IAEA
International Atomic Energy Agency

IAEA SAFETY STANDARDS

No. SSG-42 (Rev. 1)

for protecting people and the environment

Safety of Nuclear Fuel Reprocessing Facilities

SPECIFIC SAFETY GUIDE

IAEA SAFETY STANDARDS AND RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

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

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

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

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

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

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

RELATED PUBLICATIONS

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

Reports on safety in nuclear activities are issued as **Safety Reports**, which provide practical examples and detailed methods that can be used in support of the safety standards.

Other safety related IAEA publications are issued as **Emergency Preparedness and Response** publications, **Radiological Assessment Reports**, the International Nuclear Safety Group's **INSAG Reports**, **Technical Reports** and **TECDOCs**. The IAEA also issues reports on radiological accidents, training manuals and practical manuals, and other special safety related publications.

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

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

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

IAEA SAFETY STANDARDS SERIES No. SSG-42 (Rev. 1)

SAFETY OF NUCLEAR FUEL REPROCESSING FACILITIES

SPECIFIC SAFETY GUIDE

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FOREWORD

by Rafael Mariano Grossi
Director General

The IAEA's Statute authorizes it to "establish…standards of safety for protection of health and minimization of danger to life and property". These are standards that the IAEA must apply to its own operations, and that States can apply through their national regulations.

The IAEA started its safety standards programme in 1958 and there have been many developments since. As Director General, I am committed to ensuring that the IAEA maintains and improves upon this integrated, comprehensive and consistent set of up to date, user friendly and fit for purpose safety standards of high quality. Their proper application in the use of nuclear science and technology should offer a high level of protection for people and the environment across the world and provide the confidence necessary to allow for the ongoing use of nuclear technology for the benefit of all.

Safety is a national responsibility underpinned by a number of international conventions. The IAEA safety standards form a basis for these legal instruments and serve as a global reference to help parties meet their obligations. While safety standards are not legally binding on Member States, they are widely applied. They have become an indispensable reference point and a common denominator for the vast majority of Member States that have adopted these standards for use in national regulations to enhance safety in nuclear power generation, research reactors and fuel cycle facilities as well as in nuclear applications in medicine, industry, agriculture and research.

The IAEA safety standards are based on the practical experience of its Member States and produced through international consensus. The involvement of the members of the Safety Standards Committees, the Nuclear Security Guidance Committee and the Commission on Safety Standards is particularly important, and I am grateful to all those who contribute their knowledge and expertise to this endeavour.

The IAEA also uses these safety standards when it assists Member States through its review missions and advisory services. This helps Member States in the application of the standards and enables valuable experience and insight to be shared. Feedback from these missions and services, and lessons identified from events and experience in the use and application of the safety standards, are taken into account during their periodic revision.

I believe the IAEA safety standards and their application make an invaluable contribution to ensuring a high level of safety in the use of nuclear technology. I encourage all Member States to promote and apply these standards, and to work with the IAEA to uphold their quality now and in the future.

THE IAEA SAFETY STANDARDS

BACKGROUND

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

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

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

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

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

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

THE IAEA SAFETY STANDARDS

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

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

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

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

Safety Fundamentals

Safety Fundamentals present the fundamental safety objective and principles of protection and safety, and provide the basis for the Safety Requirements. The principles are expressed as 'must' statements.

Safety Requirements

Safety Requirements are governed by the objective and principles of the Safety Fundamentals. They establish the requirements to be met to ensure the protection of people and the environment, both now and in the future. The format and style of the Safety Requirements facilitate their use for the establishment of a national regulatory framework. Requirements are presented as 'overarching' requirements[2] in bold, followed by a number of associated requirements; all are equally important and are expressed as 'shall' statements.

Safety Guides

Safety Guides provide recommendations on how to comply with the Safety Requirements, indicating an international consensus that it is necessary to take the

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

[2] The IAEA Regulations for the Safe Transport of Radioactive Material do not include overarching requirements.

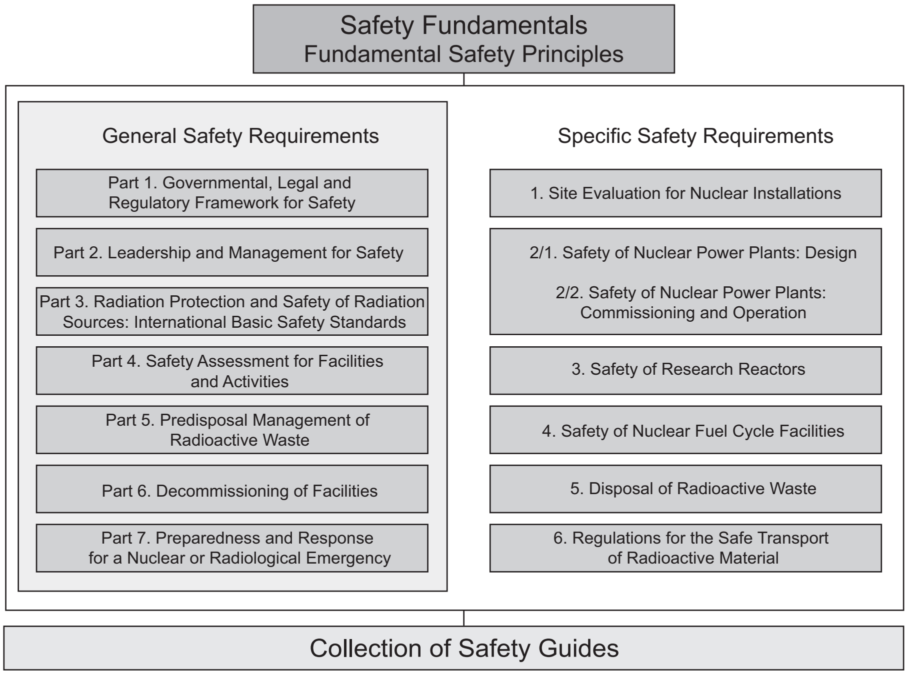

FIG. 1. The long term structure of the IAEA Safety Standards Series.

measures recommended (or alternative measures that achieve the same level of protection). Safety Guides present international good practices and, increasingly, best practices. The recommendations provided in Safety Guides are expressed as ‘should’ statements.

APPLICATION OF THE IAEA SAFETY STANDARDS

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

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

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

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

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

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

DEVELOPMENT PROCESS FOR THE IAEA SAFETY STANDARDS

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

All IAEA Member States may nominate experts for the Safety Standards Committees and may provide comments on draft standards. The membership of the Commission on Safety Standards is appointed by the Director General and includes senior governmental officials having responsibility for establishing national standards.

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

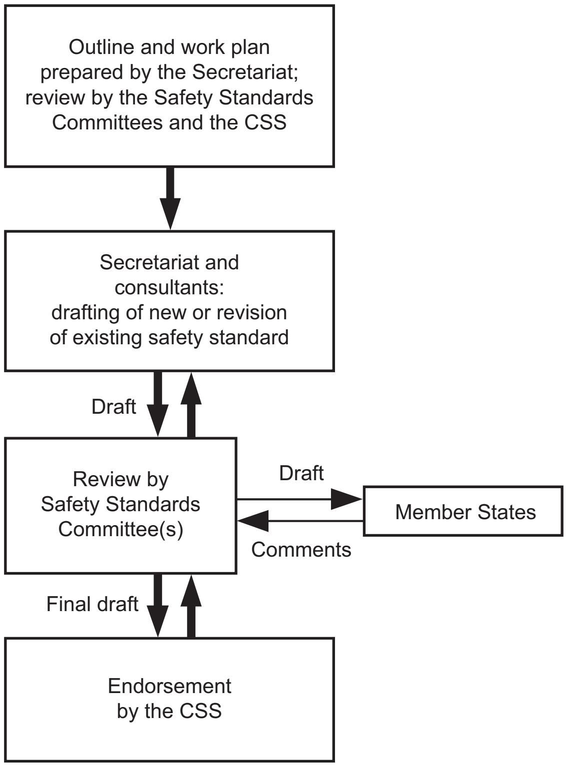

FIG. 2. The process for developing a new safety standard or revising an existing standard.

INTERACTION WITH OTHER INTERNATIONAL ORGANIZATIONS

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

INTERPRETATION OF THE TEXT

Safety related terms are to be understood as they appear in the IAEA Nuclear Safety and Security Glossary (see https://www.iaea.org/resources/publications/iaea-nuclear-safety-and-security-glossary). Otherwise, words are used with the spellings and meanings assigned to them in the latest edition of The Concise Oxford Dictionary. For Safety Guides, the English version of the text is the authoritative version.

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

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

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

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. Spent fuel, dissolved spent fuel, fission product solutions, and plutonium and other actinides and their solutions, which are all handled in a reprocessing facility, are characterized by high levels of radioactivity involving radionuclides of high radiotoxicity. Furthermore, reprocessing facilities may contain large quantities 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 and stored safely to optimize the 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. SSG-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 relevant 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.

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[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Fuel Reprocessing Facilities, IAEA Safety Standards Series No. SSG-42, IAEA, Vienna (2017).

SCOPE

1.7. Safety requirements for 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 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 that use the PUREX[3] process to reprocess fuels containing uranium and plutonium on a commercial scale. This Safety Guide does not specifically address the reprocessing of thorium from fast breeder reactors or other advanced reactor systems, or the partitioning of radionuclides other than uranium and plutonium, as there is insufficient experience with these processes and facilities at a commercial scale. However, the similarity between aqueous processes allows for the application of most of the recommendations provided in this Safety Guide, with suitable adjustments, to facilities reprocessing other types of nuclear fuel.

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

(1) The handling and short term storage of spent fuel;
(2) The dismantling, shearing[4] or decladding[5], and dissolution of spent fuel;
(3) The separation of uranium and plutonium from fission products and other transuranic actinides;
(4) The separation and purification of uranium and plutonium;
(5) The production and storage of plutonium and uranium oxides and uranyl nitrate to be used as a feed material to form ‘fresh’ uranium oxide (UO_2) or mixed oxide (UO_2/plutonium oxide (PuO_2)) fuel rods and fuel assemblies;
(6) The treatment and handling of the various waste streams.

