the following, 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 performed).
(b) Shielding the radiation source, including the use of temporary shielding.
(c) Distancing the radiation source from site personnel (e.g. by means of the position of work stations and by remotely controlled operation).
(d) Limiting the exposure time of site personnel (e.g. by means of automation of operation and through the use of alarming dosimeters).
(e) Controlling access to areas where there is a risk of external exposure.
(f) Using personal protective equipment (e.g. torso shields and organ shields). For normal operation, the need for personal protective equipment is expected to be minimized through careful design.

[13] 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.

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

5.46. In areas containing high levels of beta/gamma activity, the design of shielding should consider both the output and the location of the radiation source. In general, shielding should be designed to be as close as possible to the radiation source. In areas containing medium or low levels of activity, a combination of limiting the magnitude of the radiation source, restricting the exposure time and using shielding should be considered as a means of protecting site personnel.

5.47. The need for maintenance, including examination, inspection and testing activities, is required to be given special attention in the design of equipment installed in highly active cells, with particular consideration given to radiation levels and contamination levels in facilities with a long design lifetime: see para. 6.106 of SSR-4 [1]. In particular, the following should be implemented:

(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 and replacement where possible (e.g. 'master–slave' manipulators).
(b) For transfers of liquids, non-mechanical means (e.g. air lift or jet lift with disentrainment capabilities[14], 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[15]).

5.48. The inventories of radioactive material 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[16] of active material within pipes (especially sections containing highly radioactive material) and gloveboxes (e.g. 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.

5.49. 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 paras 6.130 and 6.199 of SSR-4 [1]).

5.50. Depending on the results of 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'[17] (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;

---

[14] An air lift or jet lift with disentrainment capabilities is a system or device for separating liquid from motive air or steam with minimum carry-over (entrainment) of activity into the ventilation system.
[15] Such flasks are sometimes referred to as mobile equipment replacement casks.
[16] The phenomenon of such deposition is called 'plate-out' in some States.
[17] A sniffer is an air sampling point or device.

(c) Personal dosimeters consistent with the type(s) of radiation present.

Prevention of nuclear criticality at a reprocessing facility

5.51. Requirement 38 of SSR-4 [1] states:

> "**The design shall ensure an adequate margin of subcriticality, under operational states and conditions that are referred to as credible abnormal conditions, or conditions included in the design basis.**"

Detailed recommendations on criticality safety are provided in SSG-27 [3].

5.52. Prevention of nuclear criticality is an important topic with various aspects to be considered during the design and operation of a reprocessing facility. The criticality safety analysis should demonstrate that the design of equipment and the related safety measures are such that the facility is in a subcritical state at all times, i.e. the values of the controlled parameters are always maintained in the subcritical range. This should be achieved by determining the effective multiplication factor (k_{eff}), which mainly depends on the mass, the geometry, the distribution and the nuclear properties of the fissionable material and all other materials with which it is associated. The calculated value of k_{eff} (including all uncertainties and biases) should then be compared with the value specified by the design limit (which should be set in accordance with paras 2.4–2.7 of SSG-27 [3]) and actions should be taken to maintain the value of k_{eff} under this limit.

5.53. Paragraph 6.142 of SSR-4 [1] states that "For the prevention of criticality by means of design, the double contingency principle shall be the preferred approach."

5.54. The system interfaces at which there is a change in the state of the fissile material or in the method of criticality control are required to be specifically assessed: see para. 6.147 of SSR-4 [1]. 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.

5.55. When required by the safety analysis, the precipitation of fissile material or neutron poisons 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 (with or without homogeneous neutron poisons) is located;
(b) The acidification of cooling or heating fluid loops for equipment containing solutions of nuclear material (to prevent precipitation in case of leakage from the cooling loop into the equipment).

5.56. The design should consider the need for cooling loops to meet subcritical design requirements.

5.57. 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 and by concentration control. The overall design should provide for any potential leakage to be transferred 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 the following:

(a) Localized drip trays or sumps (see para. 6.146(d) of SSR-4 [1]) 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 and sump sampling system to provide additional protection;
(c) Frequent inspections, continuous closed circuit television camera surveillance and adequate lighting.

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

5.59. In accordance with the criticality safety analysis, instruments specifically intended to detect accumulations of fissile material should be used where necessary. Such instruments should also be used to verify the fissile inventory of equipment during the preparation for decommissioning.

5.60. For processes in which fissile material is handled in a discontinuous manner (batch processing), the process and the related equipment should be designed to ensure that fissile material is transferred only when the limits defined for the next process are satisfied (see also para. 9.85 of SSR-4 [1]).

5.61. The requirements to be applied in respect of criticality detection and alarm systems and associated provisions are established in paras 6.149, 6.172 and 6.173 of SSR-4 [1].

5.62. The areas in a reprocessing plant containing fissile material for which criticality detection and alarm systems are necessary to initiate immediate evacuation[18] should be defined in accordance with the layout of the facility, the process at hand, the national safety regulations and the criticality safety analysis.

5.63. The need for additional shielding, remote operation and other design measures to mitigate the consequences of a criticality accident, if one should occur, should be assessed in terms of the application of the defence in depth requirements in paras 6.19–6.27 of SSR-4 [1].

POSTULATED INITIATING EVENTS FOR A REPROCESSING FACILITY

5.64. In accordance with para. 6.60 of SSR-4 [1], postulated initiating events from the list of internal hazards and external hazards for reprocessing facilities are required to be identified for detailed further analysis.

Internal hazards at a reprocessing facility

5.65. The design of a reprocessing facility is required to take into account the nature and severity of internal hazards: see Requirement 15 and paras 6.43–6.6.48 of SSR-4 [1].

Fire and explosions

5.66. The requirements for fire safety at a reprocessing facility are established in Requirement 41 and paras 6.162–6.167 of SSR-4 [1].

5.67. In a reprocessing facility, fire hazards are associated with the presence of the following:

(a) Flammable materials such as pyrophoric materials, solvents and reactive chemicals;

[18] The immediate activation of the alarm system is to minimize doses to personnel in case of repeated, multiple or slow kinetics criticality events.

(b) Potentially flammable materials such as polymeric neutron shielding (normally associated with gloveboxes), hydraulic oil used for shearing machines, electrical cabling and process and operational waste (e.g. wipes, personal protective equipment), including office waste.

5.68. Fire in a reprocessing facility might 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 fire extinguishing media, neutron absorber degradation or melting, or destroying neutron decoupling devices.

5.69. An analysis of fire and explosion hazards is required to be conducted for reprocessing facilities to meet the requirements established in Requirement 22 and paras 6.77–6.79 of SSR-4 [1]. Fire hazard analysis involves the identification of the causes of fires, assessment of the potential consequences of a fire and, where appropriate, estimation of the frequency or probability of occurrence of fires. Fire hazard analysis should be used to assess the inventory of fuels and initiation sources, and to determine the appropriateness and adequacy of measures for fire protection. Computer modelling of fires may sometimes be used in support of the fire hazard analysis.

5.70. The fire hazard analysis for a reprocessing facility is required consider both external and internal fires, including fires involving radioactive material, both directly and indirectly[19]: see paras 6.77 and 6.78 of SSR-4 [1].

5.71. Fire hazard analysis can provide valuable information on which it is possible to base design decisions or to identify weaknesses that might otherwise have gone undetected. Even if the likelihood of a fire occurring is low, it might have significant consequences with regard to safety and, as such, appropriate protective measures should be implemented (e.g. delineating small fire compartment[20] areas) to prevent fires or to prevent the propagation of a fire. The analysis should also include a systematic review of the provisions made for preventing, detecting, mitigating and fighting fires.

5.72. 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 Requirement 22 of SSR-4 [1]). In particular, the fire hazard analysis should consider 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, stores and laboratories in which flammable or combustible liquids and gases, solvents, resins or reactive chemicals are used and/or stored, including cranes where oils are used for gear boxes;
(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;

---

[19] 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.

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

(g) Rooms housing systems and components important to safety (e.g. rooms housing last stage filters of the ventilation system, 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) Cable rooms and cable trays,
(j) Evacuation routes.

5.73. Paragraph 6.162 of SSR-4 [1] states:

> "The design shall include provisions to:
>
> (a) Prevent fires and explosions;
>
> (b) Detect and quickly extinguish those fires that do start, thus limiting the damage caused;
>
> (c) Prevent the spread of those fires that are not extinguished, and prevent fire induced explosions, thus minimizing their effects on the safety of the facility."

5.74. Requirements for measures to accomplish the dual aims of fire prevention and mitigation of the consequences of a fire are established in paras 6.162–6.167 and 9.109–9115 of SSR-4 [1]. For a reprocessing facility, these measures include 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) Definition of fire zones with specific requirements on their separation from other zones and-or premisses;
(d) 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;
(e) Selection of materials, including building materials, process and glovebox components and materials for penetrations, in accordance with their functional requirements and fire resistance ratings;
(f) Compartmentalization of buildings and ventilation ducts as far as possible to prevent the spreading of fires;
(g) Limiting the use of flammable liquids or gases inside their flammability limits;
(h) Suppression or limitation of the number of possible ignition sources, such as open flames, welding or electrical sparks, and their segregation from combustible material;
(i) Insulation of hot or heated surfaces;
(j) Consistency of the fire extinguishing media with the requirements of other safety analyses, especially with the requirements for criticality control (see Requirement 38 and para. 6.146 of SSR-4 [1]).

5.75. The design and control of ventilation systems for rooms, cells and gloveboxes in a reprocessing facility 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.

5.76. The design of the ventilation system in a reprocessing facility 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 locations of filters and fans should be carefully evaluated for their 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.
(i) The use of non-combustible materials for filters and other elements of ventilation system should be considered.

5.77. 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.

5.78. Evacuation routes for fire and criticality events at a reprocessing facility 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 (i.e. to reduce the number of different evacuation routes), where this does not impact significantly on fire safety or criticality safety.

5.79. The requirements relating to the prevention of explosions at nuclear fuel cycle facilities are established Requirements 22 and 41, and paras 6.77–6.79 and 6.162–6.167 of SSR-4 [1]. 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, NH_3 and red oil) or the mixing of incompatible chemicals (e.g. strong acids and alkalis).

5.80. To prevent a release of radioactive material resulting from an internal explosion, the following provisions should be considered in the design of a reprocessing facility:

(a) The adoption of processes with a lower potential risk for fire or explosion;
(b) The need to maintain the separation of incompatible chemical materials in normal and abnormal situations (e.g. recovery of leaks);
(c) The control of parameters (e.g. concentration, temperature, pressure, flow rate) to prevent situations leading to explosion;
(d) The use of blow-out panels to mitigate the effects of the explosion of non-radioactive materials;
(e) Limits on the quantity or concentration of explosive material;
(f) 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;
(g) Design of structures and equipment to withstand the effects of an explosion.

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

Handling errors

5.82. The requirements relating to handling of fissile material and other radioactive material are established in Requirement 51 and paras 6.192–6.195 of SSR-4 [1]. Mechanical or electrical failures or human errors in the handling of radioactive or other materials might result in the degradation of criticality controls, confinement, shielding, or in a degradation 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 (see para. 6.194 of SSR-4 [1]), qualifying containers against the maximum drop, designing floors to withstand the impact of dropped loads and installing shock absorbing features, ensuring safety margins for subcriticality taking into account consequences of handling errors, and specifying safe travel paths);
(c) Minimize the failure frequency of mechanical handling systems (e.g. cranes, carts) by appropriate design[21], including control systems, with multiple fail-safe features (e.g. brakes, wire ropes, action on power loss, interlocks).

These measures should be supported by ergonomic design (see para. 6.11 of SSR-4 [1]), human factors analysis (see Requirement 27 of SSR-4 [1]) and the definition of appropriate administrative controls (see paras 9.36 and 9.37 of SSR-4 [1].

Equipment failures

5.83. Paragraphs 6.80–6.89 of SSR-4 [1] establish requirements to address equipment failure in the design of a reprocessing facility. Thus, a reprocessing facility is required to be designed to cope with the failure of equipment that would result in a degradation of confinement, shielding or criticality control or a challenge of defence in depth. As part of the design, the failure of all structures, systems and components important to safety is required to be assessed and consideration 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, the functionality of structures, systems and components important to safety is required to be maintained (e.g. by redundancy, separation, diversity and independence, as necessary).

5.84. Failure due to fatigue or chemical corrosion or lack of mechanical strength should be considered in the design of containment systems.

5.85. To prevent failure of equipment containing hazardous materials (e.g. furnaces), effective programmes for maintenance, periodic testing and inspection should be established at the design stage (see also paras 5.184–5.187).

5.86. 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 or by a functional analysis of the systems and their failure frequencies (see also Requirement 45 of SSR-4 [1]).

[21] Some regulatory bodies have specific requirements for the design for ‘nuclear loads’ or ‘nuclear lifts’, for example requiring the use of multi-roped cranes, the application of the single failure criterion, or requiring the maximum load to be a smaller fraction of the test load than for non-nuclear lifts.

Loss of services

5.87. The reprocessing facility should be designed to cope with potential loss of services that might have consequences for safety. The loss of services 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 support facilities (e.g. waste treatment and storage facilities and other facilities on the site). Requirements for electrical power supply systems and compressed air systems are established in Requirements 49 and 50 of SSR-4 [1].

5.88. To meet the requirements established in Requirements 49 and 50 and para. 6.89 of SSR-4 [1], electric power supplies and other support services in a reprocessing facility should be of high reliability[22]. In the event of a loss of normal power, and depending on the status of the facility, an emergency power supply is required to be provided to certain structures, systems and components important to safety: see para. 6.187 of SSR-4 [1]. For a reprocessing facility, this includes the following:

(a) Criticality accident detection and alarm systems;
(b) Heat removal systems;
(c) The dilution system for hydrogen generated by radiolysis;
(d) (Some) exhaust fans of the dynamic containment system;
(e) Fire detection and alarm systems;
(f) Radiation monitoring systems;
(g) Nuclear material handling equipment;
(h) Instrumentation and control associated with the above items;
(i) Adequate lighting (see also para. 6.182 of SSR-4 [1]).

5.89. 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 need to be (and remain) available in the event of a prolonged utilities outage should be identified.

5.90. 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.

Emergency procedures for power recovery should also be developed during the design (see Requirements 71 and 72 of SSR-4 [1]).

5.91. The assessments of the loss of electrical power supplies or other support services (e.g. cooling, compressed air and ventilation) should be part of the overall safety assessment for the reprocessing facility.

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

5.92. The loss of services, such as gas for instrumentation and control, cooling water for process equipment, ventilation systems and inert gas supplies, might also have consequences for safety. Examples of suitable measures to be addressed in the design of a reprocessing facility to ensure safety include the following:

(a) In accordance with the safety assessment, the design of supply systems[23] should be of adequate reliability, with diversity and/or 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 might 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.

Leaks and spills

5.93. Provisions to prevent, detect and collect leaks arising from corrosion, erosion and vibration in systems exposed to oscillations should be implemented. Consideration should be given to equipment containing acid solutions, especially when such solutions are at high temperatures.

5.94. 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 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.

5.95. 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.

5.96. 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 to maintain safety in the event of failure of a waste storage vessel. Such spare tanks and associated systems should be proven, managed, maintained, and tested during the operation to provide sufficient confidence they could be safely deployed when required. The subcriticality of the collected leaks and spills should be ensured.