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[2] Also referred to as ‘deconversion’.

[3] A process for separating plutonium and uranium from spent fuel and from each other.

[4] Shearing involves cutting spent fuel into short lengths to allow its dissolution inside its metallic cladding.

[5] Decladding involves removing the metallic cladding of spent fuel prior to its dissolution.

1.10. The fuel reprocessing processes covered by this Safety Guide are a mixture of chemical and mechanical processes, involving hazardous solid, liquid, gaseous and particulate (dry, airborne 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 consider 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 Requirement 24 (and paras 6.94–6.99) and Requirement 68 (and paras 9.102–9.108) of SSR-4 [1] and with the requirements established 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 reprocessing facility in this Safety Guide supplement the more detailed recommendations provided in IAEA Safety Standards Series No. SSG-27 (Rev. 1), Criticality Safety in the Handling of Fissile Material [3].

1.13. The implementation of safety requirements on the governmental, legal and regulatory framework and in relation to 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 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], and in IAEA Nuclear Security Series No. 35-G, Security During the Lifetime of a Nuclear Facility [7]. However, this Safety Guide does include recommendations on managing interfaces between safety, nuclear security and the State system of accounting for and control of nuclear material.

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 for a reprocessing facility to avoid or minimize any environmental impact of operations. Section 5 provides recommendations on safety in the design stage of a reprocessing facility, including recommendations on the safety analysis for operational states and accident conditions and on radioactive waste management 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 provides recommendations on safety in the operation of a reprocessing facility, including recommendations on the management of operations; maintenance and periodic testing; control of modifications; criticality control; radiation protection; fire, chemical and 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 (SSCs) 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 quantities of fissile material, radioactive material and other hazardous materials are present, often in dispersible forms (e.g. solutions, powders, 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 criticality, loss of confinement, radioactive contamination, radiation exposure (both internal exposure and external exposure), fire, flooding, earthquake, loss of cooling, chemical hazards and explosion hazards.

2.2. In normal operation, a reprocessing facility generates 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 comply with authorized limits and minimize the impact of these effluents on the public and the environment (see Requirement 25 and 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 are compatible with their reuse in the facility, which may involve the generation of additional effluents.

2.3. 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]). At a minimum, operating organizations are required to comply with the limits on discharges authorized by the regulatory body (see para. 3.123 and Requirement 31 of IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [8]) and to optimize protection and safety (see para. 6.100 of SSR-4 [1]). 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 [9], and GSG-9, Regulatory Control of Radioactive Discharges to the Environment [10].

2.4. When periodic safety reviews are being performed, the records of previous discharges should be examined to confirm that the existing engineering provisions and operating procedures 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 to determine if improvements might be made to the facility.

2.5. In reprocessing facilities, actinides and fission products in different chemical and aggregate forms are processed. Factors relevant to 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, nature and quantities of process chemicals with a potential for release through the barriers, and their chemical reactions (including radiation chemical reactions).
(c) The wide range and nature of fissile material in contact with water in a soluble form and potentially concentrated in evaporation and precipitation processes (i.e. producing a 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 (i.e. making it necessary to provide heat removal by active safety systems).
(e) The complexity of the processes, which might lead to changes in facility safety during or after modification of equipment.
(f) The presence of highly radioactive media, limited access and limited possibility to perform manual operations, posing challenges to monitoring and maintenance of items important to safety.
(g) The wide range of dispersible or difficult to control radioactive material present, including the following:
    (i) Solids, such as powders;
    (ii) Aqueous and organic liquids;
    (iii) Gases and volatile species;
    (iv) Particulates dispersed in gases and liquids.

2.6. The specific characteristics of 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 the 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, proven process technologies and engineering practices are required to be used (see Requirement 12 and para. 6.31 of SSR-4 [1]). Engineering solutions adopted to ensure the safety of the reprocessing facility are required be of high quality, proven by previous operating experience or by adequate testing, research and development and experience with operating prototypes (see paras 6.31–6.35 of SSR-4 [1]). These practices should be applied in all stages of the lifetime of the reprocessing facility, including design, construction, operation (including when conducting modifications, upgrades or modernization), and preparation for the decommissioning of the facility.

2.8. Owing to the anticipated long lifetime of an industrial scale reprocessing facility, particular consideration is required to be given to the potential for ageing (and thus degradation) of SSCs important to safety (see Requirement 32 of SSR-4 [1]). Consideration of ageing should take into account the specific mechanical, thermal, chemical, nuclear and radiological conditions of the processes in use. It should also include the impacts of obsolescence, especially for components that are difficult or impracticable to replace. In selecting and designing SSCs 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]). An ageing management programme is required to be developed and implemented to detect and monitor ageing and degradation, as well as erosion and corrosion processes (see Requirement 60 of SSR-4 [1]). The ageing management programme should include provisions for monitoring, inspection, sampling, surveillance and testing, as well as specific design provisions and equipment for inaccessible SSCs important to safety. To achieve the expected 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 systems 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 a management system that provides for quality assurance and quality control, during all stages of the lifetime of the facility. Inspection and testing should be performed against unambiguous, established performance standards and objectives.

2.10. A combination of passive design features and active design features is generally more reliable than administrative controls (see para. 6.68 of SSR-4 [1]) and is 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 (generally a shutdown state), following an anticipated operational occurrence or accident conditions.

2.11. When administrative controls are considered as an option at a reprocessing facility, the criteria for selection of an automated system versus administrative control should be based on the availability of adequate time for operating personnel to respond (grace period) and on consideration of the risks and hazards associated with a failure to act (see also para. 6.21(c) of SSR-4 [1]). Where operating personnel would need to select an optimum response from a number of possible options, consideration should be given to providing an automatic safety action and relying on passive design features. These features should be designed to limit the consequences for safety in the event that operating personnel fail to take sufficient or timely action, by providing additional defence in depth.

2.12. In addition to the SSCs important to safety identified in the safety analysis, instrumentation and control systems used in normal operation are also relevant to the overall safety of a 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 explicitly identified as important to safety. Operational systems that are classified as SSCs important to safety should be of high quality and reliability. Adequate and reliable controls and appropriate instrumentation should be provided to maintain process parameters within specified ranges and to initiate automatic safety actions, where necessary. Where computers or programmable devices are used in instrumentation and control systems, there should be evidence that the hardware and software are designed, manufactured, installed and tested appropriately, in accordance with the management system, including computer security, and verification and validation of the software (see also Requirement 45 of SSR-4 [1]).

2.13. A reprocessing facility is required to have alarm systems to enable prompt response to an emergency (see Requirement 47 of SSR-4 [1]). These systems should be designed to initiate full or partial facility evacuation in the event of an emergency (e.g. criticality event, fire, high radiation levels).

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]). At a minimum, this consideration should apply to controls, alarms and indicators relating to SSCs important to safety and to operational limits and conditions.

2.15. Support systems[6] are necessary to ensure that the safety systems of the reprocessing facility remain operational at all times, and to provide services to SSCs important to safety. Continuity of service should be achieved by means of robust design, including sufficient independent, 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. The consequences of loss of

[6] Support systems include the SSCs that provide services such as the cooling, lubrication and energy supply required by the safety systems (e.g. cooling water, compressed air).

motive power to devices such as valves should be assessed, and the items should be designed to be fail-safe, wherever possible.

2.16. All situations (including anticipated operational occurrences and accident conditions) that necessitate a shutdown or partial shutdown of the reprocessing facility or process and putting all or part of 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, on the basis of 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 criticality sequences, and natural or human induced internal or external events. The subsequent recovery sequences — for example, the managed recovery or reduction of fissile material in a multistage contactor[7] — should be similarly analysed, defined in procedures and executed, when necessary, in a timely manner.

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, buffer tanks or vessels, or from 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) Instrumentation and control systems important to safety, including for radiation monitoring systems, static and dynamic confinement, and utility supply systems important for safety;
(e) Systems ensuring the confinement function;
(f) Criticality detection and alarm systems.

2.18. Reprocessing facilities are required to be designed so as to ensure the confinement of radioactive materials and associated harmful materials (see Requirements 7 and 35 of SSR-4 [1]). This confinement may involve static and dynamic barriers, level measurement systems within tanks and vessels, batch transfer accountancy systems to ensure that transfers made between vessels are completed, and systems to detect and recover materials lost from primary

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

containment (e.g. cell sumps, liquid transfer systems) (see also paras 5.23–5.46 of this Safety Guide).

2.19. Reprocessing facilities may be designed to operate on a batch basis, with discrete processes being undertaken in separate cells within a larger facility, or even in 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 transfers of radioactive material are undertaken safely and that movement between separate stages is controlled.

3. MANAGEMENT SYSTEM FOR NUCLEAR FUEL REPROCESSING FACILITIES

3.1. A management system that integrates the safety, health, environmental, security, quality, human and organizational factor, societal, and economic elements is required to be implemented by the operating organization (see 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 reprocessing facility.

3.2. Requirements for the management system are established in IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [11]. Associated recommendations are provided in IAEA Safety Standards Series Nos GS-G-3.1, Application of the Management System for Facilities and Activities [12]; GS-G-3.5, The Management System for Nuclear Installations [13]; GSG-16, Leadership, Management and Culture for Safety in Radioactive Waste Management [14]; and TS-G-1.4, The Management System for the Safe Transport of Radioactive Material [15].

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 [11]). 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 as well as interfaces with other areas, such as those relating to nuclear security and to the State system of accounting for, and control of, nuclear material. Activities with such interfaces should be identified in the management system and should be coordinated, planned and conducted to ensure effective communication and clear assignment of responsibilities. Communications regarding safety and nuclear security should ensure that confidentiality of information is maintained. This includes communications in relation to the system of nuclear material accounting and control, for which information security should be coordinated in a manner ensuring that safety and security measures are not compromised. Potential conflicts between the transparency of information relating to safety matters and the protection of information for nuclear security reasons are required to be addressed (see para. 4.10 of GSR Part 2 [11]).

3.4. In determining how the requirements of the management system for the 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 [11]).

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 [11]) and should address all aspects of safety (including radiation safety, criticality safety, chemical safety, fire safety and industrial safety). Special consideration should be given to all processes covered by the management system that are associated with handling plutonium, including (where appropriate) transition to hot commissioning and assignment of 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. These areas may be summarized as follows:

(1) 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.

(2) Resource management includes the measures necessary to ensure that the resources essential to the implementation of the safety policy and the achievement of the safety objectives of the operating organization are identified and made available.
(3) Process implementation includes the activities and tasks necessary to achieve the safety goals of the organization.
(4) Measurement, assessment, evaluation and improvement provide 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 the safety of a reprocessing facility, including criticality safety, rests with the operating organization (see Requirement 2 of SSR-4 [1]). The senior management of a reprocessing facility is required to demonstrate leadership for and commitment to safety (see para. 3.1 of GSR Part 2 [11]). In accordance with para. 4.11 of GSR Part 2 [11], the management system for a reprocessing facility is required to clearly specify the organizational structures, processes, responsibilities, accountabilities, levels of authority and interfaces within the organization and with external organizations.

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 [11]). The documentation should also cover other management measures, including planning, scheduling and resource allocation (see also para. 9.9 of SSR-4 [1]).

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

> "[T]he 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 of a reprocessing facility is required to ensure that safety assessments and analyses are conducted, documented and updated (see Requirement 5 of SSR-4 [1]). Requirements for safety assessment are established in IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), Safety Assessment for Facilities and Activities [16].

3.11. The operating organization of a reprocessing facility is required to audit all safety related matters on a regular basis (see paras 4.2(d) and 4.23 of SSR-4 [1]). This includes examination of the arrangements for emergency preparedness and response at the facility, such as emergency communications and evacuation routes (including signage). Checks should be performed by the personnel who performed the criticality safety analyses 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 these 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 the reprocessing facility (see Requirement 9 of GSR Part 2 [11]). The senior management is also required to ensure that suitable training is conducted (see para. 4.23 of GSR Part 2 [11]). The management of the operating organization should also have frequent personal contact with personnel, including observing work in progress.

3.13. Senior management is required to determine the minimum staffing of the facility[8] (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**

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[8] Including staffing of the reprocessing facility for situations in which a large number of personnel might be unavailable, such as during an epidemic or other event affecting an area where personnel live.

qualified and competent persons.” The operating organization is required to ensure that personnel receive training and refresher training at suitable intervals, appropriate to their level of responsibility (see paras 9.38–9.48 of SSR-4 [1]). In particular, personnel involved in activities with fissile material (both uranium and plutonium), with radioactive material including waste, or 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 [11] states that “**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.**” The management system for a reprocessing facility is required to include arrangements for procurement (see paras 4.33–4.36 of GSR Part 2 [11]). The operating organization is also required to ensure that suppliers of items and resources important to safety have an effective management system (see para. 4.16(b) of SSR-4 [1]). To meet these requirements, the operating organization should conduct audits of the management systems of suppliers.

PROCESS IMPLEMENTATION FOR THE MANAGEMENT SYSTEM FOR A REPROCESSING FACILITY

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

> “**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.**”

3.17. 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 the parameters at the reprocessing facility that are intended to be controlled and the performance criteria that should be fulfilled.

3.18. The management system of a reprocessing facility should include management of criticality safety. Further recommendations on the management system for criticality safety are provided in paras 2.17–2.40 of SSG-27 (Rev. 1) [3].

3.19. Any proposed modification to an existing reprocessing facility, or any proposed new activity, is required to be assessed in terms of its implications for existing safety measures 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 paras 9.57(d), 9.57(h) and 9.59 of SSR-4 [1]). The documentation for the facility or activity is required to be updated to reflect modifications (see paras 9.57(f) and 9.57(g) of SSR-4 [1]). All relevant operating personnel, including supervisors, should receive adequate training on the modifications.

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

3.20. Requirement 13 of GSR Part 2 [11] states that "**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.**"

3.21. The audits performed by the operating organization (see para. 3.11), as well as proper control of modifications (see para. 3.19), are particularly important for ensuring the safety of the reprocessing facility. The results of audits are required to be evaluated by the operating organization and corrective actions are required to be taken where necessary (see para. 4.2(d) of SSR-4 [1]).

3.22. Deviation from operational limits and conditions, deviations from operating procedures, and unforeseen changes in process conditions that could affect safety are required to be reported and promptly investigated by the operating organization of the reprocessing facility, and the operating organization is required to notify 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 of the 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.

3.23. 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 [17].

VERIFICATION OF SAFETY AT A REPROCESSING FACILITY

3.24. The safety of a reprocessing facility is required to be verified by means of comprehensive safety assessment and to be systematically assessed throughout the lifetime of the facility, for example, by periodic safety reviews (see Requirement 5 of SSR-4 [1]). The operating organization should establish a process for periodic safety reviews as part of the management system.

3.25. 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 persons, who are suitably qualified and experienced in relevant areas, including human factors, criticality safety and radiation protection. Such persons should be available 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 [18], 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 [19].

4.2. The site evaluation process for a reprocessing facility will depend on a large number of variables. At the earliest stage of planning 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; all significant hazards are required to be evaluated and the design basis for the facility is required to be 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 operational states and accident conditions is required to be evaluated (see Requirement 12 of SSR-1 [18]).

4.3. The scope of the site evaluation for a reprocessing facility is established in Requirement 3 of SSR-1 [18] and paras 5.1–5.14 of SSR-4 [1] and should also reflect the hazards described 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 cope with 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 fulfil 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 safe and secure on-site and off-site movement and transport of nuclear fuel and other radioactive material and chemicals (including products and radioactive waste, as 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 [20], 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 personnel and, as appropriate, the surrounding population from affected areas.

(d) External hazards that might particularly affect parts of a reprocessing facility, including the following:
   (i) Flooding and meteorological hazards with potential to cause criticality, water penetration through openings in static barriers, or damage to vulnerable items such as gloveboxes;
   (ii) Earthquakes, possibly affecting containment structures for spent fuel, highly radioactive 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 [18] and section 5 of SSR-4 [1] establish requirements for site evaluation for a new reprocessing facility as well as for existing facilities, to be applied in accordance with 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 periodic review of all identified natural and human induced external hazards, and their credible combinations, and of the site conditions in the design basis for the facility;
(c) The identification of and the need to take account of all foreseeable variations in the site characteristics (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 characteristics and the development of scientific knowledge and evaluation methodologies and assumptions;
(e) Consideration of future changes to site characteristics 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 [18]). Also, in accordance with Requirement 25 and paras 6.1–6.7 of SSR-1 [18], the dispersion in air and water of any radioactive material released from a reprocessing facility is 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]). Owing to 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 (see para. 5.2(d) and Requirement 75 of SSR-4 [1]). The selection of a site should take into account both safety and nuclear security aspects, to ensure that they do not compromise one another, and should be facilitated by experts from both safety and security.

4.8. Even if an existing nuclear site is used for a new 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 [19]).

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 of the reasons behind those decisions.

4.10. The site characteristics are required to be reviewed periodically for their adequacy and continued applicability during the lifetime of a reprocessing facility (see paras 5.13 and 5.14 of SSR-4 [1]). Any changes to these characteristics that might require a revision of the safety assessment — including an increase in the reprocessing capacity beyond the original design basis — should be identified and evaluated.

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 the expected long service life of a reprocessing facility, the substantial inventory of high toxicity radioactive material, the potential for criticality, and the use of aggressive physical and chemical processes, the design of the facility should be based on the most rigorous application of the safety requirements (i.e. as are necessary for a high hazard facility).

5.3. At a reprocessing facility, particular consideration should be given to the reuse and recycling of materials to reduce discharges and waste generation (see also para. 2.2).

5.4. Requirements for the confinement of 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 by 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 [8]).

5.5. Requirements for heat removal are established in Requirement 39 and paras 6.157–6.159 of SSR-4 [1]. Owing to 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 (using passive design features, if possible) in accident conditions.

5.6. Requirements relating to 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 attention should be given to the provision of an adequate diluting airflow, where applicable, or to alternative provisions for ensuring the application of the concept of defence in depth (e.g. catalytic recombiners). If possible, these provisions should function without the need for ventilation fans or compressors, including in accident conditions. See also paras 5.18–5.22 of this Safety Guide.

5.7. 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 and/or gamma 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]).

5.8. Requirements for maintaining subcriticality at a reprocessing facility are established in Requirement 38 and paras 6.138–6.156 of SSR-4 [1]. Recommendations on ensuring subcriticality in the handling of fissile material are provided in SSG-27 (Rev. 1) [3].

Design basis and safety analysis for a reprocessing facility

5.9. 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 a conservative methodology and for which releases of radioactive material are kept within acceptable limits (see Requirement 17 of SSR-4 [1]).

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

5.11. The specification of the design basis will depend on the potential radiological hazard associated with the reprocessing 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, external hazards and their credible combinations selected in the site evaluation phase and associated with the design basis for the facility. These hazards might 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 to SSR-4 [1].

5.12. The specification for the design basis should take account of events that might be the consequence of other events, such as a flood following an earthquake, or multiple events initiated by an external event, such as fire or multiple leaks within the facility caused by an earthquake (see para. 6.61 of SSR-4 [1]).

5.13. Reprocessing facilities are characterized by a wide diversity of radioactive material and chemicals 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 within the reprocessing facility should be assessed (see paras 6.65 and 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

5.14. Paragraph 6.21 of SSR-4 [1] states:

> "The design of the nuclear fuel cycle facility:
>
> …….
>
> (e) 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 to this Safety Guide presents examples of SSCs important to safety and representative events that could challenge the associated safety functions.

Cooling of radioactive material at a reprocessing facility

5.15. At a reprocessing facility, 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 (e.g. melting, concentration, crystallization, changes in water content) relevant to radiological or criticality safety;
(e) Transition to autocatalytic chemical reactions (e.g. the formation of potentially explosive red oil) or other accelerated chemical reactions and fires;

(f) Destruction of SSCs that form part of the containment barriers;
(g) Degradation of shielding;
(h) Degradation of neutron absorbers;
(i) Overcooling of solutions;
(j) Degradation of process instrumentation.