5.97. The potential effects of corrosion on the dimensions of equipment containing fissile material are required to 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 and concentration): see para 6.146 of SSR-4 [1]). 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

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

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.

Flooding

5.98. The requirements relating to protection against internal flooding of a reprocessing facility are established in Requirement 15 of SSR-4 [1]. Flooding by process fluids (e.g. water, nitric acid) including utility feeds in the reprocessing facility might 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 implemented as far as possible. 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.

5.99. In the parts of the reprocessing facility where vessels and/or pipes containing liquids are present, the criticality analysis should take into account the presence of the maximum credible amount of liquid within each room as well as the maximum credible amount of liquid that could flow from any connected rooms, vessels or pipework.

5.100. Walls (and floors if necessary) of rooms where flooding could occur should be capable of withstanding the liquid load, and safety related equipment 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.

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

Chemical hazards

5.102. The requirements relating to chemical hazards for a reprocessing facility are established in Requirement 42 and para. 6.168 of SSR-4 [1]. For a reprocessing facility, conservative assessments of chemical hazards to site personnel 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.

5.103. 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 might cause corrosion, dissolution and damage) and indirect actions (resulting in the evacuation of control rooms or toxic effects on site personnel) should be considered.

Use of non-atmospheric pressure equipment

5.104. As far as practicable, provisions for in-service testing of equipment installed in controlled areas and cells should be defined in accordance with national requirements on pressurized and/or sub atmospheric equipment[24]. 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 the concept of defence in depth.

External hazards at a reprocessing facility

5.105. The design of a reprocessing facility is required to take into account the nature and severity of external hazards: see Requirement 16 and paras 6.49–6.54 of SSR-4 [1]. Such external hazards, either natural or human induced, are required to be identified and evaluated in accordance with the provisions of SSR-1 [17]. Detailed recommendations on external hazards are provided in Safety Standards Series Nos SSG-9 (Rev. 1), Seismic Hazards in Site Evaluation for Nuclear Installations [21], SSG-18, Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations [22], SSG-21, Volcanic Hazards in Site Evaluation of Nuclear Installations [23], SSG-67, Seismic Design for Nuclear Installations [24] and SSG-68, Design of Nuclear Installations Against External Events Excluding Earthquakes [25],

5.106. Paragraph 6.54 of SSR-4 [1] states:

> "The design shall provide for adequate margins to protect items important to safety against levels of external hazards more severe than those selected for the design basis as derived from the site hazard evaluation."

Earthquakes

5.107. To ensure that the design of the reprocessing facility provides the necessary degree of robustness, a detailed seismic assessment is required to be performed: see Requirements 15 and 16 of SSR-1 [17] Recommendations on this assessment are provided in SSG-9 (Rev. 1) [21] and SSG-67 [24]). The assessment of seismic hazards for the reprocessing facility design should include the following seismically induced events:

(a) Loss of cooling;
(b) Loss of support services, including utilities;
(c) Loss of confinement (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);

---

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

(e) The effect on criticality safety functions such as geometry, moderation, absorption and reflection of the following:
   (i) Deformation (geometry control);
   (ii) Displacement (geometry control, fixed poisons);
   (iii) Loss of material (geometry control, soluble poisons)
   (iv) Ingress of moderating material (moderation control).

5.108. In accordance with Requirement 14 and para. 6.49 of SSR-4 [1], a reprocessing facility is required to be designed to withstand the design basis earthquake. The design should also be evaluated for beyond design basis seismic events to ensure that such an event will not impair the function of control rooms, will not cause loss of confinement or a criticality accident, and that there is adequate seismic margin to avoid cliff edge effects. Supplementary control rooms, emergency control panels[25] and other 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.

5.109. Depending on the reprocessing facility's site characteristics and location, as evaluated in the site evaluation (see Section 4), the effect of a tsunami induced by an earthquake and other extreme flooding events should be addressed in the facility design.

External fires and explosion and external toxic hazards

5.110. Hazards from external fires and explosions could arise from various sources in the vicinity of a reprocessing facility, such as petrochemical installations, forests, pipelines and road, rail or sea routes used for the transport of flammable material such as gas or oil, and volcanic hazards.

5.111. To demonstrate that the risks associated with such external hazards are below acceptable levels, the operating organization should first identify all potential sources of hazards and then evaluate the associated event sequences that might affect the safety of the facility. The radiological consequences of any damage should be assessed, and it should be verified that they are within acceptance criteria. Toxic and asphyxiant hazards should also be assessed to verify that specific gas concentrations meet the acceptance criteria. It should be ensured that external toxic and asphyxiant hazards would not adversely affect the control of the facility. The operating organization is required to consider potentially hazardous installations and transport operations for hazardous material in the vicinity of the facility: see paras 5.36 and 5.37 of SSR-1 [17]. In the case of explosions, risks should be assessed for compliance with overpressure criteria. To evaluate the possible effects of flammable liquids, volcanic ashes, falling objects (such as chimneys), air shock waves and missiles resulting from explosions, their possible distance from the facility and hence their potential for causing physical damage should be assessed.

Extreme meteorological phenomena

5.112. A reprocessing facility is required to be protected against extreme meteorological conditions as identified in the site evaluation (see Section 4) by means of appropriate design provisions: see para. 5.7(b) of SSR-4 [1] and Requirement 18 of SSR-1 [17]. This should generally include the following:

(a) The ability to maintain the availability of cooling systems under extreme temperatures and other extreme conditions;

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

(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 confinement with little or no shielding function (e.g. alpha active areas);
(c) The prevention of flooding of the facility including trenches and ducts and adequate means to evacuate water from the roof in cases of extreme rainfall;
(d) The safe shutdown of the facility in accordance with the operational limits and conditions, followed by maintaining the facility in a safe and stable shutdown state, where necessary;
(e) Keeping the groundwater level within acceptable limits during flooding;
(f) Events consequential to extreme meteorological conditions.

Tornadoes

5.113. Measures for the protection of the facility against tornadoes will depend on the meteorological conditions for the area in which the facility is located. The design of buildings and ventilation systems should comply with specific national regulations relating to hazards from tornadoes. If specific national regulations do not exist, the design should adhere to international good practices.

5.114. High winds are capable of lifting and propelling large, heavy objects (e.g. automobiles or telegraph poles). The possibility of impacts of such missiles are required to be taken into consideration in the design stage for the facility: see para. 5.14 of SSR-1 [17]. This should include a consideration of both the initial impact and the effects of secondary fragments arising from collisions with concrete walls or from other forms of transfer of momentum.

Extreme temperatures

5.115. The potential duration of extreme low or high temperatures is required to be taken into account in the design: see para. 5.11 of SSR-1 [17]. For a reprocessing facility the aim should be 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 controls to limit or mitigate the consequences of extreme temperatures should only be relied upon if the operators have the necessary information, sufficient time to respond and the necessary equipment, for example portable air-conditioning.

5.116. If limits for humidity and/or temperature are specified in a building or a compartment, the air conditioning system should be designed to perform efficiently also under extreme hot or wet weather conditions. Structural components of buildings (as static containment) should also be designed for extreme temperature and humidity and its associated thermal stress effects such as shrinkage in concrete.

Snowfall and ice storms

5.117. The occurrence of snowfall and ice storms and their effects are required to be taken into account in the design of the facility and the safety analysis: see paras 5.11 and 5.27 of SSR-1 [17]. Snow and ice are generally taken into account as an additional load on the roofs of buildings. Snow can also block the inlets of ventilation systems and the outlets of drains. 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 effect, or the interspersed moderation effect of the snow should be considered if relevant.

Flooding

5.118. For any flood events such as extreme rainfall (for an inland site) or storm surge (for a coastal site) 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. Equipment containing fissile material is required to be designed to prevent any criticality accident in the event of flooding: see para. 6.146(e) of SSR-4 [1]. Gloveboxes should be designed to be resistant (remain undamaged and static) to the dynamic effects of flooding and all glovebox penetrations should be above any design basis flood levels. Electrical systems, instrumentation and control systems, emergency power systems (batteries and power generation systems) and control rooms should be protected by design.

5.119. 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 take into account uncertainties (e.g. in postulated effects of climate change), to avoid major damage from flooding.

Inundation events (of natural and human induced origin)

5.120. 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 reprocessing facility is located. The design of buildings, electrical systems and instrumentation and control systems should comply with specific national regulations for these hazards, including the recommendations provided in paras 5.117 and 5.118 of this Safety Guide. 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 regionally, depending on the magnitude of the event.

Accidental aircraft crashes or hazards from externally generated missiles

5.121. In accordance with the risk identified in the site evaluation (see Section 4), the reprocessing facility is required to be designed to withstand the design basis impact: see para. 5.7(e) of SSR-4 [1] and para. 5.35 of SSR-1 [17].

5.122. 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, velocity 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 should be established and implemented as necessary.

Terrestrial and aquatic flora and fauna

5.123. The potential for a wide range of interactions with flora and fauna is required to be considered in the design of the reprocessing facility: see para. A.1(g) of SSR-4 [1] and para. 5.32 of SSR-1 [17]. This includes the potential for the restricting or blockage of cooling water and ventilation inlets and outlets, and 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 SYSTEMS AT A REPROCESSING FACILITY

5.124. Requirement 43 of SSR-4 [1] states:

> "**Instrumentation and control systems shall be provided for monitoring and control of all the process parameters that are necessary for safe operation in all operational states. Instrumentation shall provide for bringing the system to a safe state and for monitoring of accident conditions. The reliability, redundancy and diversity required of instrumentation and control systems shall be proportionate to their safety classification.**"

Therefore, instrumentation is required to be provided for measuring all the main parameters whose variation might affect the safety of processes (such as pressure, temperature and flowrate). Other parameters include radiation levels, air quality in operational areas, building pressure, the correct operation of ventilation systems, and general conditions of the facility (such as temperature, contamination levels). Monitoring and control is required to cover normal operation, anticipated operational occurrences and accident conditions, to ensure that adequate information can be obtained on the status of operations and the facility, and proper actions can be undertaken in accordance with operating procedures, emergency procedures or accident management guidelines, as appropriate, for all facility states.

5.125. Instrumentation and control systems are required to be provided for criticality safety, and for hot cells, gloveboxes and hoods: see paras 6.172–6.174.

5.126. Passive and active engineering controls are more reliable than administrative controls and should be preferred for control in operational states and in accident conditions. Automatic systems are required to be designed to maintain process parameters within the operational limits and conditions or to bring the process to a predetermined safe state: see paras. 6.169 and 6.170 of SSR-4 [1]. The safe state for a reprocessing facility is generally the shutdown state.

5.127. Appropriate information should be made available to operating personnel for monitoring the effects of automatic actions. The layout of instrumentation and the manner of presentation of information should provide the operating personnel with an adequate picture of the status and performance of the facility. Devices should be installed that provide in an efficient manner visual and, as appropriate, audible indications of deviations from normal operation that could affect safety. Provision should be made for the automatic measurement and recording of values of parameters that are important to safety and where applicable, manual periodic testing should be used to complement automated continuous testing of conditions.

Safety related instrumentation and control systems at a reprocessing facility

5.128. Safety related instrumentation and control at a reprocessing facility includes systems for the following:

(a) Criticality control, criticality detection and alarm:
    (i) Depending on the method of criticality control, the monitoring and control parameters should include mass, concentration, acidity, isotopic composition or fissile content, burnup and quantity of reflectors and moderators as appropriate.
    (ii) Specific control parameters indicated by criticality safety analyses where burnup credit is taken into account, such as burnup measurement for spent fuel assemblies and elements before shearing or decladding.
    (iii) Specific control parameters indicated by criticality safety analyses where criticality control relies upon soluble poison, such as concentration measurements in reagent feeds.

(iv) Radiation detectors (gamma and/or neutron detectors) with audible and, where necessary, visual alarms for initiating immediate evacuation from the affected area, which are required to cover all the areas where a significant quantity of fissile material is present: see para. 6.173 of SSR-4 [1].

(b) Fire detection and extinguishing systems (see Requirement 41 of SSR-4 [1]):
   (i) All rooms with fire loads or significant amounts of fissile and/or toxic chemical material should be equipped with provisions for fire detection and fire extinguishing;
   (ii) Gas detectors should be used in areas where a leakage of gases (e.g. hydrogen) could produce an explosive atmosphere.

(c) Process control: the key safety related control systems of concern are those for:
   (i) Removing decay heat;
   (ii) Diluting hydrogen due to radiolysis and other sources;
   (iii) Monitoring liquid levels in vessels;
   (iv) Controlling temperature and pressure and other conditions to prevent explosions including red oil explosions.

(d) Glovebox control and cell control:
   — 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:
   (i) 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;
   (ii) Monitoring ventilation (stack) flows for the monitoring of environmental discharges.

(f) Control of occupational radiation exposure:
   (i) Electronic dosimeters with real time displays and/or alarms to monitor occupational exposure.
   (ii) Portable equipment and installed equipment to monitor whole body exposures (and, where appropriate, exposures of the hands and/or lens of the eye) to gamma radiation and neutron emissions.
   (iii) Continuous air monitors to detect airborne radioactive material, installed as close as possible to working areas.
   (iv) Devices for detecting surface contamination, installed or located close to relevant working areas and close to the exits from these areas.
   (v) Detectors and interlocks associated with engineered openings (i.e. access controls).

(g) Monitoring for control of liquid and gaseous discharges (see para. 5.42 of this Safety Guide), including monitoring the operation of the sampling system for environmental discharges.

5.129. The implementation of Requirement 43 of SSR-4 [1] should include a reliable and uninterruptable power supply to the instrumentation and control systems, as necessary.

Local instrumentation at a reprocessing facility

5.130. 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 workers as appropriate.

Sample taking and analysis at a reprocessing facility

5.131. The preference in reprocessing facilities should be for measurement by the following means:

(1) In-line instruments;
(2) At-line instruments[26];
(3) Sampling with local analysis (e.g. checking the dilution of reagents from concentrated stock solutions to ensure the correct concentration);
(4) Sampling with analysis at a separate laboratory, for example, at a central site laboratory.

5.132. In choosing the type of instrumentation to install at a reprocessing plant 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:
   (i) Diversity and redundancy considerations;
   (ii) The need to ensure that the delivery and measurement of samples that are 'representative and fresh'[27].
(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.

5.133. 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, for example measurement of plutonium concentration, plutonium isotopic composition or solution acidity. For such strategic sample points, all the aspects relating to the quality of sample taking and labelling, its safe transfer to analytical laboratories, the quality of the measurements and their reporting to the relevant operating personnel should be documented and justified as part of the management system (see Section 3). The use of bar-coding or similar systems that reduce the opportunity for error should be considered.

5.134. Occupational exposures from sampling operations and the possibility for human error in such operations should be analysed, 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, redundancy in sampling points and provision for dilution near sampling point for high active solution are required to be considered where beneficial to safety and for optimizing operational exposure: Para. 6.199 of SSR-4 [1].

Control systems at a reprocessing facility

5.135. The recommendations in paras 2.9–2.12 apply to all control systems in a reprocessing facility. In particular, the hierarchy of design measures established in para. 6.12 of SSR-4 [1] (application of passive design features, in preference to application of active design features, in preference to administrative controls (operator action)) are required to be applied in accordance with a graded approach and the available reaction time (grace period). Application of the concept of defence in depth to avoiding challenges to safety features or safety controls should also be considered.

---

[26] 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 the bulk material directly.

[27] 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.

5.136. Appropriate information should be made available to personnel 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. Ergonomic principles are required to be applied to in the design of displays (instrument, computer, facility and process schematics and mimic displays), control rooms and panels: see para. 6.108 of SSR-4 [1]. The layout of instrumentation and the presentation of information should provide personnel with a clear and comprehensive view of the status and performance of the facility, to assist the operating personnel in comprehending the facility status rapidly and correctly, in making informed decisions and in executing those decisions accurately.

5.137. Devices should be installed that provide, in an effective manner, visual and, as appropriate, audible indications of deviations from normal operation and that could affect safety. Specifically, information is required to be displayed in such a way that operating personnel 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 para. 6.15 of SSR-4 [1].

5.138. Requirements for transfers of radioactive material and other hazardous material are established in Requirement 28 and paras 6.111 and 6.112 of SSR-4 [1]. In addition, the following measures should be applied, as far as practicable, to allow early detection of anticipated operational occurrences as part of defence in depth:

(1) The use of transfers by batch between units, buildings or facilities (see para. 5.42);
(2) Characterization of a batch before transfer;
(3) The use of a procedure in which the receiving installation authorizes the start of the transfer and monitors 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 at a reprocessing facility

5.139. Requirements for the design of control rooms for nuclear fuel cycle facilities are established in Requirement 46 and para. 6.180 of SSR-4 [1]. In a reprocessing facility, 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 very low or negligible. Where applicable, it may be useful to have dedicated control rooms to allow for the remote monitoring of operations, thereby reducing exposures and risks to workers. Particular consideration should be paid to identifying those events, both internal and external to control rooms, that might pose a direct threat to control room operators, to the operation of the control room and to the control of the reprocessing facility itself. Ergonomic principles are required to be applied to control rooms and the design of control room displays and systems: see para. 6.108 of SSR-4 [1].

HUMAN FACTORS ENGINEERING AT A REPROCESSING FACILITY

5.140. The requirements relating to consideration of human factors are established in Requirement 27 and paras 6.107–6.110 of SSR-4 [1].

5.141. In accordance with Requirement 27 of SSR-4 [1], human factors in operation, inspection, periodic testing and maintenance are required to be considered at the design stage. Human factors to be considered for reprocessing facilities should include the following:

(a) The ease of intervention by operating personnel in all facility states;
(b) Possible effects on safety of inappropriate or unauthorized human actions (with account taken of tolerance of human error);
(c) The potential for occupational exposure.

5.142. In the design of the reprocessing facility, work locations should be evaluated for all modes of operation of the facility, including maintenance. The circumstances in which human intervention is necessary under abnormal conditions or accident conditions should be considered. The aim should be to facilitate the necessary actions of operating personnel and ensure that safety functions and the structures, systems and components that support them are resistant to human error during such actions. 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, operating personnel need to make a rapid, accurate, fault tolerant identification of the problem, and select an appropriate response or action.

5.143. Experts in human factors engineering and experienced operating personnel should be involved from the earliest stages of the design. Areas that should be considered include the following:

(a) Application of ergonomic principles to the design of the workplace, considering the following aspects:
    (i) Design of human–machine interfaces, e.g. well laid-out electronic control panels displaying all the necessary information and no more;
    (ii) Reliability and ease of access and use for sampling systems;
    (iii) 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 easily be kept clean.
(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 versus 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 (see paras 8.6–8.9 of this Safety Guide) and the combination of skills needed during the most demanding occurrences, based on task analysis of operator responses.
(f) Consideration of the need for additional space and of access needs during the lifetime of the facility (see also para. 6.11 of SSR-4 [1].
(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 inspection, maintenance, testing, cleaning and replacement.
(i) Minimization of the need to use personal protective equipment and, where it remains necessary, careful attention to the selection and design of such equipment.
(j) Operational experience feedback relevant to human factors.

5.144. Consideration should be given to providing computer-aided tools to assist operating personnel in detecting, diagnosing and responding to events.

5.145. In the design and operation of gloveboxes (see para. 6.108 of SSR-4 [1]), the following 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 might result in injuries to personnel, including internal radiation exposure through cuts in the gloves and/or wounds, 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) The maintenance requirements for 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[28] in relation to the operating and maintenance activities within the glovebox.
(e) The possible use of mock-ups and conducting extensive testing of glovebox ergonomics at the manufacturers before finalizing the design.
(f) The potential for damage to gloves and the provisions for glove change, and, where applicable, filter changing. Sharp edges and corners on equipment and fittings and associated tools should be avoided to minimize risks of glove damage.
(g) Training of operators on procedures to be followed for normal and abnormal conditions (see para. 9.48 of SSR-4 [1]).

SAFETY ANALYSIS FOR A REPROCESSING FACILITY

5.146. Requirement 14 of GSR Part 4 (Rev. 1) [15] states:

> "**The performance of a facility or activity in all operational states and, as necessary, in the post-operational phase shall be assessed in the safety analysis.**"

The safety analysis of reprocessing facilities should include the analysis of the variety of hazards for the whole facility (see Section 2) and all the activities performed within the facility.

5.147. The list of postulated initiating events identified is required to take into account all the internal and external hazards and the resulting event scenarios: see Requirement 19 of SSR-4 [1]. The safety analysis is required to consider all the structures, systems and components important to safety that might be affected by the postulated initiating events identified: see para. 4.20 of GSR Part 4 (Rev. 1) [15].

5.148. For reprocessing facilities, the safety analysis should be performed iteratively with the development of the design with the objectives of achieving the following:

(a) That doses to workers and the public during operational states do not exceed dose limits and are as low as reasonably practicable, in accordance with Requirement 9 of SSR-4 [1];
(b) That the doses to workers and the public during and following accident conditions remain below acceptable limits and are as low as reasonably achievable in accordance with Requirement 9 of SSR-4 [1];
(c) The development of appropriate operational limits and conditions.

5.149. Bounding cases (see para. 6.62 of SSR-4 [1]) 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 bounding cases is nevertheless

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

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

Safety analysis for operational states at a reprocessing facility

5.150. A facility specific, enveloping and robust (i.e. conservative) assessment of occupational exposure and public exposure during normal operation and anticipated operational occurrences should be performed on the basis of the following assumptions:

(a) External exposures should be calculated 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).
(b) Two approaches are possible to assess external exposure:
   (i) The specification of a dose value that will allow a person to be present without time constraints, and irrespective of the distance between the (shielded) radiation source and the person; or
   (ii) Determination of the type of activity to be performed by each worker, the time required for the activity and the distance between the worker and the (shielded) radiation source.
(c) Calculations to determine the shielding requirements for (b), as appropriate.

5.151. The calculation of estimated dose to the public should include all the exposure pathways associated with the facility, i.e. external exposure through direct or indirect radiation (e.g. sky shine, cloud shine or ground shine), and internal exposure through intakes of radioactive material (e.g. received through the food chain as a result of authorized discharges of radioactive material). The dose should be estimated for the representative person(s): detailed recommendations are provided in GSG-10 [20].

5.152. This Safety Guide addresses also chemical hazards associated with reprocessing facilities, some of which might give rise also to radiological hazards (see para. 2.4 of SSR-4 [1]). Facility specific, realistic, robust (i.e. conservative) estimations of chemical hazards to personnel and releases of hazardous chemicals to the environment should be performed, in accordance with the standards applied in the chemical industry (see Requirement 42 and para. 6.168 of SSR-4 [1]).

Safety analysis for accident conditions at a reprocessing facility

5.153. The acceptance criteria associated with the safety analysis for accident conditions should be defined in accordance with Requirement 16 of GSR Part 4 (Rev. 1) [15], and with respect to any national regulations.

5.154. 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 need to be considered, and bounding cases[29] encompassing the worst consequences should be determined.

---

[29] Bounding cases (also called limiting cases or enveloping cases) are used for the estimation of consequences, see para. 6.62 of SSR-4 [1] and para. 5.148 of this Safety Guide.

5.155. The main steps in the assessment of the possible radiological or chemical consequences of an accident at a reprocessing plant include the following:

(a) Analysis of the current site conditions (e.g. meteorological, geological and hydrogeological site conditions) and the conditions expected in the future.
(b) Specification of facility design and facility configurations, with the corresponding operating procedures and administrative controls for operations.
(c) Identification of individuals and population groups (for site personnel and members of the public) who might be affected by radiation risks and/or associated chemical risks arising from the facility.
(d) Identification and analysis of conditions at the facility, including internal and external 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) Quantification of the consequences for the site personnel and for the representative person(s) identified in the safety assessment.
(f) Specification of the structures, systems and components important to safety that may be credited to reduce the likelihood and/or to mitigate the consequences of accidents. These structures, systems and components important to safety that are credited in the safety assessment are required to be qualified to perform their functions reliably in accident conditions: see paras 6.30 and 6.36 of SSR-4 [1].
(g) Characterization of the source term (e.g. type of material, radionuclides and activity, mass, release rate, temperature).
(h) Identification and analysis of pathways by which material that is released could be dispersed in the environment.

5.156. The analysis of the 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 might influence facility operations or affect the dispersion of material or the transferring of energy that might be released from the facility. Development of preparatory measures and guidelines to reduce the risk of accidents and return the facility to a controlled state is required: see para. 9.118 of SSR-4 [1].

5.157. Environmental dispersion of material should be calculated using suitably validated models and codes or using data derived from such codes, with account taken of the meteorological and hydrological conditions at the site that would result in the highest public exposure.

5.158. Further recommendations on the assessment of potential radiological impact to the public are provided in GSG-10 [20]. Guidelines for assessing the acute and chronic toxic effects of chemicals used in reprocessing facilities are provided in Ref. [26].

Analysis of design extension conditions

5.159. The safety analysis is also required to identify design extension conditions, and analyse their progression and consequences: see Requirement 21 and paras 6.73–6.75 of SSR-4 [1]. Paragraph 6.74 of SSR4 [1] states:

> "New facilities shall be designed such that the possibility of conditions arising that could lead to early releases of radioactive material or to large releases of radioactive material is practically eliminated. The design shall be such that, for design extension conditions, off-site protective actions that are limited in terms of times and areas of application shall be sufficient for the protection of the public, and sufficient time shall be available to take such actions. The postulated initiating events that lead to design extension conditions shall also be analysed for their capability to compromise the ability to provide an effective emergency response. Only

> those protective actions that can be reliably initiated within sufficient time at the location shall be considered available.”

5.160. Design extension conditions include events more severe than design basis accidents that originate from extreme events or combinations of events that could cause damage to structures, systems, and components important to safety or that could challenge the fulfilment of the main safety functions. The list of postulated initiating events provided in the Appendix of SSR-4 [1], including combinations of these events, should be used, as well as events with additional failures.

5.161. Additional safety features or increased capability of safety systems (see para. 6.75 of SSR-4 [1]), identified during the analysis of design extension conditions, should be implemented in existing reprocessing facilities, where practicable.

5.162. For analysing design extension conditions, best estimate methods with realistic boundary conditions can be applied. Acceptance criteria for the analysis, consistent with para 6.74 of SSR-4 [1], should be defined and reviewed by the regulatory body.

5.163. Examples of design extension conditions that are applicable to reprocessing facilities are listed in Ref. [27].

5.164. Analysis of design extension conditions should also demonstrate that the reprocessing facility can be brought into the state where the confinement function and sub-criticality can be maintained in the long term.

MANAGEMENT OF RADIOACTIVE WASTE AT A REPROCESSING FACILITY

5.165. Requirements for safety in radioactive waste management are established in GSR Part 5 [2]. Supporting recommendations are provided in IAEA Safety Standards Series Nos GSG-3, The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste [28], GSG-1, Classification of Radioactive Waste [29], SSG-41 [8] and GSG-16, Leadership, Management and Culture for Safety in Radioactive Waste Management [30].

5.166. In accordance with Requirement 24 of SSR-4 [1], the generation of radioactive waste from reprocessing facilities is required to be kept to the minimum practicable in terms of both activity and volume, by means of appropriate design measures.

5.167. 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 results in a wide variety of waste, in terms of type, waste characteristics (e.g., radiological, chemical) and quantity. Paragraph 6.97 of SSR-4 [1] states:

> “The design of facilities shall endeavour, as far as practicable, to ensure that all waste types anticipated to be produced during the lifetime of the facility have designated disposal routes. Where such routes do not exist at the design stage of the facility, provision shall be made to facilitate envisioned future options.”

Where necessary, process options should be chosen or design provisions should be made to facilitate the disposal of waste by existing routes. The identification of disposal routes should take into account waste characteristics.

5.168. 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, with account taken of occupational exposure and technological constraints on the use of recycled materials. The design should include appropriate facilities for recovery and recycling and should include the need to minimize secondary waste in the overall waste strategy.

5.169. Where waste is intended for identified and existing disposal routes, the waste characteristics for each route should be specified. Equipment and facilities should be provided (or existing equipment and facilities identified) for characterizing, pre-treating, treating and transporting, as necessary, waste to the appropriate identified disposal route, temporary storage location or facility for further waste treatment.

5.170. 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, and regulatory requirements and the best available potential disposal routes in accordance with paras 1.6 and 1.8 of GSR Part 5 [2]. As disposal is the final step of radioactive waste management, any interim waste processing techniques and procedures applied are required to produce waste forms and waste packages that are compatible with the anticipated waste acceptance requirements for the disposal (with care paid to the retrievability of waste intended for temporary storage): see para. 3.21 of GSR Part 5 [2].

5.171. The design of a reprocessing plant 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.

5.172. The design of a reprocessing facility should incorporate (or have provision to provide incrementally) sufficient waste storage capacity for the lifetime of the facility including, as necessary, decommissioning. This should include, in accordance with the safety assessment, provisions for decay heat removal, hydrogen concentration control, and 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 ATMOSPHERIC AND LIQUID RADIOACTIVE DISCHARGES AT A REPROCESSING FACILITY

5.173. Reprocessing facilities are required to be designed so that discharges to the environment are minimized: see para. 6.17 of SSR-4 [1]. If discharges cannot be avoided, the operating organization is required to ensure that authorized limits on such discharges can be met in normal operation and in anticipated operational occurrences: see Requirement 25 of SSR-4 [1].

5.174. 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.

5.175. Equipment for monitoring the status and performance of filters at a reprocessing facility 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);

(d) Filter temperature monitoring.

5.176. Liquid effluents to be discharged to the environment from a reprocessing facility are required to be monitored, treated and managed as necessary to reduce the discharges of radioactive material and hazardous chemicals: see para. 6.101 of SSR-4 [1]. 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. 5.174 should be made to allow the efficiency of these systems to be monitored.

5.177. The design and location of effluent discharge systems should be chosen to maximize the dilution and dispersal of discharged effluents (see para. 4.3 of GSR Part 5 [2]) 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 FOR A REPROCESSING FACILITY

5.178. The Government is required to ensure that a hazard assessment is being performed in accordance with Requirement 4 of GSR Part 7 [19]. The results of the hazard assessment provide a basis for identifying the emergency preparedness category relevant to the facility, as well as the on-site areas and off-site areas where protective actions and other response actions may be warranted in the case of a nuclear or radiological emergency. Further recommendations on emergency arrangements are provided in IAEA Safety Standards Series No. GS-G-2.1, Arrangements for Preparedness for a Nuclear or Radiological Emergency [31].