5.16. 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 radioactive liquid waste[9] and PuO_2 containers (see paras 6.157 and 6.158 of SSR-4 [1]). Cooling may also be used to control corrosion rates in aggressive environments.

5.17. 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 explosive or flammable materials at a reprocessing facility

5.18. Requirement 40 of SSR-4 [1] states: "**The design shall include features to control reactive, flammable, corrosive and pyrophoric materials and mixtures used or produced in the processing of radioactive material.**"

5.19. Applicable 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 for a reprocessing facility, to prevent the buildup of unstable products and exothermic chemical reactions that might result in explosion and loss of confinement. The design is also 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, hydrazoic acid (HN_3) in extraction cycles, ion exchange resins). See also Requirement 41 and paras 6.162–6.167 of SSR-4 [1].

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

5.20. In a reprocessing facility, the production and buildup of degradation products might result from radiolysis in water (including cooling water) or in organic materials, or from chemical reactions (e.g. interaction of radioactive metals with water). Such products may be flammable or explosive (e.g. hydrogen, methane or other hydrocarbons, organic nitrate or nitrites (red oils), peroxides) or corrosive (e.g. chlorine, hydrogen peroxide) and might damage containment barriers. As far as practicable, dilution systems using air or inert gas should be provided to prevent the formation of explosive gaseous mixtures resulting from radiolysis in vessels and the subsequent loss of confinement. For product containers and other systems, the design should take into account the potential for corrosion and gas production that might lead to pressurization of the container.

5.21. Pyrophoric materials (e.g. particles from fuel shearing or cladding removal) can cause fire or explosion. The design of the facility should therefore include measures to avoid the unexpected accumulation of such materials and should provide an inert environment, as necessary (see paras 6.160 and 6.161 of SSR-4 [1]).

5.22. 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 of a reprocessing facility:

(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 the cell sump;
(f) The potential for any inactive services (e.g. cooling water) 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

5.23. To meet Requirement 35 of SSR-4 [1] in a reprocessing facility, multiple barriers providing static and dynamic confinement should be provided (as determined by the safety analysis and considering the application of a graded approach), in accordance with the concept of defence in depth. The first static barrier in a reprocessing facility 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 gloveboxes. The third static barrier is the building itself. The design of the static containment system should take into account openings between the different confinement zones (e.g. doors, through-wall drive mechanisms, sampling instrument 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.

5.24. 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 between all static barriers inside the building. The dynamic containment systems 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 applicable:

(a) Operational states and accident conditions;
(b) Maintenance that could cause localized changes to conditions (e.g. opening access doors, removing access panels);
(c) Where more than one ventilation system is used, measures to ensure 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 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 making conservative assumptions regarding the meteorological conditions.

5.25. The reprocessing facility should be designed to promptly detect and retain any leakage of liquids (including small leaks) from process equipment, vessels and pipes and to recover the volume of liquid to the primary containment. This is important for both design and operation, especially 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.

5.26. Particular consideration should be given to the design of equipment in those parts of the reprocessing facility that handle solids (i.e. powders) with radioactive, fissile or 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. Care should be taken to ensure that this equipment is based on well proven designs and is subject to rigorous qualification, and the effectiveness of the design solutions should be rigorously tested during commissioning. As far as practicable, considering both the risk and the optimization of protection and safety, the need for operator intervention should be avoided.

5.27. Paragraph 6.126 of SSR-4 [1] states:

> "Dynamic containment systems in nuclear fuel cycle facilities shall be designed with an appropriately sized ventilation system in areas that have been identified as having significant potential for concentrations of airborne hazardous material in all facility states."

The ventilation system should include, at a minimum, both ventilation for the building (cells and rooms) and ventilation for process equipment (e.g. vessels contained in a cell). The ventilation system may also include an off-gas cleaning system.

5.28. The assessment and design of the building's ventilation system, including redundant subsystems[10], filtration equipment and other discharge control equipment, should take account of the following:

(a) The type and design of static barriers (e.g. gloveboxes, cells, the building);
(b) The classification of areas in accordance with the radiological hazards that they contain;
(c) The nature of potential airborne contamination (i.e. the predicted or actual radionuclides or chemicals, and levels of airborne contamination);
(d) The levels of surface contamination and the risk of additional contamination;
(e) Requirements for maintenance.

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

5.29. The process ventilation system creates low pressure and collects and then treats most of the radioactive vapours, gases and particulates generated by the processes. 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 of the reprocessing facility.

5.30. All filtration stages of the ventilation systems that need testing should be designed in accordance with relevant standards, such as those of the International Organization for Standardization and relevant national requirements.

5.31. For the parts of the process involving powders, primary filters should be located as close as practicable to the source of contamination (e.g. near gloveboxes) to minimize the potential buildup of powders in ventilation ducts. Particular care should be taken to avoid accumulations of fissile material in powder form at junctions and connections in ventilation ducts of less favourable geometry.

5.32. 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 so that, in the case of a loss of electrical power, the standby ventilation system will begin operation within a specified period. 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 be used to define an operational limit or condition. Local monitoring and alarm systems should be installed to alert operating personnel to system malfunctions that result in high or low flows or differential pressures.

5.33. When indicated by the safety assessment, alarm systems should be installed to alert operating personnel to system malfunctions resulting in high or low differential pressures (e.g. near the gloveboxes).

5.34. To meet Requirement 22 of SSR-4 [1] in a reprocessing facility, fire dampers should be installed in ventilation ducts between areas separated by fire barriers to prevent the propagation of a fire through ventilation ducts and to limit the propagation of fire products through the ventilation system.

Radiation protection of workers

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

5.36. In a reprocessing facility, the static barriers (see paras 5.23 and 5.24) normally protect workers from internal exposure and external exposure. The design of such barriers should be specified to ensure their integrity and effectiveness and, where appropriate, to facilitate maintenance. The design specifications of such barriers should include, for example, weld specifications, selection of materials, leaktightness (including specifications for seals for electrical and mechanical penetrations) and the ability to withstand seismic loads.

5.37. For items that need to be regularly maintained or accessed (e.g. sampling stations, pumps), consideration should be given to installing them in bulges[11] or gloveboxes adjacent to the process cells where they are needed, depending on 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 (e.g. by short sample lines) and the generation of additional waste at decommissioning.

5.38. Where readily dispersible radioactive material is processed and a loss of containment with the potential for contamination, and hence internal exposure, is a significant risk, gloveboxes are often the preferred design solution. Seals on glovebox windows should be capable of being tested for leaktightness in operation, and the gloves should be replaceable without breaking containment. A negative pressure should be maintained inside the glovebox. See also paras 6.108, 6.174 and 9.48 of SSR-4 [1].

5.39. For normal operation of a reprocessing facility, the need for the use of respiratory protective equipment should be minimized through careful design of the static and dynamic containment systems 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 and 9.101 of SSR-4 [1]). Careful consideration should also be given to the need to distinguish airborne naturally occurring radionuclides (e.g. radon) from artificial radionuclides.

5.40. The design of a reprocessing facility is required to include equipment for real time monitoring of airborne radioactive material (see para. 6.120 of SSR-4 [1]).

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[11] 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 container via a shielded docking port.

The system design and the location of monitoring points should be chosen with account taken of the following:

(a) The most likely locations of workers and areas where radioactive material is likely to be airborne;
(b) Airflows and air movement within the facility;
(c) Evacuation zoning and evacuation routes;
(d) The use of mobile monitoring equipment for temporarily controlled areas (e.g. for maintenance).

5.41. To avoid the inadvertent spread of contamination within the reprocessing facility, control points with personnel contamination monitoring equipment (e.g. for exposed skin and clothing) should be located at the exit airlocks and barriers around areas that could be contaminated (see para. 6.121 of SSR-4 [1]).

5.42. As far as practicable, tools and equipment should not be transferred through airlocks or across barriers. When such transfers are unavoidable, the transferred items should be monitored for contamination. Consideration should be given in the design of a reprocessing facility 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.

Radiation protection of the public and protection of the environment

5.43. Paragraph 3.9 of GSR Part 3 [8] states:

> "Any person or organization applying for authorization:
>
> …….
>
> (e) 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 [21].

5.44. To the extent prescribed by the safety analysis, 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 that cannot be filtered should be controlled by appropriate engineered measures designed to retain, as far as practicable, any radioactive material within the system.

5.45. The design of a reprocessing facility is required to ensure that radioactive discharges comply with authorized limits and ensure optimization of protection and safety (see Requirement 25 and para. 6.101 of SSR-4 [1]). The design should provide measures for the continuous monitoring and control of discharges from the stack exhaust(s) and for monitoring of the environment around the facility (see also paras 6.102 and 6.104 of SSR-4 [1] and Requirements 14 and 32 of GSR Part 3 [8]).

5.46. 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 the loss of any containment barrier (e.g. by detection of airborne activity, detection of liquid levels, and sampling in cell sumps[12] and collection vessels).

Protection against external exposure at a reprocessing facility

5.47. The aims of protection against external radiation exposure are to ensure that exposures are below the dose limits established in schedule III of GSR Part 3 [8] and to optimize protection and safety (see paras 2.7 and 6.6 of SSR-4 [1]) through the 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 through the use of temporary shielding.
(c) Distancing the radiation source from site personnel (e.g. by means of workstation positioning and remotely controlled operation).
(d) Limiting the exposure time of site personnel (e.g. by means of automated operation and alarm dosimeters).

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[12] 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.

(e) Controlling access to areas where there is a risk of external exposure.
(f) Using personal protective equipment (e.g. torso shields, organ shields). For normal operation, the need for personal protective equipment is required to be minimized through careful design (see para. 3.93 of GSR Part 3 [8]).

5.48. Optimization of protection and safety in the design of a reprocessing facility should 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.

5.49. 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 lower levels of activity, a combination of (a) limiting the magnitude of the radiation source using shielding and (b) restricting the exposure time should be considered as a means of protecting site personnel.

5.50. The need for maintenance, including inspection and testing activities, is required to be given special attention in the design of equipment installed in cells containing high levels of radioactivity, 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 operations where possible (e.g. using remote handling tools or manipulators).
(b) For transfers of liquids, non-mechanical means (e.g. air lift or jet lift with disentrainment capabilities[13], 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[14]).

5.51. The inventories of radioactive material used in calculations for the design and safety assessment of a reprocessing facility should take into account the deposition of material inside pipes and equipment, including processed radioactive

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[13] 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.

[14] Such flasks are sometimes referred to as ‘mobile equipment replacement casks’.

material and decay products. Examples of such deposits include particulates and coatings[15] of radioactive material within pipes (especially sections containing highly radioactive material) and gloveboxes (which might contain deposits of americium, for example). 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.

5.52. In a reprocessing facility, process control relies in part on analytical data from samples. To minimize occupational exposure, automatic and remote operation should be preferred for sampling devices, for the sample transfer network to the laboratories and for analytical laboratories (see also paras 6.130 and 6.199 of SSR-4 [1]).

5.53. Paragraph 6.132 of SSR-4 [1] states that "Means of monitoring radiation levels shall be provided so that any abnormal conditions would be detected in a timely manner and personnel may be evacuated." Depending on the results of the safety assessment, the monitoring system for radiation protection in a reprocessing facility should consist principally of the following:

(a) Fixed area monitors (for gamma and neutron radiation) and stationary air samplers (for beta and gamma activity, and for alpha activity) to monitor air for purposes of access and/or evacuation;
(b) Mobile area monitors (for gamma and neutron radiation) and mobile air samplers (for beta and gamma activity, and for alpha activity) to monitor air for purposes of personnel protection and evacuation during maintenance and at barriers between normal access areas and controlled areas;
(c) Personal dosimeters consistent with the types of radiation present in the facility.

Prevention of criticality at a reprocessing facility

5.54. Prevention of criticality is an important topic, with various aspects to be considered during the design and operation of a reprocessing facility. 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 (Rev. 1) [3].

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[15] The phenomenon of such deposition is called 'plate-out' in some States.

5.55. The criticality safety analysis should demonstrate that the design of equipment and the related safety measures are in accordance with Requirement 38 of SSR-4 [1]. 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 fissile material and of all other materials with which it is associated. The calculated value of k_{eff} (including all uncertainties and biases) should be compared with the value specified by the design limit, and actions should then be taken to maintain the value of k_{eff} under this limit (i.e. to define controlled parameters and provisions to maintain the values of these controlled parameters in the subcritical domain). Safety margins should be derived and applied in accordance with paras 2.8–2.12 of SSG-27 (Rev. 1) [3].

5.56. 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."

5.57. Any 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 of the reprocessing facility.

5.58. When indicated 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 or the avoidance of any permanent physical connection between units containing reagents and 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 a loop into the equipment).

5.59. 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/or by concentration control. Criticality safety analyses should consider any potential leakage, including leakage from or into cooling or heating loops. The design should consider the need for cooling or heating loops to meet subcritical design requirements.

5.60. The overall design should include provisions for any potential leakage to be transferred to a criticality safe containment. These provisions should include a drain or 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 then 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 video surveillance and adequate lighting.

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

5.62. When indicated by the 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.

5.63. For any process 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]).

5.64. Requirements for criticality detection and alarm systems are established in paras 6.149, 6.172 and 6.173 of SSR-4 [1]. The areas in a reprocessing facility containing fissile material for which criticality detection and alarm systems are necessary to initiate immediate evacuation[16] should be defined in accordance with the layout of the facility, the process being undertaken in the area, the criticality safety analysis and regulatory requirements.

5.65. The need for additional shielding, remote operation and other design measures to mitigate the consequences of a criticality accident, if one should

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

occur, should be assessed in terms of the application of the concept of defence in depth, as described in paras 6.19–6.27 of SSR-4 [1].

POSTULATED INITIATING EVENTS FOR A REPROCESSING FACILITY

5.66. In accordance with Requirement 19 and paras 6.1 and 6.60–6.76 of SSR-4 [1], postulated initiating events from the list of internal hazards and external hazards for a reprocessing facility, and credible combinations thereof, are required to be identified for detailed further analysis.

Internal hazards at a reprocessing facility

5.67. The design of a reprocessing facility is required to take into account the nature and severity of internal hazards (see Requirement 15, paras 6.43–6.48 and the appendix to SSR-4 [1]).

Internal fires and explosions

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

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

(a) Pyrophoric materials, solvents and reactive chemicals;
(b) Other combustible materials (e.g. 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.

5.70. Fire in a reprocessing facility might lead to the dispersion of radioactive material 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, by altering the moderating or reflecting conditions due to the presence of fire extinguishing media or the degradation or melting of neutron absorbers.

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

5.72. The fire hazard analysis for a reprocessing facility is required to consider both external and internal fires, including fires involving radioactive material, both directly and indirectly[17] (see paras 6.77 and 6.78 of SSR-4 [1]). Fire hazard analysis provides useful information that could be a basis for making decisions on the design of the facility or for identifying potential weaknesses in the design. Even if the likelihood of a fire occurring is low, the severity of the consequences in some areas of a reprocessing facility might be significant. Appropriate preventive and protective measures should be implemented (e.g. use of non-combustible or fire retardant construction materials, provision of fire barriers, provision of fire retardant coating for cables, provision of adequate separation distances for items important to safety) to prevent fires or to prevent the propagation of a fire. The analysis should also include a systematic review of the provisions made for prevention of fire initiation, for timely detection of fires, for extinguishing of fires, and for prevention of the spread of fires that cannot be extinguished.

5.73. An important aspect of the fire hazard analysis for a reprocessing facility is the identification of areas of the facility that warrant 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, laboratories and storage areas containing flammable and/or combustible liquids and gases, solvents, resins or reactive chemicals, including cranes where combustible lubricants are used for gearboxes;
(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;

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

(g) Rooms containing items important to safety (e.g. rooms containing the last stage filters of the ventilation system, electrical switch rooms), whose failure might lead to radiological consequences or consequences that are unacceptable in terms of criticality safety;
(h) Process control rooms and supplementary control rooms;
(i) Cable rooms, cable trays and ducts;
(j) Access and escape routes.

5.74. 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."

5.75. 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 9.109–9.115 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 process areas from the areas where non-radioactive hazardous material is stored;
(c) Specification of fire compartments, with specific requirements for their separation and/or segregation from other fire compartments or buildings;
(d) Implementation of a fire detection and alarm system designed to allow the timely detection and identification of the location of any fire, rapid dissemination of information on the fire and, where in place, 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) Compartmentation of buildings and ventilation ducts as far as possible to prevent the spread of fires between fire compartments;
(g) Avoidance of the use of flammable liquids or gases inside their flammability limits;

(h) Minimization of the number of possible ignition sources such as open flames, welding, or electrical sparks, and their segregation from combustible material to the extent practicable;
(i) Insulation of hot or heated surfaces;
(j) Selection of suitable fire extinguishing media consistent with the findings of other safety analyses, especially with the requirements for criticality control (see Requirement 38 and para. 6.146 of SSR-4 [1]).

5.76. 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. A balance should be maintained between the objectives of limiting the spread of fire, maintaining the dynamic containment system for as long as possible, and protecting the final stage of filtration.

5.77. 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) Where necessary, the ventilation ducts should be airtight and resistant to heat and corrosive products that might result from a fire.
(d) The design of ventilation ducts and filter units for dynamic containment should be such that 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. The use of non-combustible materials for filters and other elements of the ventilation system should be considered.
(g) The locations of filters and fans should be carefully evaluated for their ability to perform in the case of 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.

5.78. Penetrations for cable routes and pipework crossing the boundaries of fire compartments and firewalls (e.g. process lines, service lines, cables, cable trays) should be designed to ensure that fire does not spread through the penetrations.

5.79. Access and escape routes for fire and criticality events at a reprocessing facility should be considered in the design in accordance with regulatory requirements and the safety assessment.

5.80. Requirements relating to the prevention of explosions at a reprocessing facility are established in 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, nitric acid), degradation products, pyrophoric materials (e.g. zirconium or uranium particles), or the chemical or radiochemical production of explosive materials (e.g. hydrogen, ammonia, red oil) or from the mixing of incompatible chemicals (e.g. strong acids and alkalis).

5.81. To prevent a release of radioactive material as a result of 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 operation and anticipated operational occurrences (e.g. recovery of leaks);
(c) The control of parameters (e.g. concentration, temperature, pressure, flow rate) to prevent conditions that might lead to explosion;
(d) The use of blow-out panels to mitigate the effects of explosions;
(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.

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

Handling errors

5.83. 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 such materials might result in the degradation of criticality controls, confinement or shielding or a reduction in defence in depth. The following should be achieved in the design of a reprocessing facility:

(a) Elimination of the need to lift loads, where practicable, especially within the facility, by using track-guided transport or another stable means of transport;
(b) Limitation of 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 the consequences of handling errors, and specifying safe travel paths);
(c) Minimization of the failure frequency of mechanical handling systems (e.g. cranes, carts) by appropriate design[18], including through 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 appropriate administrative controls (see paras 9.36 and 9.37 of SSR-4 [1]).

Equipment failures

5.84. 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 reduction in defence in depth. As part of the design, the failure of all SSCs important to safety is required to be assessed (see paras 6.1 and 6.80 of SSR-4 [1]), and consideration is required to be given (in accordance with the results of safety assessment) to the design or procurement of items that fail to a safe configuration. Where no safe configuration can be assured, the functionality of SSCs important to safety is required to be maintained (see para. 6.89 of SSR-4 [1]), for example, through diversity, redundancy, physical separation and/or independence, as necessary.

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[18] Some States have specific regulatory requirements for the design for ‘nuclear loads’ or ‘nuclear lifts’, for example, requiring the use of multi-roped cranes, requiring 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.

5.85. Failure due to fatigue, chemical corrosion or lack of mechanical strength should be considered in the design of containment systems for a reprocessing facility.

5.86. 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 of a reprocessing facility (see also paras 5.187–5.190).

5.87. In evaluating failure and fail-safe conditions, special consideration should be given to computer security and to the failure of computer systems, computerized control and software systems, through the application of appropriate national or international codes and standards or through a functional analysis of the systems and their failure frequencies (see also Requirement 45 of SSR-4 [1]).