5.179. Requirements for emergency preparedness and response at nuclear fuel cycle facilities are established in Requirement 72 and paras. 9.120–9.132 of SSR- 4 [1]. The operating organization of a reprocessing facility is required to establish arrangements for emergency preparedness and response that take into account the hazards identified and the potential consequences of an emergency associated with the facility: see Requirement 72 of SSR-4 [1]. The emergency plans and procedures and the necessary equipment and provisions are required to be based on the accidents analysed in the safety analysis report: see para. 9.124 of SSR-4 [1]. The conditions under which an off-site emergency response might need to be initiated include the internal hazards and external hazards identified as the postulated initiating events for a reprocessing facility: see paras 5.64–5123.

5.180. The emergency plans is required to cover all the functions to be performed in an emergency response: see para. 9.124 of SSR-4 [1]. It should also address the infrastructural elements (including training, drills and exercises) that are necessary to support these functions.

5.181. The design of the reprocessing facility is required to take into account the on-site infrastructure that is necessary for an effective emergency response (including the emergency response facilities, suitable escape routes and logistical support: see Requirement 47 of SSR-4 [1]. This includes the need for on-site and off-site monitoring of releases and the environment in the event of an accident: see para. 6.182 of SSR-4 [1].

5.182. The reprocessing facility is required to 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 paras 6.15, 6.83, 6.84 of SSR-4 [1]. Control room(s) and emergency response facilities are required to 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): see Requirements 46 and 48 of SSR-4 [1].

5.183. The safety analysis should identify those safety functions that should continue during and after events that might 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.

5.184. The infrastructure for off-site emergency response (e.g. emergency centres, medical facilities) should be based on the site characteristics and the location of the reprocessing facility (see para. 9.122 of SSR-4 [1] and Requirement 24 of GSR Part 7 [19]).

AGEING MANAGEMENT AT A REPROCESSING FACILITY

5.185. The design of a reprocessing facility is required to take into account the effects of ageing on systems, structures and components important to safety to ensure their reliability and availability during the lifetime of the facility: see Requirement 32 of SSR-4 [1].

5.186. The design of the reprocessing facility is required to facilitate the inspection of systems, structures and components important to safety: see Requirement 26 of SSR-4 [1]. This should include the direct detection of the effects of material ageing and degradation processes (e.g. static containment deterioration, corrosion), and/or indirect detection using technical ageing evaluation based on the relevant inspection data, and allow the maintenance or replacement of such items, if needed.

5.187. 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.

5.188. An ageing management programme is required to be implemented by the operating organization: see Requirement 60 of SSR-4 [1]. This programme should be implemented at the design stage to maintain the operability and reliability of items important to safety and allow equipment replacement to be anticipated.

6. CONSTRUCTION OF NUCLEAR FUEL REPROCESSING FACILITIES

6.1. Requirements for construction of a reprocessing facility are established in Requirement 53 and paras 7.1–7.7 of SSR-4 [1]. Recommendations on the construction of nuclear installations are provided in Construction for Nuclear Installations, IAEA Safety Standards Series No. SSG-38 [32].

6.2. A construction project for a reprocessing facility will involve a large number of designers and contractors, 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 [32] are followed, and that adequate procedures are implemented to minimize potential problems and deviations from the design intent as design and construction proceeds, as part of the management system.

6.3. 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 accident alarm systems), the need to make, where justified, safety improvements and other improvements using proprietary designs and equipment (see para. 2.9), and the need to have access to the necessary experts for reviews. In all cases, the management system (see Section 2) should include provisions to ensure that the necessary information is transferred to the operating organization.

6.4. 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 will also aid commissioning, operation, maintenance and decommissioning.

6.5. Reprocessing facilities are complex facilities, and regulatory body authorization should be sought in several stages. Each stage may have a hold point at which approval by the regulatory body may be necessary before the subsequent stage may be commenced, as described in para. 7.2 of SSR-4 [1].

6.6. As far as possible, equipment should be tested and verified at manufacturers' workshops and/or on the site before its installation at the reprocessing facility, in accordance with a quality assurance programme that is part of the management system. 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 might not be possible or might be limited after installation.

6.7. The operating organization should implement 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).

6.8. The recommendations in paras 4.16(h), 5.27–5.30 and 5.39–5.41 of SSG-38 [31] on the care of installed equipment and the exclusion of foreign material[30] should be followed. After their installation, structures and components should be properly cleaned and painted with suitable primer followed by appropriate surface treatment. The potential effects of nearby activities involving corrosive substances should also be considered.

6.9. 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, as far as practicable, from other parts of the

[30] 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 can also cause or promote corrosion by forming electrochemical cells or crevices or impeding heat transfer.

reprocessing facility that are already constructed or in operation, to prevent negative effects such as cross contamination through ventilation systems.

6.10. Consideration should be given to the quality assurance programme during the construction of a reprocessing facility. This programme should be prepared early in the construction stage and should include:

(a) Applicable codes and standards;
(b) The organizational structure;
(c) Design change programme (configuration control);
(d) Procurement control;
(e) Maintenance of records (see also para. 7.4 of SSR-4 [1]);
(f) Equipment testing;
(g) Coding and labelling of safety relevant components, cables, piping and other pieces of equipment.

7. COMMISSIONING OF NUCLEAR FUEL REPROCESSING FACILITIES

7.1. Requirements for design provisions for the commissioning of nuclear fuel cycle facilities are established in Requirement 31 and para. 6.116 of SSR-4 [1]. Requirements for the commissioning programme for nuclear fuel cycle facilities are established in Requirement 54 and paras 8.1–8.27 of SSR-4 [1]. For reprocessing facilities, these requirements apply in full (see para. 8.6 of SSR-4 [1]), 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 applied.

7.2. This Safety Guide addresses only the safety related aspects of the commissioning of reprocessing facilities. Demonstration of performance and optimization of processes not related to safety are outside the scope of this Safety Guide.

7.3. The operating organization should make the best use of the commissioning stage to become completely familiar with the facility before operation. It should also be an opportunity to promote and further enhance safety culture, including behavioural expectations and learning attitudes, throughout the entire organization. In becoming familiar with the facility, consideration should be given to the following:

(a) Campaigns of fuel reprocessing;
(b) Start-up 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.

7.4. Senior management is responsible for communicating and implementing the safety policy, including during commissioning: see para. 4.6 of SSR-4 [1]. A safety committee, which should report to senior management, is required to be established before active commissioning commences: see Requirement 6 and paras 4.29 and 4.30 of SSR-4 [1]. Items to be considered by the safety committee are listed in para. 4.31 of SSR-4 [1]. With regard to the commissioning of a reprocessing facility, the safety committee should also 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) Any modifications to the safety case for the facility as a result of commissioning.

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

7.6. Paragraph 8.10 of SSR-4 [1] states:

> During commissioning, operational limits and conditions and values for significant parameters shall be confirmed, as well as any acceptable variation in values due to facility transients and other small perturbations. Any margins necessary to make allowance for the precision of measurements or the response times of equipment shall be determined and incorporated in control, alarm and safety trip settings and operational limits and conditions, as necessary.

The commissioning stage should also be used to validate any limits and values justified by the safety analysis. Such limits and values may include the type, quantity and state of the fuel to be accepted (see para. 8.22). These limits and values should be embedded in any instructions relating to safety, including emergency procedures. A further consideration is the effects of changing from one mode of operation to another (e.g. at the start and end of a campaign).

7.7. Where necessary (and in accordance with a graded approach[31]), 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, such as spent welding rods, waste building materials and general debris. Such material might 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 also para. 7.16).

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

(a) Establish suitable controls over the use of temporary works and devices, including the use of the modification process as required;
(b) 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 (i.e. as a modification: see paras 8.45–8.54) and included in the safety case for operation.

[31] 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.

7.9. The procedures and training of personnel that support these non-routine activities may 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. 7.8 to control these activities and all such procedures 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.

7.10. Where inactive simulants or temporary reagent supplies are introduced for commissioning purposes, care should be taken that, as far as practicable, they have identical characteristics (for achieving the commissioning purpose) to material to be used during operations. 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 test 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 used instead of demineralized water), unless a full evaluation of the potential effects has been made.

7.11. Some stages of commissioning may require regulatory approval in accordance with national regulations, both prior to starting and at completion. The operating organization should define and agree with the regulatory body hold points and witness points commensurate with the complexity and potential hazard of the activity and facility, as appropriate, to ensure proportionate inspection during commissioning. The purpose of these hold points should be principally to demonstrate safety in accordance with the safety analysis, prior to advancement to the next phase of commissioning or operation. 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.

7.12. The commissioning programme may vary in accordance with national practices. Nevertheless, for a reprocessing facility, as a minimum the following activities are required to be performed (see paras 8.9 and 8.14 of SSR-4 [1]):

(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 of the availability of other detection and alarm systems (e.g. fire detection and alarm system).

In addition, the commissioning of a reprocessing facility should include the demonstration and confirmation of the satisfactory training and assessment of operating personnel.

7.13. Clear communications between management, supervisors and site personnel and between and within different shifts of personnel 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 FOR A REPROCESSING FACILITY

7.14. Requirement 54 SSR-4 [1] states:

> "The operating organization shall ensure that a commissioning programme for the nuclear fuel cycle facility is established and implemented."

7.15. Paragraph. 8.13 of SSR-4 [1] states:

> "When the direct testing of safety functions is not practicable, alternative methods for adequately demonstrating their performance shall be applied, subject to appropriate approval in accordance with national requirements. This is particularly applicable to nuclear fuel reprocessing facilities."

Such alternative methods may include the verification and audit of materials or suppliers' training records. This further emphasizes the importance of an effective management system.

7.16. 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.

7.17. 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. 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. 7.15). 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.

7.18. Consideration should be given to the need to sequence the commissioning so that parts of the facility necessary 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'[32] sections of the facility (including supplies of utilities such as electrical power, steam, reagents, cooling water and compressed air), 'downstream'[33] sections of the facility (including waste treatment, aqueous and aerial discharges, and environmental monitoring) and

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

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

‘support’[34] 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 FOR A REPROCESSING FACILITY

7.19. In accordance with para. 8.12 of SSR-4 [1], the commissioning of a nuclear fuel cycle facility is required to be divided into a number of distinct stages, depending on the objectives to be achieved. For a reprocessing facility, this may involve four stages, which are described below.

Stage 1: Construction testing

7.20. For some structures, systems and components important to safety, where verification of compliance might 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 other passive structures, leak tight test of underground cells, 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.

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

7.22. Further recommendations are provided in SSG-38 [32].

Stage 2: Cold commissioning (‘inactive commissioning’)

7.23. 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 performed because of the relative ease of taking corrective actions at this stage, unimpeded by the introduction of radioactive material.

7.24. In this stage, operating personnel 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. Leaktightness and the stability of control systems are best tested at this stage.

7.25. The completion of cold 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, such as 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.

---

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

7.26. 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. Maintenance is known to be a major contributor to occupational exposure in reprocessing facilities; consequently, the opportunity should be taken to verify active maintenance procedures and controls, enhance the arrangements for the control of exposures, and identify any aids necessary to simplify or speed up maintenance. Video recording of the maintenance procedures should be considered for training purposes.

7.27. To avoid potential errors in reprocessing facilities, 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.

7.28. Particular attention should also be paid to confirming that all physical connections within the reprocessing facility 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. Any non-conformances should be assessed for their safety consequences and should then either be corrected or accepted, with suitable approvals and updating of documentation.

Stage 3: Uranium commissioning (‘warm commissioning’ or ‘trace active commissioning’)

7.29. Natural or depleted uranium should be used[35] at this stage, to avoid criticality risks, to minimize 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.

7.30. 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. Checks should also be made for unexpected accumulations of material.

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

7.32. This stage should also be used to provide measurable verification of certain parameters that had previously been calculated only theoretically (in particular, in relation to discharges). The use of tracers[36] should also be considered to enhance or allow such verification.

7.33. Prior to active commissioning, emergency arrangements (on-site and off-site) need to be in place, including procedures, training, sufficient numbers of trained personnel, emergency drills and exercises. The on-site and off-site emergency response capabilities should be demonstrated .

---

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

[36] 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.

Stage 4: Hot commissioning (or 'active commissioning' or 'hot processing commissioning')

7.34. The authorization to operate the facility is generally issued by the regulatory body to the operating organization before the start of this stage. Hot commissioning will then be performed under the arrangements for safety for a fully operational reprocessing facility. These arrangements should be applied in full during active commissioning, as far as defined and applicable. The arrangements for safety should not be suspended or modified unless a safety assessment has been made and any approval required by the regulatory body has been granted.

7.35. The full operational radiation protection programme should also be implemented, including individual monitoring.

7.36. Compared to cold commissioning, hot commissioning involves major changes in the control arrangements for the facility and in the associated skills of operating personnel, for example those relating to confinement, criticality safety, cooling and radiation protection. The management of the reprocessing facility should ensure that both the facility and the personnel are fully ready for the change to active commissioning before it is implemented. This should include actions to foster and promote a strong safety culture, to contribute further to safe operation.

7.37. This commissioning 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 reprocessing facility, as far as such an incremental approach is practicable.

7.38. This stage provides further measurable verification of parameters that have previously only been calculated, in particular radiation levels, airborne activity levels, environmental discharges and occupational exposures. The feedback from this verification should be used to identify and implement any corrective actions and to update the assumptions in any estimates and calculations.

COMMISSIONING REPORTS FOR A REPROCESSING FACILITY

7.39. The requirements for commissioning reports[37] are established in paras 8.21–8.23 of SSR-4 [1].

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

7.41. The commissioning report should describe the safety commissioning tests that were performed to demonstrate the facility's compliance with the design, the design intent and the safety assessment, and should summarize any necessary corrective actions. Such corrective actions include making changes to the safety case, adding or changing safety features and work practices. All such changes should be treated as modifications (see paras 8.45–8.54). If commissioning tests are brought forward or put back from other commissioning stages, this should also be described and justified in the commissioning report for each individual stage.

---

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

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

7.43. To demonstrate the operating organization's readiness for operation, the commissioning reports should also describe or provide references to the following:

(a) The numbers, specialities, training, development and assessment of the operating personnel, 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, and summaries of any dose investigations;
(d) Audits and summaries of feedback from the operating organization and of feedback from site personnel on as the following:
    (i) The organization of activities and tasks;
    (ii) Briefings, procedures, work methods, ergonomics and human factors (in general and in relation to specific activities);
    (iii) Equipment and tools;
    (iv) Support activities (such as radiation and contamination surveys, decontamination, the use of personal protective equipment and responses to issues arising during tasks);
    (v) Emergency drills and exercises;
    (vi) Safety culture.

7.44. Any incidents or events that occurred during the commissioning stage should also be summarized in the commissioning report and any learning from experience including replacement of equipment should be identified and reported to the regulatory body and to other operating organizations.

7.45. Detailed findings from commissioning, including the results of all tests, calibrations and inspections, may be provided in supporting documents, but the commissioning reports should list all structures, systems and components important to safety and all 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.

7.46. 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.

7.47. Where possible, lessons identified from the commissioning and operation of similar reprocessing facilities should be applied [33].