Loss of services

5.88. A 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].

5.89. To meet the requirements established in Requirements 49 and 50 and para. 6.89 of SSR-4 [1], electrical power supplies and other support services in a reprocessing facility should be of high reliability. Contributions to reliability include the use of diverse and redundant electrical power sources, switching and connections, the design of power supplies to withstand external hazards, and the use of uninterruptible power sources when necessary. 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 SSCs important to safety (see para. 6.187 of SSR-4 [1]). For a reprocessing facility, these SSCs include the following:

(a) Criticality 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;[19]
(e) Fire detection and alarm systems;
(f) Monitoring systems for radiation protection;
(g) Nuclear material handling equipment;
(h) Instrumentation and control associated with the above items;
(i) Emergency lighting (see also para. 6.182 of SSR-4 [1]).

5.90. Consideration should be given to the need to provide emergency power at a reprocessing facility for an extended period in the event of a major external event. The SSCs 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.

5.91. 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' of items (e.g. off, running on emergency supply (including time to loss of supply));
(b) The safety significance or priority of the item being restored to (normal) service;
(c) Interruptions of supply during switching operations;
(d) The initial power demand of items within the reprocessing facility and the power supply capabilities and capacity.

Emergency procedures for power recovery should also be developed during the design (see also Requirements 71 and 72 of SSR-4 [1] on accident management and emergency preparedness, respectively).

5.92. The assessments performed in relation to the loss of electrical power supplies or other support services (e.g. cooling, compressed air, ventilation) should be part of the overall safety assessment (see Requirement 5 of SSR-4 [1]) for the reprocessing facility.

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[19] An emergency power supply needs to be provided to enough exhaust fans to maintain the necessary hierarchical negative pressures to ensure dynamic containment. The exhaust systems for which an emergency power supply is needed depend on facility design but typically include: (a) process off-gas fans; (b) glovebox exhausts, where radioactive material of high activity is handled in powder form; (c) cell exhaust fans; (d) some sampling fume hoods, depending on the occupancy; and (e) some area ventilation exhausts that are run at lower speeds.

5.93. The loss of services such as process gas for instrumentation and control of operations, cooling water for process equipment, ventilation systems, and inert gas supplies might also have an impact on safety. Examples of suitable measures that should be addressed in the design of a reprocessing facility include the following:

(a) In accordance with the safety assessment, the design of supply systems[20] should be of adequate reliability, with diversity and redundancy, as necessary.
(b) The maximum period that a loss of support supplies can be sustained with acceptable levels of safety should be assessed and considered in the design provisions for all such supplies.
(c) As far as practicable, pneumatically actuated valves should be designed to be fail-safe in the event of a loss of air supply, in accordance with the safety analysis.
(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.
(e) With regard to a loss of breathing air, adequate backup capacity or a secondary supply should be provided to allow work in areas with airborne radioactive material to be terminated safely and workers to evacuate.

Leaks and spills

5.94. Requirement 35 and para. 6.120 of SSR-4 [1] establish requirements for confinement and leak detection for radioactive material. At a reprocessing facility, provisions to prevent, detect and collect leaks arising from corrosion, erosion and, in systems exposed to oscillations, vibration should be implemented. Specific consideration should be given to equipment containing acid solutions, especially when such solutions are at high temperatures.

5.95. The materials of the equipment at a reprocessing facility should be selected to withstand, as far as possible, the effects 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.

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

5.96. Where cooling circuits are installed in a reprocessing facility, especially in highly radioactive systems, the effects of waterside corrosion, water chemistry, radiolysis (e.g. peroxide production) and stagnant coolant (e.g. where cooling is not needed for a certain period or in a redundant cooling system) should be included in the design considerations.

5.97. 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 radioactive 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 operation to provide sufficient confidence that they could be safely deployed when needed. The subcriticality of the collected leaks and spills is required to be demonstrated (see para. 6.146(a) of SSR-4 [1]).

5.98. The potential effects of corrosion or abrasion on the dimensions of equipment containing fissile material (e.g. the thickness of the walls of process vessels whose method of criticality control is geometry) are required to be taken into account in the criticality safety analysis (see para. 6.146(d) of SSR-4 [1]). Consideration should also be given to the corrosion of support structures for fixed neutron absorbers and, where an absorber is in contact with the process medium, to the corrosion of the absorber itself (e.g. the corrosion of packing in the condensers connected to evaporators). Process parameters should be optimized to give acceptable corrosion rates, balanced with the need to ensure that waste is minimized and that process performance and efficiency are enhanced. Examples of such parameters include the operating temperature of evaporators and specifications for the acceptable use of reagents or feeds recycled from facility effluents.

Flooding

5.99. 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, the mixing of incompatible chemicals, changes in moderation and/or reflection conditions, the failure of electrically powered safety devices, the failure or false activation of alarms and trips, or 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 SSCs important to safety. Electrical services, instrumentation and control systems and their power supplies, and data and control cables should be segregated from liquid and gaseous feeds (e.g. steam lines) as far as practicable. All floor penetrations and wall penetrations for electrical power supplies and supplies to instrumentation and control systems should be protected against liquid ingress. Where possible, electrical power supplies and cabling to instrumentation and control systems should be routed high up, above potential flood levels. Particular care should be taken with the routing of steam and cooling water pipework owing to the potential of such pipes to release large volumes of vapour or liquid.

5.100. In the parts of the reprocessing facility where vessels and/or pipes containing liquids are present, the criticality safety 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.

5.101. Walls (and floors, as necessary) of rooms where flooding could occur should be capable of withstanding the liquid load, and SSCs important to safety should not be affected by flooding. The dynamic effects of large leaks and the potential failure of any temporary ‘dams’ formed by equipment or internal structures should also be considered.

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

Chemical hazards

5.103. Requirements for the management of chemical hazards in a nuclear fuel cycle 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 of releases of hazardous chemicals to the environment should be made on the basis of standards and regulatory requirements applied to chemical industries, taking into account any potential for radiological or criticality hazards. Where possible, such chemicals should be chosen in accordance with, and used under, the physical conditions in which they are intrinsically safe.

5.104. On the basis of the safety assessment, the design should take into account the effects of hazardous chemical releases from the reprocessing facility. The possibility of direct effects (e.g. toxic effects on site personnel, corrosion or other types of damage to SSCs) and indirect effects (e.g. evacuation of control rooms) should be considered.

Use of equipment operated at non-atmospheric pressure

5.105. 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 equipment operated at non-atmospheric pressure[21]. 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 during 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

5.106. 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 requirements established in SSR-1 [18]. Detailed recommendations on the protection of nuclear installations against external hazards are provided in IAEA Safety Standards Series Nos SSG-9 (Rev. 1), Seismic Hazards in Site Evaluation for Nuclear Installations [22]; SSG-18, Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations [23]; SSG-21, Volcanic Hazards in Site Evaluation for Nuclear Installations [24]; SSG-67, Seismic Design for Nuclear Installations [25]; SSG-68, Design of Nuclear Installations Against External Events Excluding Earthquakes [26]; and SSG-79, Hazards Associated with Human Induced External Events in Site Evaluation for Nuclear Installations [27].

5.107. Paragraph 6.54 of SSR-4 [1] states that “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.”

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[21] Most equipment in reprocessing facilities is operated at negative pressure or close to atmospheric pressure; exceptions are dissolvers and evaporators operating at reduced pressure for safety reasons, certain equipment designed to resist potential violent or runaway reactions, and service supplies (e.g. air, steam).

Earthquakes

5.108. 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 [18]). Recommendations on this assessment are provided in SSG-9 (Rev. 1) [22] and SSG-67 [25]. The assessment of seismic hazards for the reprocessing facility design should include the following seismically induced events, as applicable:

(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, flooding).
(e) The effect of the following on criticality safety functions such as geometry control, moderation, absorption and reflection:
    (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);
    (v) Accumulation of fissile material;
    (vi) Homogeneous or heterogeneous mixing of fissile material with a moderator.
(f) Collapse of structures and fall of objects onto items important to safety.

5.109. In accordance with Requirement 14 and paras 6.49 and 6.50 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 considered as design extension conditions (see para. 6.73 of SSR-4 [1]) to ensure that such an event will not impair the function of control rooms and 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[22] and other equipment necessary 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

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

appropriate conservative methodologies, including the use of an earthquake simulation platform.

5.110. Depending on the reprocessing facility's site characteristics and location, as identified in the site evaluation (see Section 4), the effects of a tsunami or other extreme flooding events induced by an earthquake are required to be addressed in the facility design (see paras 5.18–5.20 of SSR-1 [18]).

External fires and explosions and external toxic hazards

5.111. Hazards from external fires and explosions could arise from various sources in the vicinity of a reprocessing facility, such as petrochemical installations; combustible vegetation; pipelines and road, rail or sea routes used for the transport of flammable material (e.g. gas, oil); and volcanoes.

5.112. The hazards associated with external fires and explosions and external toxic hazards are required to be evaluated (see para. 5.33 of SSR-1 [18]). To demonstrate that the risks associated with such external hazards are below acceptable levels, the operating organization should first identify all potential sources of hazard and then evaluate the associated event sequences that might affect the safety of the reprocessing facility. The radiological consequences of any damage should be assessed, and it should be verified that they are within acceptance criteria.

5.113. The operating organization is required to consider potentially hazardous installations and transport operations for hazardous material in the vicinity of the reprocessing facility (see paras 5.36 and 5.37 of SSR-1 [18]). Toxic and asphyxiant hazards should be evaluated 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 reprocessing facility. In the case of explosions, risks should be assessed for compliance with overpressure criteria. To evaluate the possible effects of flammable liquids, volcanic ash, falling objects (e.g. chimneys), and air shock waves and missiles resulting from explosions, the possible distance of these hazards from the facility, and hence their potential for causing physical damage, should be assessed.

Extreme meteorological phenomena

5.114. 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 [18]). These provisions should address the events consequential to extreme meteorological conditions and generally include the following:

(a) The ability to maintain the availability of cooling systems under extreme temperatures and other extreme conditions;
(b) The ability of structures important to safety to withstand extreme weather loads, with particular attention to parts of the facility structure designed to provide confinement with little or no shielding function (e.g. areas containing alpha emitting radionuclides);
(c) The prevention of flooding of the facility, including trenches and ducts, and adequate means to remove water from the roof in cases of extreme rainfall;
(d) The ability to safely shut down 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) Means of ensuring that high water levels during floods do not jeopardize the integrity and functionality of SSCs important to safety.