8. OPERATION OF NUCLEAR FUEL REPROCESSING FACILITIES

ORGANIZATION OF OPERATION OF REPROCESSING FACILITIES

8.1. The large scale and complexity of fuel reprocessing facilities together with the specific hazards in nuclear fuel reprocessing (see Section 2) should be taken into account in meeting the requirements for operation of nuclear fuel cycle facilities established in section 9 of SSR-4 [1].

8.2. Suitable arrangements are required to 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: see Requirement 73 of SSR-4 [1] and paras 8.133 and 8.134 of this Safety Guide). This includes lessons learned from other organizations that operate reprocessing facilities. Similar arrangements should be made to learn lessons from other hazardous facilities (e.g. chemical plants).

8.3. The organization of a reprocessing facility should be arranged so as to ensure that the appropriate authority is always present on the site, with appropriate access to suitably qualified and experienced personnel (either on the site or available to be called to the site), 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.

8.4. The operating organization of a reprocessing facility should undertake the following:

(a) Establish and maintain appropriate interfaces (in particular, in relation to communication procedures) between the following:
    (i) Shift staff and day operations staff (especially maintenance personnel and radiation protection personnel) within the reprocessing facility[38];
    (ii) 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 operating personnel have the latest information on the continuity of utility supplies;
    (iii) The reprocessing facility and the organizational unit responsible for on-site transport of radioactive material, if any;
    (iv) The reprocessing facility and any organization engaged to make modifications to the facility (e.g. projects to improve throughput or to provide additional capacity);
    (v) The reprocessing facility and off-site emergency services involved in emergency response functions at the reprocessing facility (see Requirement 72 and paras 9.120–9.132 of SSR-4 [1]);
(b) Periodically review the operational management structure, training, experience and expertise of operating personnel (individually and collectively) to ensure that, as far as practicable, sufficient knowledge and experience is available at all times. This review should consider all reasonably foreseeable circumstances including staff absences. The requirements in para. 9.10 of SSR-4 [1] for the control of organizational change should include key safety personnel and other posts, based on this review.

8.5. A safety committee in a reprocessing facility (see Requirement 6 of SSR-4 [1]) is required to established prior to active commissioning: see para. 4.30 of SSR-4 [1]. The arrangements for the safety committee should be reviewed at the start of operation. Its function should be specified in the management system, and it should be adequately staffed. The safety committee is required to include diverse expertise and have appropriate independence from the direct line management of the operating organization: see para. 4.29 of SSR-4 [1]).

[38] Reprocessing facilities typically operate on a continuous basis even when not processing material.

STAFFING OF A REPROCESSING FACILITY

8.6. Requirement 56 of SSR-4 [1] states that "**The operating organization shall ensure that the nuclear fuel cycle facility is staffed with competent managers and sufficient qualified personnel for the safe operation of the facility.**" Paragraph 9.16 of SSR-4 [1] states that "A detailed programme for the operation and utilization of the nuclear fuel cycle facility shall be prepared in advance and shall be subject to the approval of senior management."

8.7. The operation of a reprocessing facility should be reviewed and updated periodically to ensure that it is consistent with and supports long term objectives. The staffing of the facility should address the development of professional and managerial skills and experience, and should take into account losses of personnel and their knowledge due to retirement and other reasons. The long term staffing plan should allow sufficient time for the transfer of responsibilities to new personnel, and thereby facilitate continuity in the conduct of duties.

8.8. The staffing of a reprocessing facility should be based on the functions and responsibilities of the operating organization. A detailed analysis of tasks and activities to be performed should be made to determine the staffing and qualification needs at different levels in the organization. This analysis should also be used to determine the recruitment, training and retraining needs for the facility.

8.9. The operating organization should establish the necessary arrangements to ensure the safety of personnel and the safe operation of a reprocessing facility during situations in which a large number of personnel might be unavailable, such as during an epidemic or a pandemic affecting areas in which personnel live. Such arrangements should include the following:

(a) Retaining a minimum number of qualified personnel on the site to ensure safe operation of the facility;

(b) Ensuring that a minimum number of qualified back-up personnel remain available off the site;

(c) Establishing additional measures to prevent the spread of an infection on the site, in accordance with national and international guidance (e.g. enabling remote working for non-essential personnel).

QUALIFICATION AND TRAINING OF PERSONNEL AT A REPROCESSING FACILITY

8.10. Requirements for the qualification and training of facility personnel are established in Requirements 56 and 58 of SSR-4 [1]. Further recommendations are provided in paras 4.6–4.25 of GS-G-3.1 [11].

8.11. 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.

8.12. Operating personnel should be provided periodically with basic training in criticality safety, radiation safety, and decontamination procedures, with the emphasis placed on criticality control, radiation protection, and emergency preparedness and response.

8.13. Dedicated training facilities should be established, as necessary.

8.14. Comprehensive training should cover both automatic operations and manual operations, and be commensurate with the potential safety consequences of these operations. For manual activities, training should include the following:

(a) Use of master–slave manipulators and other remote equipment (in highly radioactive 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).

8.15. For automatic modes of operation, training should include 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).

8.16. Complementary training of safety and security personnel and their mutual participation in exercises of both types should be part of the training programme to effectively manage the interface between safety and nuclear security. In particular, personnel with responsibilities and expertise in safety analysis and safety assessment should be provided with a working knowledge of the security arrangements at the reprocessing facility. Similarly, security experts should be provided with a working knowledge of the safety considerations of the facility, so that potential conflicts between safety and security can be resolved effectively.

OPERATION OF REPROCESSING FACILITIES

Operational limits and conditions and operating procedures at a reprocessing facility

8.17. Requirement 57 and paras 9.27–9.37 of SSR-4 [1] establish requirements for operational limits and conditions be developed for a reprocessing facility. Operating personnel should be clearly informed of the safety significance of the operational limits and conditions, including safety limits, safety system settings and limiting conditions for safe operation. Examples of structures, systems and components relevant to defining operational limits and conditions for each process area are presented in Annex II.

8.18. In order to ensure that, under normal circumstances, the reprocessing facility operates well within its operational limits and conditions, a set of limits on operating parameters are required to be defined by the operating organization (para. 9.31 of SSR-4 [1]). 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.

8.19. The authority to make operating decisions should be assigned to suitable levels of management, depending on 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. If a sub-limit or an operational limit or condition is exceeded, the appropriate level of management should be informed (see also paras 9.34 and 9.35 of SSR-4 [1]). The circumstances that would necessitate an immediate decision or action for safety reasons should be defined, as far as practicable, in procedures developed in accordance with the management system. The appropriate shift staff or day staff should be trained and authorized to make the necessary decisions, and take the necessary actions, in accordance with these procedures.

8.20. Any non-compliance with limits on operating parameters 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 non-compliances and any immediate actions taken and should be kept informed of the subsequent investigations and their outcome.

8.21. All limits and conditions for a reprocessing plant should be clearly and consistently identified in procedures and in directly relevant procedural steps. Consideration should be given to classifying procedures in accordance with their safety significance (i.e. using a graded approach).

8.22. User-friendly operating procedures (see Requirement 63 of SSR-4 [1]) should be developed to directly control process operations at a reprocessing facility. These procedures should cover all modes of operation of the facility, including ramp-up and ramp-down. In accordance with Requirement 63 of SSR-4 [1], procedures for anticipated operational occurrences and accident conditions are also required to be developed. Operating personnel are required to be trained in the use of the procedures: see para. 9.69 of SSR-4 [1]. This training should include assessments of competence, and include simulations or exercises, where appropriate.

8.23. The documents prepared should 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 observance of operating procedures. Records of operation should be capable of demonstrating compliance with operational limits and conditions at all times.

Specific provisions for the operation of reprocessing facilities

8.24. The development and maintenance of a feed programme (see para. 9.89(a) of SSR-4 [1]) 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.

8.25. 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 a reactor) and safety related constraints at the facility.

8.26. 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 optimize occupational exposure and any wastes generated should be managed in accordance with established procedures. Decisions that are based on sample analysis should take into account the accuracy of the sampling process, the analytical methods used and, where relevant, the delay between sampling and the result being available.

8.27. Following the batch transfer of process liquids and wastes, operating personnel should, as far as practicable, confirm that the volume transferred from the sending vessel corresponds to the volume received (see para. 5.138).

8.28. 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 for purposes of nuclear material accounting and control). It is safer to perform maintenance during inter-campaign periods, although the risks of contamination and increased occupational exposures do still increase as more maintenance work is undertaken. In addition, intensive maintenance periods may involve 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 personnel to teams and additional supervision of work.

8.29. Systematic walk-throughs of the facility — by operating personnel and 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-throughs 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 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[39], lifting equipment, fire extinguishers and electrical equipment);
(c) Conditions at access points to supervised areas 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 and storage of waste;
(g) The proper storage of materials and equipment;
(h) The ready availability of emergency equipment.

Exclusion of foreign material at a reprocessing facility

8.30. 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 (see para. 7.7) and are particularly relevant for maintenance activities and for the supply and delivery of process reagents.

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

Maintenance, calibration, periodic testing and inspection at a reprocessing facility

8.31. Requirements relating to maintenance, calibration, periodic testing and inspection of reprocessing facilities are established in Requirement 65 and paras 9.74–9.82 of SSR-4 [1].

8.32. Reprocessing facilities are large and complex facilities: consequently, maintenance should be coordinated and managed to ensure that unanticipated interactions, either with operation or between two maintenance activities, will not result in adverse safety consequences.

8.33. All maintenance activities in a reprocessing facility should be pre-approved within the operating organization on the basis of a safety analysis report or safety assessment, produced in accordance with the management system.

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

8.35. 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 levels of contamination and occupational exposures will be acceptable. The analysis should specify appropriate protection measures and monitoring requirements (see paras 8.70 and 8.71).

8.36. During maintenance, isolation between the equipment being maintained and other parts of the facility that contain radioactive material should be ensured, as far as practicable.

8.37. Hands-on maintenance should, as far as practicable, be performed after equipment drain-down and wash-out, or following decontamination, to reduce the radiation risks and the risk of spreading contamination.

8.38. For maintenance tasks with high anticipated doses (or the risk of high doses), consideration should be given to the use of mock-ups and/or electronic models of the area or equipment, as well as other training methods designed to develop familiarity with the task and allow work techniques to be optimized. The development of operator aids, including ‘stand-off’ tools, should also be considered.

8.39. A programme of periodic inspections of the facility is required to be established to verify that the facility and the structures, systems and components important to safety are functioning in accordance with the operational limits and conditions: see paras 9.74 and 9.76 of SSR-4 [1]. Suitably qualified and experienced persons are required to perform these inspections: see para. 9.39 of SSR-4 [1].

8.40. The accurate and timely calibration of equipment is important for the safe operation of a reprocessing facility. Calibration procedures should cover equipment used by the reprocessing facility and by organizations that support the 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, in accordance with national or international standards, including its traceability.

8.41. The frequency of calibration and periodic testing of instrumentation important to safety (including instrumentation located in analytical laboratories), should be defined in the operational limits and conditions, based on the safety analysis.

AGEING MANAGEMENT FOR REPROCCESSING FACILITIES

8.42. Requirements for an effective ageing management programme for nuclear fuel cycle facilities are established in Requirement 60 and paras 9.53–9.55 of SSR-4 [1]. In implementing these requirements, the operating organization of a reprocessing facility should take into account the following:

(a) Ensuring support for the ageing management programme by the management of the operating organization;
(b) Ensuring early implementation of an ageing management programme;
(c) Following a proactive approach based on an adequate understanding of structures, systems and components ageing, rather than a reactive approach responding to the failure of structures, systems and components;
(d) Ensuring optimal operation of structures, systems and components to slow down the rate of ageing degradation;
(e) Ensuring the proper implementation of maintenance and testing activities in accordance with operational limits and conditions, design requirements and manufacturers' recommendations, and following approved operating procedures;
(f) Minimizing human performance factors that may lead to premature degradation, through enhancement of staff motivation, sense of ownership and awareness, and understanding of the basic concepts of ageing management;
(g) Ensuring availability and use of correct operating procedures, tools and materials, and of a sufficient number of qualified personnel for a given task;
(h) Collecting feedback of operating experience to learn from relevant ageing related events.

8.43. The aging management programme should consider the physical ageing and the non-physical ageing (obsolescence i.e. their becoming out of date in comparison with current knowledge, codes, standards and regulations, and technology).

8.44. The surveillance and periodic testing undertaken as part of the ageing management programme (see para. 9.54 of SSR-4 [1]) should be implemented through regular checks performed by the operating personnel, such as the following:

(a) Systematic monitoring of the condition of systems, structures and components;
(b) Regular visual inspections of structures, systems and components (e.g. UO_2 and PuO_2 powder pipes) for evidence of deterioration due to ageing effects;
(c) Monitoring of operating conditions (e.g. taking heat images of electrical cabinets, checking the temperature of ventilator bearings).

CONTROL OF MODIFICATIONS AT A REPROCESSING FACILITY

8.45. Requirement 61 of SSR-4 [1] states that "**The operating organization shall establish and implement a programme for the control of modifications to the facility.**" The management system of a reprocessing facility should include a standard process for all modifications (see para. 3.20). A work control system, quality assurance procedures and appropriate testing procedures should be used for the implementation of modifications (including temporary modifications) at a reprocessing facility.

8.46. The operating organization is required to prepare procedures and provide training to ensure that relevant personnel have the necessary competence and authority to ensure that modification projects are carefully controlled: see paras 9.56–9.59 of SSR-4 [1]. The safety of modifications should be assessed for potential hazards during installation, commissioning and operation. Decision making relating to modifications should be conservative.

8.47. Proposed modifications should be reviewed in detail, and be subject to approval by, qualified and experienced persons to verify that the arguments used to demonstrate safety are suitably robust. This is considered particularly important if the modification could have an effect on criticality safety.

8.48. The depth of the safety arguments and the degree of scrutiny to which they are subjected are required to be commensurate with the safety significance of the modification: see paras 9.58 and 9.59 of SSR-4 [1].

8.49. The safety committee is required to review the proposed modifications: see para. 4.31(d) of SSR-4 [1]. Suitable records should be kept of their decisions and recommendations.

8.50. The modification 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). Procedures for the control of documentation are required to be implemented to ensure that relevant documents are updated to reflect the planned modification: see 9.57 of SSR-4 [1]. Personnel involved in making the modification are required to be suitably trained and qualified: see para. 9.57(f) of SSR-4 [1].

8.51. The management system for the reprocessing facility (see Section 3) should include a process for the overall monitoring of the progress of modifications and to ensure that all proposals for modification receive a sufficient level of scrutiny. The documentation supporting the proposed modification should specify the functional (commissioning) checks that are necessary before the modified system may be declared fully operational again.

8.52. Modifications of the design, layout or procedures of a reprocessing facility might adversely affect nuclear security. Therefore, in addition to a review of the implications for safety, the possible effects on nuclear security are required to be evaluated before approval and implementation of the modification, to verify that safety measures and security measures do not compromise each other: see Requirement 75 of SSR-4 [1].

8.53. The modifications made to a reprocessing facility (including those to the operating organization) should be reviewed on a regular basis to ensure that the cumulative 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.

8.54. The modification control documentation (see para. 9.57(f) of SSR-4 [1]) should be retained at the reprocessing facility in accordance with regulatory requirements.

CONTROL OF CRITICALITY HAZARDS AT A REPROCESSING FACILITY

8.55. Requirements for criticality safety in the operation of a reprocessing facility are established in Requirement 66 and paras 9.83–9.85 and 9.89 of SSR-4 [1]. Recommendations for criticality safety in all facilities and activities are provided in SSG-27 [3].

8.56. Operational aspects of the control of criticality hazards in a reprocessing facility should be taken into consideration, including the following:

(a) Rigid adherence to the predetermined feed programme;
(b) Prevention of unexpected changes in conditions that could increase the probability 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 (see para. 9.83 of SSR-4 [1]);

(d) Management of moderating materials, particularly hydrogenated materials, where moderation control is used;
(e) Management of reflecting materials more efficient than water, such as additional shielding, where additional shielding is used;
(f) Management of mass in transfers of fissile material, where mass control is used;
(g) Reliable methods for detecting the onset of any of the deviations from normal operation, particularly those parameters relied upon for the avoidance of criticality;
(h) Periodic calibration or testing of systems for the control of criticality hazards;
(i) Emergency drills to prepare for the occurrence of a criticality and/or the actuation of a criticality alarm.

8.57. For each reprocessing campaign, before starting to feed fuel to the dissolver, the limits of criticality-controlled 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 is required to be suitably verified and validated: see para. 6.145 of SSR-4 [1].

8.58. When burnup credit is used in the criticality safety analysis, appropriate justification for this is required (see para. 6.148 of SSR-4 [1]), and care should be taken to allow for the any uncertainties associated with burnup measurements.

8.59. 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 during normal operation as well as during anticipated operational occurrences). 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.

8.60. If identified by the criticality safety analysis, the following issues should be addressed in the procedures for criticality safety at a reprocessing facility:

(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) in accordance with the facility flowsheet (the technical basis).

In addition, appropriate alarm settings on the instruments used for monitoring the feeds and solutions should be considered.

8.61. Where there are any uncertainties in the characteristics of fissile material, conservative values are required to be used for parameters such as fissile content and isotopic composition: see paras 6.140 and 6.156 of SSR-4 [1]. Particular issues may be encountered when carrying out maintenance work and during inter-campaign periods when material and residues from different campaigns might become mixed.

8.62. In some situations, the requirements for criticality safety and conservative decision making may make it necessary to halt the transfer of fissile material in a reprocessing facility to ensure compliance 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 reprocessing facility to a safe and stable state. Nevertheless, the personnel responsible for criticality safety should be involved in all such decisions and should subsequently analyse the event to produce feedback and identify lessons to be learnt

RADIATION PROTECTIONAT AT REPROCESSING FACILITY

8.63. The requirements for radiation protection in operation of a nuclear fuel cycle facility are established in Requirement 67 and paras 9.90–9.101 of SSR-4 [1]. General requirements for radiation protection are established in Part 3 of and GSR Part 3 [7]; and recommendations on the implementation of GSR Part 3 [7] requirements for the protection of workers are provided in IAEA Safety Standards Series No. GSG-7, Occupational Radiation Protection [34].

8.64. The operating organization of a reprocessing facility should have a policy to optimize protection and safety in a systematic manner, and is required to ensure doses are below authorized limits and are as low as reasonably achievable within any dose constraints set by the operating organization: see paras 9.91 and 9.93 of SSR-4 [1].

8.65. Requirement 67 of SSR-4 [1] states that "**The operating organization shall establish and implement a radiation protection programme.**" This programme should be established and maintained to fulfil the management's responsibility for protection and safety and should take into account the large inventories, the variety of sources, the complexity and the size of the reprocessing facility. In accordance with Requirement 24 of GSR Part 3 [7], the radiation protection programme for a reprocessing facility is expected to include the following elements:

(a) Assignment of responsibilities (decision making, corresponding organizational arrangements, including itinerant workers, advisory committee);
(b) Designation and functions of qualified experts (radiation protection, internal and external dosimetry, workplace monitoring, ventilation, occupational health, radioactive waste management);
(c) Integration of radiation protection with other areas of health and safety (industrial hygiene, industrial safety, chemical safety and fire safety);
(d) Accountancy system for radiation generators and radioactive sources (location, description of each radiation generator or radioactive source, output, activity, physical and chemical form);
(e) Designation of controlled areas and supervised areas;
(f) Local rules and procedures that are necessary for protection and safety for workers and other persons
(g) Provision of personal protective equipment;
(h) Arrangements for monitoring workers and the workplace;
(i) System for recording and reporting;
(j) Training programme;
(k) Methods for reviewing and auditing;
(l) Emergency procedures;
(m) Programme for workers' health surveillance;
(n) Requirements for the assurance of quality and process improvement.

8.66. Requirements for the designation of controlled areas and supervised areas are established in paras 3.88–3.92 of GSR Part 3 [7]. Consideration should also be given to the further classification of such designated areas in accordance with the radiation hazard. This helps operating personnel in assessing the radiation risks associated with tasks in an area, and can be used in setting the frequency of workplace radiation monitoring. The classification assigned should be based initially on that used in the facility design (see para. 6.121 of SSR-4 [1]) and should be developed on the basis of advice from radiation protection personnel, as necessary. Individual contamination zones and the boundaries between them should be regularly checked and adjusted, if necessary to reflect the radiological conditions.

8.67. In areas where there is the potential for air contamination, continuous air monitoring should be performed to alert operating personnel if levels of airborne radioactive material exceed predetermined action levels. The action levels should be set as near as practicable to the normal level of air contamination 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, when there is a risk of contamination spreading. Prompt investigation should be conducted in response to readings of high levels of airborne radioactive material.

8.68. The 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. The programme should also be designed to ensure that problems are promptly diagnosed and that corrective and/or mitigatory actions are identified and implemented in a timely manner.

8.69. Doses to workers should be estimated in advance and should be monitored during work activities, using suitably located devices and/or personal dosimeters (preferably with electronic alarms), as appropriate.

8.70. The assessment of doses due to internal occupational exposure should be based on in vivo and in vitro monitoring, as appropriate, 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 samplers and individual doses should be verified by the use of personal air samplers in sampling campaigns of, preferably, limited duration.

8.71. Workplace monitoring inside and outside the reprocessing facility buildings should be complemented by a regular radiological survey 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 is required to be related to the relative risk of radiation or contamination in the individual areas: see para. 3.97 of GSR Part 3 [7]. 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.

8.72. Radiation protection personnel (i.e. radiation protection manager, radiation protection officer and their representatives) should be part of the decision-making processes associated with the optimization of protection and safety (e.g. for the early detection and mitigation of hot spots) and proper housekeeping (e.g. waste segregation, packaging and removal).

8.73. Protection against internal exposure and external exposure should be provided during all operations including maintenance. Limitation of exposure time, the use of additional shielding, remote operations and the use of mock-ups should be implemented, as necessary. In addition, for complex high dose tasks, training should be provided for the personnel involved to minimize exposure times and optimize exposures.

8.74. A high standard of housekeeping is required to be maintained within the reprocessing facility: see Requirement 64 of SSR-4 [1]. 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 temporary storage or disposal as appropriate, in a timely manner[40].

8.75. Regular contamination surveys of facility areas and equipment should be performed to confirm the adequacy of facility cleaning programmes. Prompt investigations should be conducted 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.

8.76. Newly identified contamination zones should be delineated, with proper posting and barriers provided in accordance with 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.

8.77. 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.

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

8.79. Paragraph 9.43 of SSR-4 [1] states:

> "Even where there are separate radiation protection personnel, the operating personnel, including technical support personnel, shall be given suitable training in radiation protection before the start of their duties. Periodic retraining in operational radiation protection shall be conducted."

8.80. Site personnel should be trained in the use of personal dosimeters and personal protective equipment (including dressing and undressing), and in self-monitoring. Personal protective equipment is required to be maintained in good condition, periodically inspected and kept readily available: see para. 3.95 of GSR Part 3 [7].

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

[40] Allowing waste (including industrial waste material that is suspected to contain radioactive material) to accumulate in work areas contributes to occupational exposure, 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).

8.82. 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.

8.83. Intrusive maintenance[41] 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 persons involved (including decontamination personnel).
(b) Preparatory activities to optimize individual and collective doses, including:
  (i) The identification of specific risks due to the intrusive maintenance;
  (ii) Operations to minimize the radiation source (inventory), e.g. flushing out and rinsing of parts of the process;
  (iii) Consideration of the use of mock-ups, remote devices, additional shielding or personal protective equipment, monitoring devices and dosimeters;
  (iv) The identification of relevant procedures within the work permit, including procedures for optimizing protection and safety, 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.

8.84. When a normal containment barrier is to be reduced or removed as part of a maintenance or modification activity, procedures that address the following aspects should be developed and applied in accordance with the level of risk[42]:

(a) A temporary controlled area should be created that includes the work area. Depending on the assessed risk, this may include, as necessary:
  (i) An enclosure[43] with a temporary ventilation system with filtration and/or exhaust to the facility's ventilation system;
  (ii) Barriers with appropriate additional radiation and/or airborne and surface contamination monitors.
(b) Personal protective equipment (e.g. respiratory protective equipment, over-suits), as specified, should be provided at the entry points and used whenever there is a risk of release of radioactive material.
(c) 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 individual should also provide

[41] 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.

[42] 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.

[43] 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'.

assistance to the maintenance staff in putting on, taking off and monitoring personal protective equipment.

Requirement 37 of SSR-4 [1] states:

> "**Equipment shall be provided at the nuclear fuel cycle facility to ensure that there is adequate radiation monitoring in operational states, in design basis accidents and, if appropriate, in design extension conditions.**"

8.85. The extent and type of workplace monitoring at a reprocessing facility should be commensurate with the expected level of airborne activity, contamination and radiation, and the potential for these to change. The selection and use of personal dosimeters and radiation monitoring instrumentation should take into account the range of doses and dose rates and the radiation energies (alpha, beta/gamma or neutron) expected to be present within the reprocessing facility.

8.86. Equipment for monitoring dose rates, individual doses, surface contamination and airborne activity in reprocessing facilities should include, as necessary, the following:

(a) Passive dosimeters and/or electronic beta/gamma and neutron dosimeters;
(b) Criticality detectors (area and individual);
(c) Extremity dosimeters (e.g. to measure doses to the fingers or the lens of the eye);
(d) Mobile airborne activity monitors with immediate, local alarms (for maintenance work areas, tents and temporary enclosures and air locks);
(e) Mobile air samplers.

8.87. In the event of abnormal radiation or contamination being detected in a room or area, checks of the personnel present in the area should be performed and 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.

8.88. Further recommendations on occupational radiation protection and the assessment of internal exposure and external exposure, including recommendations on decontamination are provided in GSG-7 [34].

MANAGEMENT OF FIRE SAFETY, CHEMICAL SAFETY AND INDUSTRIAL SAFETY AT A REPROCESSING FACILITY

8.89. Requirements for protection against fire and explosion are established in Requirement 69 and paras 9.109–9.115 of SSR-4 [1]. Requirements relating to industrial and chemical safety are established in Requirement 70 and paras 9.116 and 9.117 of SSR-4 [1].

8.90. 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. The list of conventional non-nuclear hazards found in reprocessing facilities is extensive and includes 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 and anoxia;
(f) Dropped loads;

(g) Falls from elevated working places;
(h) Noise;
(i) Dust.

8.91. The exposure of personnel to chemical hazards should be assessed using a method similar to that for the assessment of radiation exposure and should be based upon the collection of data from air sampling in the workplace, in combination with personnel occupancy data. This method should be assessed and reviewed as appropriate by the appropriate regulatory authority. The acceptance levels of exposure for various chemical hazards in a reprocessing facility can be found in Ref. [26].

8.92. 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.

8.93. 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.

8.94. Chemicals should be stored in well-ventilated 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.

8.95. Personnel should be informed about the chemical hazards that exist. Operating personnel are required to be properly trained with respect to the hazards associated with the process chemicals (see para. 9.117 of SSR-4 [1] in order to adequately identify and respond to the problems that might lead to chemical accidents.

8.96. As required by national regulations, a health surveillance programme should be set up for routinely monitoring the health of personnel who might be exposed to harmful chemicals. The surveillance programme should address short term effects (acute exposure) and long term effects (chronic exposure).

8.97. During an emergency, special consideration should be given to the presence of both chemical and radiological hazards.

8.98. 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.

8.99. To minimize the fire hazard of pyrophoric metals (e.g. zirconium or uranium particles), hot cells where fuel shearing takes place 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) or inerting of equipment may be necessary.

8.100. 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 (see SSG-27 [3] for further recommendations).

8.101. 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. See also para. 5.73.

8.102. 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.

8.103. To ensure the efficiency and operability of fire protection systems, suitable procedures, training and drills are required to be implemented: see para. 9.109 of SSR-4 [1]. This includes 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 workers.

MANAGEMENT OF RADIOACTIVE WASTE AND EFFLUENTS AT A REPROCESSING FACILITY

8.104. The requirements relating to the management of radioactive waste and effluents in operation are established in Requirement 68 and paras 9.102–9.108 of SSR-4 [1].

8.105. All operating personnel should be trained in the waste management hierarchy (eliminate, reduce, reuse, recycle and dispose: see para. 6.17 of SSR-4 [1]), the waste management programme for the reprocessing facility 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 the work performed) should be implemented.

8.106. All waste generated at a reprocessing plant should be treated and stored in accordance with pre-established criteria, taking into account any national waste classification schemes. Waste management involves a consideration both on-site and off-site waste 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 for which a disposal route has not yet been identified. Where a disposal route does exist, waste characterization should be performed in such a way that compliance with waste acceptance criteria can be demonstrated. The information characterizing the waste is required to be held and be retrievable: see paras 9.104 and 9.106 of SSR-4 [1].

8.107. Operational arrangements should be such that the requirement to minimize the generation of radioactive waste of all kinds (see para. 9.102 of SSR-4 [1]) is met (e.g. 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.

8.108. 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.

8.109. Any radioactive waste generated at a reprocessing facility is required to be characterized: see paras 6.94 and 9.103 of SSR-4 [1]. This should include a determination of its physical, chemical and radiological properties to allow its subsequent optimum management, i.e. appropriate pre-treatment, treatment, conditioning and selection or determination of a temporary storage or disposal route. To the extent possible, the management of waste should ensure that all waste will meet the specifications for existing temporary storage or disposal routes, as appropriate. Particular care should be taken to segregate waste containing fissile material and ensure criticality safety for such waste (see also paras 9.84 and 9.85 of SSR-4 [1]).

8.110. Consideration should be given to segregating solid waste in accordance with its origin, which can be indicative of its potential radioactive 'fingerprint'[44] and thus can provide information on routes for processing, storage and disposal. The radioactive fingerprint, in conjunction with rapid, local radiological 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 necessary, the sorting of the waste in dedicated waste handling areas. Remote or automatic equipment should be used to the extent possible.

8.111. The collection and further processing of the waste (i.e. pre-treatment, treatment and conditioning) is required to be performed in accordance with approved procedures: see para. 9.105 of SSR-4 [1], with the aim of ensuring that waste acceptance criteria for established or planned routes for storage and disposal are met.