Tornadoes

5.115. Measures for the protection of a reprocessing 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 regulatory requirements relating to hazards from tornadoes. If such regulations do not exist, the design should adhere to international good practices.

5.116. High winds are capable of lifting and propelling large, heavy objects (e.g. automobiles, telegraph poles). The possibility of impacts of such missiles is required to be taken into consideration during the design stage for the facility (see para. 5.14 of SSR-1 [18]). This should include 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

5.117. Extreme low or high temperatures, and their potential duration, are required to be taken into account in the design of the facility (see para. 5.11 of

SSR-1 [18]). For a reprocessing facility, the aim should be to prevent 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 (i.e. during hot weather);
(c) Adverse effects on a building's ventilation, heating and cooling systems that could cause poor working conditions and excess humidity in the buildings and adverse effects on SSCs important to safety.

Administrative controls to limit or mitigate the consequences of extreme temperatures should be relied on only if operating personnel have the necessary information and equipment (e.g. portable air-conditioning) and sufficient time to implement the measures.

5.118. If limits for humidity and/or temperature are specified in a building or a compartment, the air-conditioning system should be designed to also meet these limits during extreme weather conditions. Structural components of buildings, such as static containment, should also be designed to withstand extreme temperature and humidity and associated thermal stress effects, such as shrinkage in concrete.

Snowfall and ice storms

5.119. The occurrence of snowfall and ice storms and their effects are required to be taken into account in the design and the safety analysis for a reprocessing facility (see paras 5.11 and 5.27 of SSR-1 [18]). 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, and icing in outdoor switchyards can lead to short circuits and thus a loss of off-site power. The flooding resulting from snow or ice accumulation and infiltration, as well as the possibility that it could damage equipment important to safety (e.g. electrical systems), should be considered. The neutron reflecting effect and the interspersed moderation effect of the snow should be considered, if relevant. The effect of ice on wall loadings should also be considered where this is a possibility.

Flooding

5.120. A reprocessing facility is required to be protected against flooding (see para. 5.7(c) of SSR-4 [1] and Requirement 20 of SSR-1 [18]). For all potential 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 on SSCs important to safety that are at risk of damage.

5.121. Equipment containing fissile material is required to be designed to prevent a criticality accident in the event of flooding (see para. 6.146(e) of SSR-4 [1]). Gloveboxes should be designed to be resistant (i.e. 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 (i.e. batteries and power generation systems) and control rooms should be protected by design.

5.122. With regard to 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. In addition to the results of the flooding hazard assessment, performed in accordance with the recommendations provided in SSG-18 [23], 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

5.123. Measures for the protection of the facility against natural and human induced inundation events (e.g. dam burst, flash flood, storm surge, tidal wave, seiche, tsunami), including static effects (e.g. floods) and dynamic effects (e.g. runup, drawdown), 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 regulatory requirements for inundation hazards and with the recommendations provided in paras 5.120–5.122. Particular attention should be given to the rapid onset of inundation events, the probable lack of warning, and the potential for these events to cause widespread damage, disruption of utility supplies and common cause failures both within the reprocessing facility and at other facilities on the site (and potentially locally and regionally, depending on the magnitude of the event).

Accidental aircraft crashes or hazards from externally generated missiles

5.124. In accordance with the risk identified in the site evaluation (see Section 4), a reprocessing facility is required to be designed to withstand the design basis impact from accidental aircraft crashes or hazards from externally generated missiles (see para. 5.7(e) of SSR-4 [1] and para. 5.35 of SSR-1 [18]).

5.125. In evaluating the consequences of aircraft or secondary missile impacts on a reprocessing facility and the adequacy of the design to resist such impacts, only realistic crash scenarios, rotating equipment scenarios or structural failure scenarios should be considered. Knowledge of factors such as the possible angle of impact, the possible velocity or the potential for fire and explosion due to the aviation fuel load is needed to develop these scenarios. In general, fire cannot be ruled out following an aircraft crash. Therefore, specific design provisions for fire protection should be implemented, as necessary.

Terrestrial and aquatic flora and fauna

5.126. 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 [18]). This includes the potential for the restriction or blockage of cooling water and ventilation inlets and outlets and the effect of vermin on electrical and instrument cabling and waste storage areas. Where physical or, particularly, chemical measures are necessary to control flora and fauna, these measures should be subject to the same level of evaluation as any other physical or chemical measures used in the process, in accordance with a graded approach.

INSTRUMENTATION AND CONTROL SYSTEMS AT A REPROCESSING FACILITY

5.127. 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 (e.g. pressure, temperature and flow rate within processes) whose variation might affect the safety of processes at a reprocessing facility.

Other parameters include radiation levels and contamination levels, air quality in operational areas, and the correct operation of ventilation systems. As stated above, monitoring and control systems are 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 that proper actions can be undertaken in accordance with operating procedures, emergency procedures or accident management guidelines, as appropriate, for all facility states.

5.128. Instrumentation and control systems are required to be provided for criticality control and for hot cells, gloveboxes and hoods to fulfil the requirements for static and dynamic confinement (see paras 6.172–6.174 of SSR-4 [1]).

5.129. 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 6.21(d), 6.109 and 6.169 of SSR-4 [1]). The safe state for a reprocessing facility is generally the shutdown state.

5.130. Appropriate information is required to be made available to operating personnel for monitoring the effects of automatic actions (see para. 6.170 of SSR-4 [1]). The layout of instrumentation and the manner of presentation of information should provide 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. Information is required to be displayed in such a way that operating personnel can easily determine if a facility is in a safe condition and, if it is not, operating personnel can readily determine the appropriate course of action to return the facility to a safe and stable condition (see para. 6.15 of SSR-4 [1]).

5.131. Provision should be made for the automated measurement and recording of parameters that are important to safety; 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

5.132. 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 include mass, geometry, concentration, acidity (which might have an impact on solubility, extraction, stripping or precipitation), isotopic composition or fissile content, and quantity of reflectors and moderators as appropriate.
   (ii) Specific control parameters indicated by criticality safety analyses in which 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 in which criticality control relies on 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 material and/or toxic chemicals should be equipped with provisions for fire detection and fire extinguishing.
   (ii) Gas detectors should be used in areas where a leakage of gas (e.g. hydrogen) could produce an explosive atmosphere.
(c) Process control, for which the key safety related control systems of concern are those for:
   (i) Removing decay heat.
   (ii) Diluting hydrogen produced from radiolysis and other sources.
   (iii) Monitoring liquid levels in vessels.
   (iv) Controlling temperature, pressure and other relevant conditions to prevent explosions, including red oil explosions.
(d) Glovebox control and cell control:
   (i) Monitoring the dynamic containment for cells and gloveboxes.
   (ii) Monitoring temperatures.
   (iii) 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 environmental discharges.

(f) Control of occupational radiation exposure, including provision of:
   (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 and neutron radiations.
   (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 as well as 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. 5.44), including monitoring the operation of the sampling system for environmental discharges.

5.133. 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

5.134. 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 workers or instruments as appropriate.

Sample taking and analysis at a reprocessing facility

5.135. For taking measurements in reprocessing facilities, descending preference should be given to the following methods:

(1) Using in-line instruments;
(2) Using at-line instruments[23];

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

(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 (e.g. a central site laboratory).

5.136. In choosing the type of instrumentation to install at a reprocessing facility, the following factors should be considered:

(a) The availability of suitable 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 the delivery and measurement of samples that are ‘representative and fresh’[24].
(c) Realistic calibration and testing options (e.g. in situ, on-line or off-line calibration and testing).
(d) The ease and ergonomics of maintenance and replacement, including radiation protection considerations and timing issues.
(e) Ageing and technological obsolescence.

5.137. 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 sampling points, all aspects relating to the quality of sample taking and labelling, the safe transfer of samples to analytical laboratories, the quality of measurements, and the reporting of results to the relevant operating personnel should be documented and justified as part of the management system (see Section 3). The use of barcoding or similar systems that reduce the opportunity for error should be considered.

5.138. 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 (i.e. from the request for sampling to the receipt of results) for frequent analytical

[24] 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 SSC 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.

measurements, redundancy in sampling points, and provision for dilution near the sampling point for highly radioactive solutions should be considered where beneficial to safety and for optimization of occupational exposure (see also para. 6.199 of SSR-4 [1]).

Control systems at a reprocessing facility

5.139. 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] (the application of passive design features, in preference to the application of active design features, in preference to administrative controls (operator action)) is required to be applied in accordance with the concept of defence in depth and the available reaction time (grace period) (see Requirement 10 of SSR-4 [1]).

5.140. Appropriate information should be made available to personnel for monitoring the actuation of, and facility response to, remote actions and automated operations. Preference should be given to an 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 in the design of displays (e.g. 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.

5.141. Requirements for transfers of radioactive material and other hazardous material are established in Requirements 28 and 57 and paras 6.111, 6.112 and 9.32 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:

(a) The use of transfers by batch between units, buildings or facilities (see para. 5.46 of this Safety Guide);
(b) Characterization of a batch before transfer;
(c) 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

5.142. 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 control rooms in parts of the facility where the levels of radiation are very low. Where applicable, it may be useful to have dedicated control rooms to allow for the remote monitoring of specific operations, thereby reducing occupational exposures. Particular consideration should be given to identifying events, both internal and external to the control room, 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 in the design of control rooms and their displays and systems (see para. 6.108 of SSR-4 [1]).

HUMAN FACTORS ENGINEERING AT A REPROCESSING FACILITY

5.143. Requirements relating to consideration of human factors are established in Requirement 27 and paras 6.107–6.110 of SSR-4 [1]. 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 that should be considered for reprocessing facilities 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.

5.144. In the design of a 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 SSCs 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.