8.112. Decontamination methods should be adopted at a reprocessing facility that minimize the generation of primary and secondary waste and facilitate the subsequent treatment of the waste, for example by ensuring the compatibility of decontamination chemicals with available waste treatment routes.

8.113. As far as reasonably achievable, decontamination should be used to minimize the environmental impact and maximize 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.

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

[44] 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.

8.115. Information about the radioactive waste that is necessary for its safe management and eventual disposal now and in the future is required to be collected, recorded and preserved in accordance with the management system and with regulatory requirements: see para. 9.104 of SSR-4 [1].

8.116. Reprocessing facilities usually have a number of discharge points corresponding either separately or collectively to the specific authorized limits on 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.

8.117. Discharges of radioactive effluents and associated hazardous chemical effluents from nuclear fuel cycle facilities are required to be monitored: see para. 9.104 of SSR-4 [1]. For reprocessing facilities, effluent streams should be measured where possible before discharge or, where this is not practicable, in real time at the point of discharge. Sampling devices and procedures should provide representative and timely results corresponding to the actual flows or batch releases to the environment.

8.118. As described in para. 5.172, the operating organization is required to ensure that discharges are minimized and are within authorized limits. The personnel involved in the management of discharges from a reprocessing facility should have the authority to shut down processes and halt discharges, subject to safety considerations, when they have reason to believe that these aims might not be met.

8.119. 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.

8.120. 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 regulatory body. An environmental monitoring programme is required (see para. 9.108 of SSR-4 [1]), and the results of this programme should be used to verify the impact of discharges (and any unplanned releases) on the public and on the surrounding area, to identify any trends and to assess public exposure.

8.121. Radioactive gaseous discharges should be treated, as appropriate, by dedicated off-gas treatment systems and by means of HEPA filters. After a filter change, it should be verified 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. 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 (see also para. 6.103 of SSR-4 [1]).

8.122. 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.

8.123. The effectiveness of the liquid effluent system (i.e. collection and discharge pipework, and temporary storage, if any) should be maintained as part of the reprocessing facility (see also para. 6.103 of SSR-4 [1]).

8.124. 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.

8.125. 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 FOR A REPROCESSING FACILITY

8.126. General requirements for emergency preparedness and response are established in GSR Part 7 [19], and supporting recommendations on emergency arrangements are provided in GS-G-2.1 [31] and in IAEA Safety Standards Series No. GSG-2, Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency [35]. Requirements for emergency preparedness and response at nuclear fuel cycle facilities are established in Requirement 72 and paras 9.120–9.132 of SSR-4 [1].

8.127. As part of emergency preparedness, arrangements are required to be developed for the local, regional and national emergency response organizations: see para. 3.1 and Requirement 22 of GSR Part 7 [19]. These arrangements are required to be tested periodically to ensure that emergency response functions are performed effectively during a nuclear or radiological emergency: see Requirement 25 of GSR Part 7 [19] and para. 9.130 of SSR-4 [1].

8.128. Clear communication protocols are required to be established with local authorities and response organizations: see para. 5.43 of GSR Part 7 [19].

8.129. The operating organization is required to ensure availability of personnel with specific expertise on the nature and extent of hazards in facility as well as availability and reliability of all supplies, equipment, communication systems, plans, procedures and other arrangements necessary for effective response in an emergency: see paras. 9.128, 9.129 and 9.132 of SSR-4 [1]. The operating organization and response organizations should develop analytical tools that may be used early in an emergency response for supporting decision making on protective actions and other response actions in due recognition of the limitation and in a way would not reduce the effectiveness of response actions: see para. 6.21 of GSR Part 7 [19].

8.130. The emergency arrangements are required to be periodically reviewed and updated: see para. 9.131 of SSR-4 [1]). In performing this review, any lessons from operating experience at the facility and at similar facilities, emergency exercises, modifications, periodic safety reviews, emerging knowledge and changes to regulatory requirements should be taken into account.

8.131. In accordance with para. 4.14(b) of GSR Part 7 [19], emergency plans, security plans and contingency plans are required to be developed in a coordinated manner. This should take into account the responsibilities of personnel with responsibilities for safety and personnel with responsibility for nuclear security, to ensure that in the case of an event involving both safety and nuclear security, all crucial functions can be performed in a timely manner. Emergency response plans are required to consider nuclear security events as possible initiators of an emergency: see para. 1.16 of GSR Part 7 [19]. Strategies for rapidly determining the origin of events and deploying appropriate teams (safety personnel, security forces or a combination of both) should be developed. These strategies should also include the roles and actions of security forces and emergency workers, with a focus on coordinated command and control interfaces and communications. The response to such events should be jointly exercised and evaluated by security forces and emergency response workers. From these exercises or evaluations, lessons should be identified and recommendations should be made to improve the overall response to a potential event.

8.132. For establishing access control procedures during emergencies, when there is a necessity for rapid access and egress of personnel, safety and security specialists should cooperate closely. Both safety and security objectives should be sought for during emergencies as much as possible, in accordance with regulatory requirements.

FEEDBACK OF OPERATING EXPERIENCE AT A REPROCESSING FACILITY

8.133. Requirements on feedback of operating experience are established in Requirement 73 and paras 9.133–9.137 of SSR-4 [1]. Further recommendations on a programme for operating experience feedback are provided in SSG-50 [16].

8.134. The programme for the feedback of operational experience at a reprocessing facility is required to cover experience and lessons learnt from events (including low-level events) and accidents at the facility as well as from other nuclear installations worldwide: see para. 9.133 of SSR-4 [1]. Lessons from relevant events at other (i.e. non-nuclear) facilities should also be considered. This programme should include the evaluation of trends in operational disturbances, trends in malfunctions, near misses and other incidents that have occurred at the reprocessing facility and, as far as applicable, at other nuclear installations. The programme is required to include a consideration of technical, organizational and human factors: see para. 9.134 of SSR-4 [1].

8.135. Useful information on the causes and consequences of many of the most important anomalies and accidents that have been observed in reprocessing facilities and other nuclear fuel cycle facilities is provided in Ref. [33].

9. PREPARATION FOR DECOMMISSIONING OF NUCLEAR FUEL REPROCESSING FACILITIES

9.1. General requirements for the decommissioning of facilities are established in IAEA Safety Standards Series No. GSR Part 6, Decommissioning of Facilities [36]. Requirements for the preparation for decommissioning of a reprocessing facility are established in Requirement 74 and paras 10.1–10.13 of SSR-4 [1].

9.2. The developed decommissioning plan and the safety assessment are required to be periodically reviewed and updated throughout the lifetime of the reprocessing facility: see paras 7.5 and 7.6 of GSR Part 6 [36] and paras 10.1 and 10.2 of SSR-4 [1]. This review should take into account new information and emerging technologies to ensure that:

(a) The (updated) decommissioning plan is realistic and can be performed safely;
(b) Updated provisions are made for adequate decommissioning resources and their availability, when needed;
(c) The radioactive waste anticipated remains compatible with available (or planned) temporary storage capacities and disposal facilities, including any transport and treatment.

9.3. Special measures are required to be implemented during the preparatory works for decommissioning to ensure that criticality control is maintained when handling equipment containing nuclear material for whose subcriticality is controlled by geometry, moderation or absorption: see paras 10.11–10.13 of SSR-4 [1].

9.4. For any period between a planned or unplanned shutdown and prior to decommissioning starting, safety measures are required to 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: see para. 10.9 of SSR-4 [1]. The need to revise the safety assessment for the facility in its shutdown state is also required to be considered. The application of knowledge management methods to retain the knowledge and experience of operating personnel 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.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Fuel Cycle Facilities, IAEA Safety Standards Series No. SSR-4, IAEA, Vienna (2017).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Predisposal Management of Radioactive Waste, IAEA Safety Standards Series No. GSR Part 5, IAEA, Vienna (2009).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Criticality Safety in the Handling of Fissile Material, IAEA Safety Standards Series No. SSG-27, IAEA, Vienna (2009). (A revision of this publication is in preparation.)

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

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5), IAEA Nuclear Security Series No. 13, IAEA, Vienna (2011).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Physical Protection of Nuclear Material and Nuclear Facilities (Implementation of INFCIRC/225/Revision 5), IAEA Nuclear Security Series No. 27-G, IAEA, Vienna (2018).

[7] EUROPEAN COMMISSION, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA Safety Standards Series No. GSR Part 3, IAEA, Vienna (2014).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Predisposal Management of Radioactive Waste from Nuclear Fuel Cycle Facilities, IAEA Safety Standards Series No. SSG-41, IAEA, Vienna (2016).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulatory Control of Radioactive Discharges to the Environment, IAEA Safety Standards Series No. GSG-9, IAEA, Vienna, 2018.

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Leadership and Management for Safety, IAEA Safety Standards Series No. GSR Part 2, IAEA, Vienna (2016).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Application of the Management System for Facilities and Activities, IAEA Safety Standards Series No. GS-G-3.1, IAEA, Vienna (2006). (A revision of this publication is in preparation.)

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, The Management System for Nuclear Installations, IAEA Safety Standards Series No. GS-G-3.5, IAEA, Vienna (2009).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Leadership, Management Sy and Culture for Safety in Radioactive Waste Management, IAEA Safety Standards Series No. GSG-16, IAEA, Vienna (in preparation).

[14] INTERNATIONAL ATOMIC ENERGY AGENCY, The Management System for the Safe Transport of Radioactive Material, IAEA Safety Standards Series No. TS-G-1.4, IAEA, Vienna (2008).

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

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Operating Experience Feedback for Nuclear Installations, IAEA Safety Standards Series No. SSG-50, IAEA, Vienna (2018).

[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSR-1, IAEA, Vienna (2019).

[18] INTERNATIONAL ATOMIC ENERGY AGENCY, Site Survey and Site Selection for Nuclear Installations, IAEA Safety Standards Series No. SSG-35, IAEA, Vienna (2015).

[19] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL CIVIL AVIATION ORGANIZATION, INTERNATIONAL LABOUR ORGANIZATION, INTERNATIONAL MARITIME ORGANIZATION, INTERPOL, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, PREPARATORY COMMISSION FOR THE COMPREHENSIVE NUCLEAR-TEST-BAN TREATY ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, UNITED NATIONS OFFICE FOR THE COORDINATION OF HUMANITARIAN AFFAIRS, WORLD HEALTH ORGANIZATION, WORLD METEOROLOGICAL ORGANIZATION, Preparedness and Response for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GSR Part 7, IAEA, Vienna (2015).

[20] INTERNATIONAL ATOMIC ENERGY AGENCY, Prospective Radiological Environmental Impact Assessment for Facilities and Activities, IAEA Safety Standards Series No. GSG-10, IAEA, Vienna (2018).

[21] INTERNATIONAL ATOMIC ENERGY AGENCY, Seismic Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSG-9 (Rev. 1), IAEA, Vienna (in preparation).

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

[23] INTERNATIONAL ATOMIC ENERGY AGENCY, Volcanic Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSG-21, IAEA, Vienna (2012).

[24] INTERNATIONAL ATOMIC ENERGY AGENCY, Seismic Design for Nuclear Installations, IAEA Safety Standards Series No. SSG-67, Vienna (2021).

[25] INTERNATIONAL ATOMIC ENERGY AGENCY, Design of Nuclear Installations Against External Events Excluding Earthquakes, IAEA Safety Standards Series No. SSG-68, IAEA, Vienna (in preparation).

[26] AMERICAN CONFERENCE OF GOVERNMENTAL INDUSTRIAL HYGIENISTS, 2021 Threshold Limit Values (TLVs) and Biological Exposure Indices (BEIs), ACGIH, Cincinnati (2021).

[27] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Reassessment for Nuclear Fuel Cycle Facilities in Light of the Accident at the Fukushima Daiichi Nuclear Power Plant, IAEA Safety Reports Series No. 90, IAEA, Vienna (2016).

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

[29] INTERNATIONAL ATOMIC ENERGY AGENCY, Classification of Radioactive Waste, IAEA Safety Standards Series No. GSG-1, IAEA, Vienna (2009).

[30] INTERNATIONAL ATOMIC ENERGY AGENCY, Leadership, Management and Culture for Safety in Radioactive Waste Management, , IAEA Safety Standards Series No. GSG-16, IAEA, Vienna (2022).

[31] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR OFFICE, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS OFFICE FOR THE COORDINATION OF HUMANITARIAN AFFAIRS, WORLD HEALTH ORGANIZATION, Arrangements for Preparedness for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GS-G-2.1, IAEA, Vienna (2007).

[32] INTERNATIONAL ATOMIC ENERGY AGENCY, Construction for Nuclear Installations, IAEA Safety Standards Series No. SSG-38, IAEA, Vienna (2015).

[33] INTERNATIONAL ATOMIC ENERGY AGENCY, NUCLEAR ENERGY AGENCY, IAEA/NEA Fuel Incident Notification and Analysis System (FINAS), http://finas.iaea.org/.

[34] INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR OFFICE, Occupational Radiation Protection, IAEA Safety Standards Series No. GSG-7, IAEA, Vienna (2018).

[35] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR OFFICE, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GSG-2, IAEA, Vienna (2011).

[36] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Facilities, IAEA Safety

Standards Series No. GSR Part 6, IAEA, Vienna (2014).

ANNEX I

MAIN PROCESS ROUTES AT A REPROCESSING FACILITY

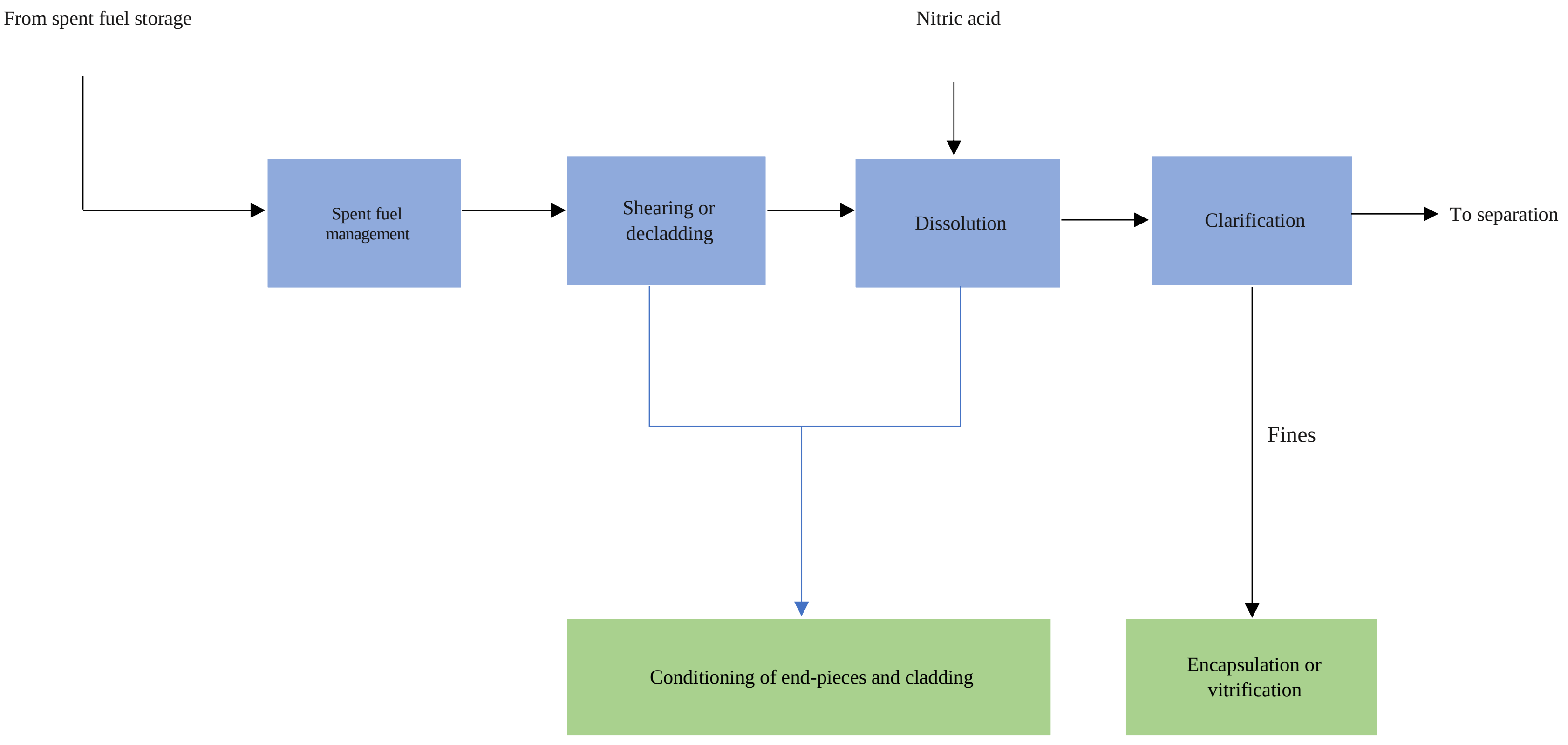

FIG. I–1. Main process routes at the head end of a reprocessing facility.

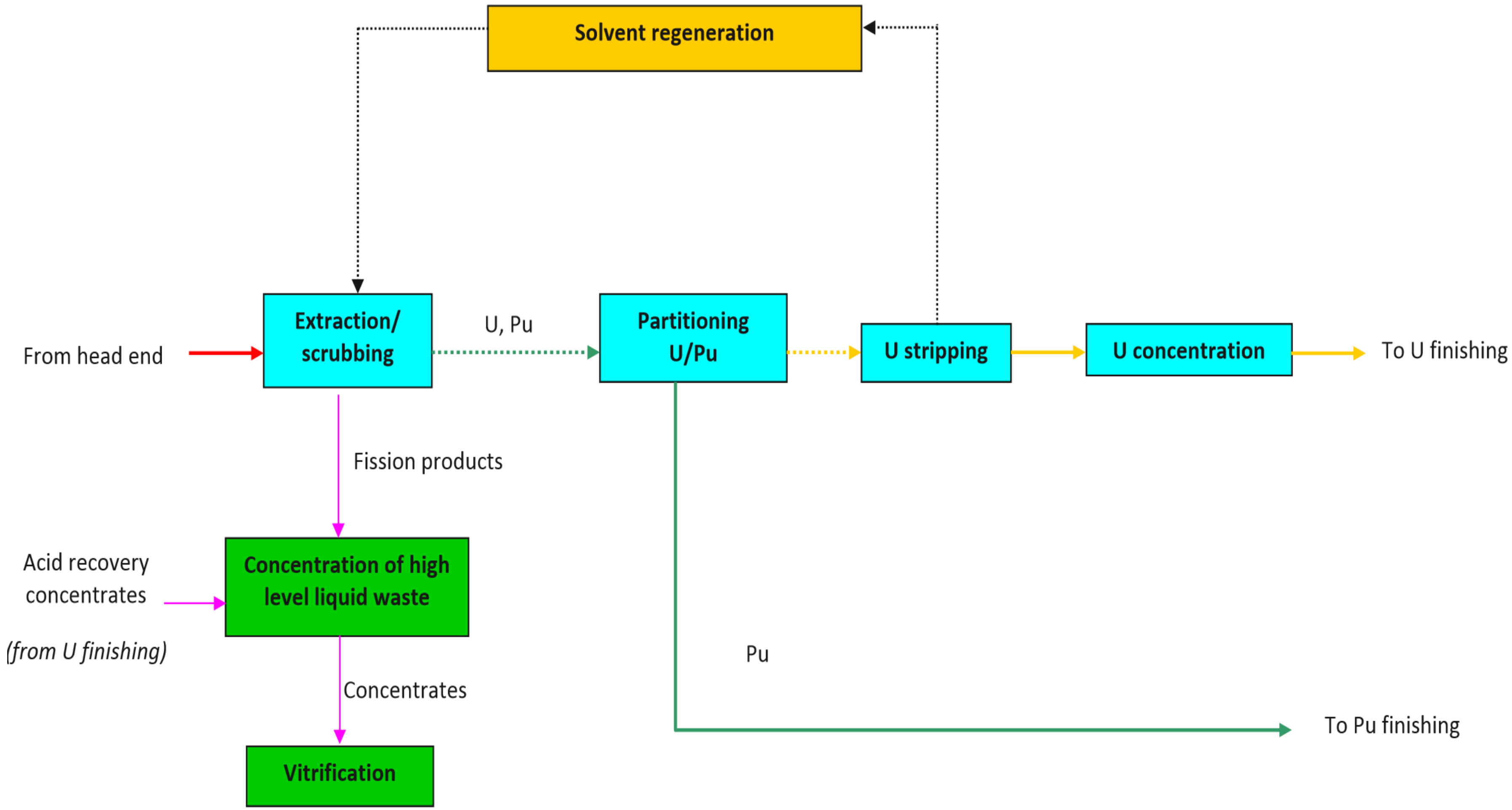

FIG. I–2. Separation of uranium and plutonium at a reprocessing facility.

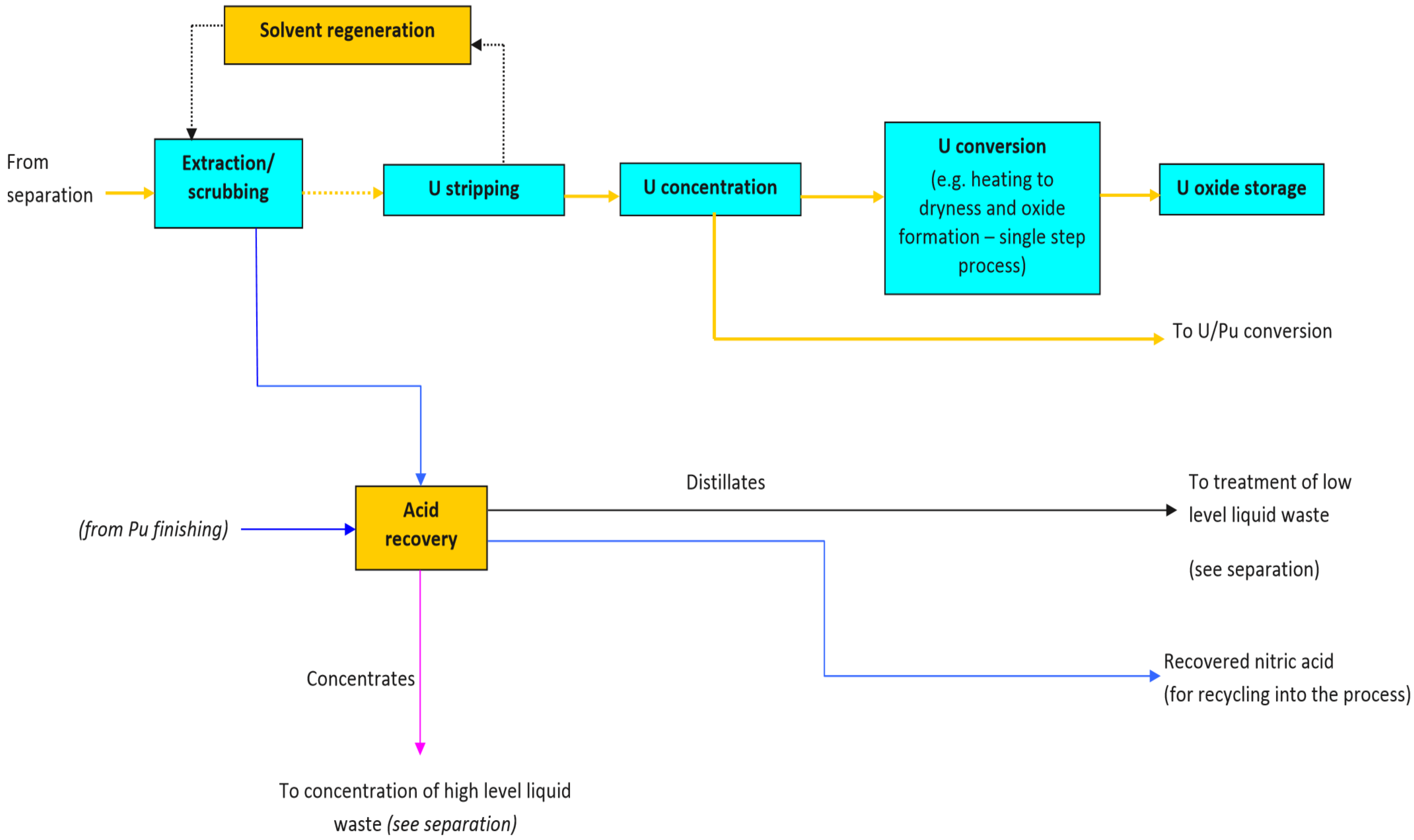

FIG. I–3. Uranium finishing at a reprocessing facility.

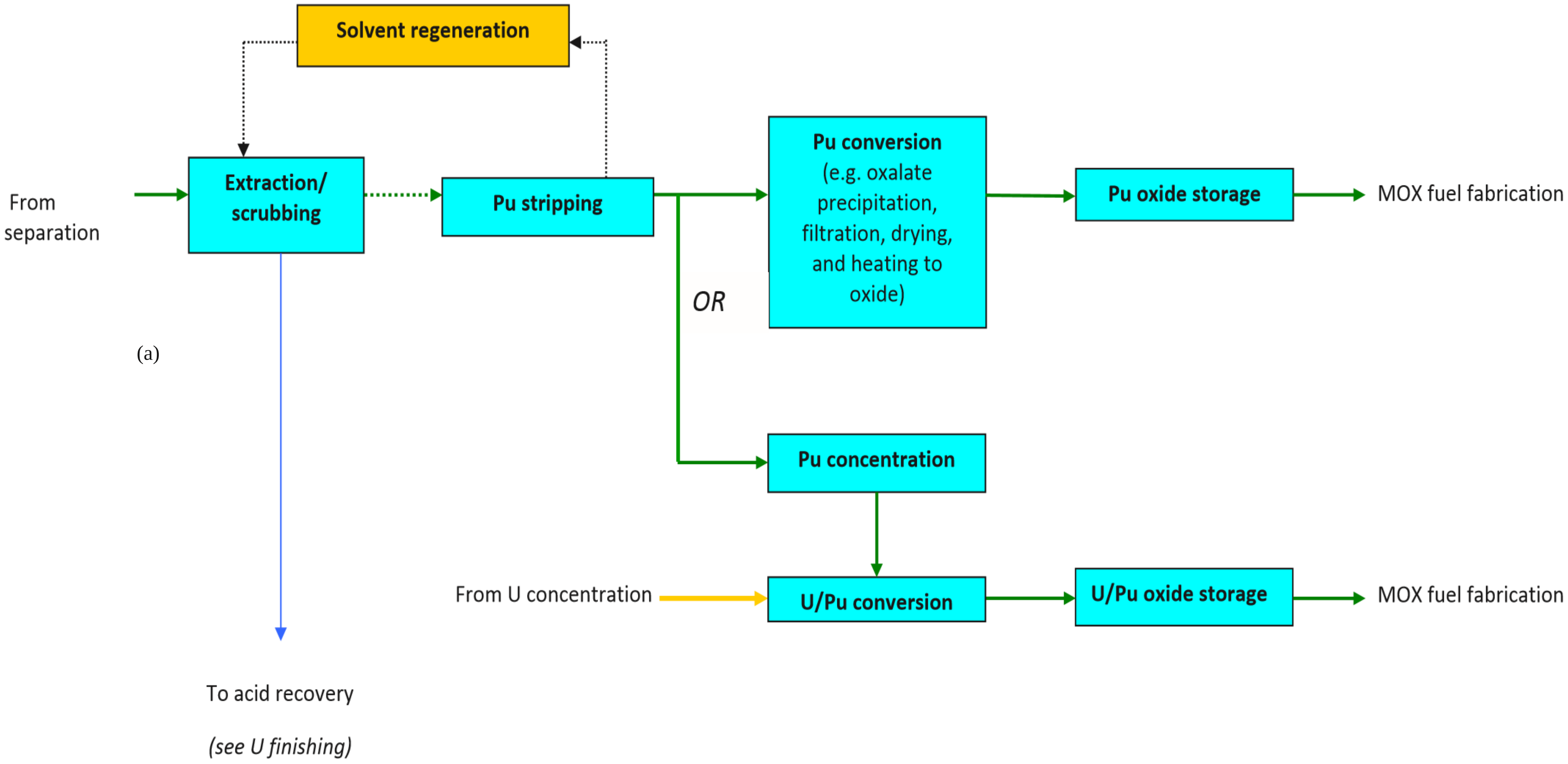

FIG. I–4. Plutonium finishing at a reprocessing facility.

Annex II

STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY AT A REPROCESSING FACILITY

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 radiation exposure.

TABLE II–1. HEAD END PROCESS AT A REPROCESSING FACILITY (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 or decladding	Shearing machine/dissolver	Zirconium fire	2c	Cleanness of the shearing machine (accumulation of material)
		Criticality event/Potential release of radioactive material	1	
Dissolution	(See the process area 'Vessel')		2	
	Measurement systems for temperature, vacuum, 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 for pressure drop
Conditioning of hulls and end pieces	Measurement system for fissile material contents in hulls	Non-acceptance by the hulls conditioning facility	1	Residual fissile material

TABLE II–1. HEAD END PROCESS AT A REPROCESSING FACILITY (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	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
	System for measurement of parameters relating to criticality control (if necessary)	Criticality event	1	Specific operational limits and conditions

Process area

TABLE II–2. SEPARATION PROCESS AT A REPROCESSING FACILITY (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
	Criticality event detection system	Criticality event (mitigation)	1	Criticality alarm system

TABLE II–2. SEPARATION PROCESS AT A REPROCESSING FACILITY (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
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
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

Process area

TABLE II–3. URANIUM PRODUCT TREATMENT PROCESS AT A REPROCESSING FACILITY (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
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
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 AT A REPROCESSING FACILITY (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

Process area

CONTRIBUTORS TO DRAFTING AND REVIEW

Buchan, A.	Sellafield Ltd, United Kingdom
Cousin, R.	Institut de Radioprotection et de Sûreté Nucléaire, France
Kubota, K.	Nuclear Regulatory Authority, Japan
Kyriazidis, G.	Commissariat à l’énergie atomique et aux énergies alternatives, France
Rodin, A.	Scientific and Engineering Centre for Nuclear and Radiation Safety, Russian Federation
Rovny, J.	International Atomic Energy Agency
Shokr, A.	International Atomic Energy Agency
Tanaka, Y.	Japan Nuclear Fuel Limited, Japan