5.145. Experts in human factors engineering and experienced operating personnel should be involved from the earliest stages of the design. Areas that should be considered in the design of a reprocessing facility 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 of sampling systems;
    (iii) The working environment (e.g. good accessibility and spacing of equipment, good lighting (including emergency lighting), surface finishes that 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 needed.
(c) Allocation of function, considering the advantages and drawbacks of automatic action versus manual (i.e. operator) 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 staffing levels (see paras 8.6–8.9) and the combination of skills needed during the most demanding scenarios, 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) The 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.

5.146. Consideration should be given to providing computer-aided tools to assist operating personnel at a reprocessing facility in detecting, diagnosing and responding to events.

5.147. In the design and operation of gloveboxes at a reprocessing facility (see para. 6.108 of SSR-4 [1]), the following should be taken into account:

(a) In the design of equipment inside gloveboxes, the potential for accidents 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 the maintenance operations.
(d) The number and location of glove ports and posting ports[25] necessary for the operating and maintenance activities within the glovebox.
(e) The possible use of mock-ups and extensive testing of glovebox ergonomics at the manufacturer's site before finalizing the design.
(f) The potential for damage to gloves and the provisions for glove change and, where applicable, filter change. Sharp edges and corners on equipment and fittings and associated tools should be avoided to minimize risks of glove damage.
(g) The training of operating personnel on procedures to be followed in operational states and in accident conditions (see para. 9.48 of SSR-4 [1]).

SAFETY ANALYSIS FOR A REPROCESSING FACILITY

5.148. Requirement 14 of GSR Part 4 (Rev. 1) [16] states that "**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 for a reprocessing facility should cover the various hazards for the whole facility (see Section 2 of this Safety Guide) and all the activities performed within the facility.

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

5.149. 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 SSCs important to safety that might be affected by the postulated initiating events identified (see para. 4.20 of GSR Part 4 (Rev. 1) [16]).

5.150. For a reprocessing facility, the safety analysis should be performed iteratively with the development of the design, with the following objectives:

(a) Doses to workers and the public during operational states do not exceed dose limits and are as low as reasonably achievable, in accordance with Requirement 9 of SSR-4 [1].
(b) 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) Appropriate operational limits and conditions are developed.

5.151. Bounding cases[26] (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 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

5.152. For a reprocessing facility, 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:

(a) External exposures should be calculated using a bounding radiation source term established on the basis of:
    (i) The maximum inventory, including the 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).

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[26] Bounding cases (also called ‘limiting cases’ or ‘enveloping cases’) are used for the estimation of consequences.

(b) Two approaches may be used to assess external exposure:
   (i) 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;
   (ii) Determination of the type of activity to be performed by each worker, the time needed for the activity and the distance between the worker and the (shielded) radiation source.

(c) Calculations should be performed to determine the shielding requirements for point (b), as appropriate.

(d) Internal exposure can be a highly significant component of the total exposure and should be considered explicitly.

5.153. The calculation of the estimated dose to the public should include all the exposure pathways associated with the facility; namely, external exposure through direct or indirect radiation (e.g. sky shine, cloud shine, ground shine) and internal exposure through intakes of radioactive material (e.g. received through inhalation or 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 [21].

5.154. This Safety Guide addresses only those chemical hazards associated with a reprocessing facility that might give rise to radiological hazards (see para. 2.4 of SSR-4 [1]). Facility specific, credible, 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

5.155. The acceptance criteria associated with the safety analysis for accident conditions at a reprocessing facility are required to be defined in accordance with Requirement 16 of GSR Part 4 (Rev. 1) [16] and with any regulatory requirements.

5.156. To estimate the on-site and off-site consequences of an accident at a reprocessing facility, the range of physical processes that could lead to a release of radioactive material to the environment or to a loss of shielding needs to be considered, and bounding cases encompassing the worst consequences should be determined.

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

(a) Analysis of the current site conditions (e.g. meteorological, geological, hydrogeological) 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, in accordance with reasonable scenarios, 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 time frame for emissions; and the exposure time.
(e) Quantification of the consequences for site personnel and for the representative person(s) identified in the safety assessment.
(f) Specification of the SSCs important to safety that may be credited to reduce the likelihood and/or to mitigate the consequences of accidents. The SSCs important to safety that are credited in the safety assessment are required to be qualified to perform their functions reliably in accident conditions (see Requirement 30 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 migration pathways by which material that is released could be dispersed in the environment.
(i) Identification of exposure pathways for both internal and external exposure.

5.158. 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 transfer of energy that might be released from the facility. The operating organization is required to develop preparatory measures and guidelines to reduce the risk of accidents and return the facility to a controlled state (see paras 9.118 and 9.119 of SSR-4 [1]).

5.159. 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.

5.160. Further recommendations on the assessment of the potential radiological impact to the public are provided in GSG-10 [21]. Guidelines for assessing the acute and chronic toxic effects of chemicals used in reprocessing facilities are provided in Ref. [28]. Information on methods and practices, based on the IAEA safety standards and current international good practice, for performing safety analysis and preparing licensing documentation for nuclear fuel cycle facilities is provided in Ref. [29].

Analysis of design extension conditions

5.161. The safety analysis for a reprocessing facility 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 SSR-4 [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."

5.162. 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 SSCs important to safety or that could challenge the fulfilment of the main safety functions at the reprocessing facility (see paras 5.1–5.8). Examples of design extension conditions that are applicable to reprocessing facilities are listed in Ref. [30].

5.163. The list of postulated initiating events provided in the appendix to SSR-4 [1], including combinations of these events, should be used; events with additional failures should also be considered.

5.164. 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.

5.165. For analysing design extension conditions, best estimate methods with realistic boundary conditions are applied. Acceptance criteria for the analysis, consistent with para. 6.74 of SSR-4 [1], should be defined by the operating organization and should be reviewed by the regulatory body. The analysis of design extension conditions should also demonstrate that the reprocessing facility can be brought to a safe state.

MANAGEMENT OF RADIOACTIVE WASTE AT A REPROCESSING FACILITY

5.166. 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 [31]; GSG-1, Classification of Radioactive Waste [32]; SSG-41 [9]; and GSG-16 [14].

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

5.168. Owing to the nature and diversity of the composition of spent fuel (e.g. structural parts, spectrum of fission products, activation products, 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, 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.

5.169. At a reprocessing facility, 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.

5.170. 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 waste characterization, pretreatment and treatment, as necessary, and then for transport to the appropriate identified disposal route, temporary storage location or other facility for further waste treatment.

5.171. 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, 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 due attention paid to the retrievability of waste intended for temporary storage (see para. 3.21 of GSR Part 5 [2]).

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

5.173. 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. The design should include, in accordance with the safety assessment, provisions for decay heat removal, hydrogen concentration control, and 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

5.174. Reprocessing facilities are required to be designed so that discharges to the environment are minimized as far as practicable (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 are met in normal operation and in anticipated operational occurrences (see Requirement 25 of SSR-4 [1]).

5.175. The design of waste storage areas and waste containers is required to take account of the type of radioactive waste, its characteristics and associated hazards, even if the storage is intended to be short term (see para. 4.20 of GSR Part 5 [2] and para. 6.95 of SSR-4 [1]). Requirement 11 of GSR Part 5 [2] states that "**Waste shall be stored in such a manner that it can be inspected, monitored, retrieved and preserved in a condition suitable for its subsequent management.**" Measures should be taken to ensure the integrity of the facility and the waste containers, taking into account low probability events, even for short term storage.

5.176. The activity of gaseous effluent discharged from a reprocessing facility should be reduced by process specific ventilation treatment systems. These systems 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.

5.177. Equipment for monitoring the status and performance of filters at a reprocessing facility should be installed, including the following:

(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, where necessary.

5.178. Liquid effluents to be discharged to the environment from a reprocessing facility are required to be monitored, treated and managed as necessary to reduce discharges of radioactive material and hazardous chemicals to as low as reasonably achievable and below the authorized limits for such discharges (see para. 6.101

of SSR-4 [1]). The use of filters, ion exchange beds or other technologies should be considered, where appropriate. Analogous provisions to those in para. 5.177 of this Safety Guide should be made to allow the efficiency of these systems to be monitored.

5.179. 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

5.180. Requirement 4 of GSR Part 7 [20] states that "**The government shall ensure that a hazard assessment is performed to provide a basis for a graded approach in preparedness and response for a nuclear or radiological emergency.**" 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 [33].

5.181. Requirements for emergency preparedness and response at nuclear fuel cycle facilities are established in Requirements 47 and 72 and paras 6.181–6.183 and 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 plan 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]). Emergency arrangements are required to be integrated with those of other response organizations, as appropriate; be integrated with contingency plans; and are required to provide, to the extent practicable, assurance of an effective response to a nuclear or radiological emergency (see para. 4.14 of GSR Part 7 [20]). The conditions under which an off-site emergency response might need to be initiated include the internal hazards, external hazards and their credible combinations identified as the postulated initiating events for a reprocessing facility (see paras 5.67–5.126 of this Safety Guide).

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

5.183. The design of the reprocessing facility is required to take into account the on-site infrastructure necessary for an effective emergency response (including 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]).

5.184. In accident conditions, the reprocessing facility is required to be capable of being returned 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 (see paras 6.15, 6.83 and 6.84 of SSR-4 [1]). The control room(s) and emergency response facilities are required to be designed and located so that they remain habitable during postulated emergencies (e.g. with separate ventilation and with a low calculated dose in the case of a criticality event) (see Requirements 46 and 48 of SSR-4 [1]).

5.185. The safety analysis should identify those safety functions that should continue during and after events that might affect control rooms; 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 to ensure that the safety functions identified by this analysis can continue to be fulfilled.

5.186. 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 [20]).

AGEING MANAGEMENT AT A REPROCESSING FACILITY

5.187. The design of a reprocessing facility is required to take into account the effects of ageing on SSCs important to safety to ensure their reliability and availability during the lifetime of the facility (see Requirement 32 of SSR-4 [1]).

5.188. The design of the reprocessing facility is required to facilitate the inspection of SSCs important to safety (see Requirement 26 of SSR-4 [1]). This inspection 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 a technical ageing evaluation based on the relevant inspection data; it should also allow for the maintenance or replacement of such items, if needed. To implement an effective ageing management programme, design provisions should be made for remote inspections of areas that are generally not accessible during the operation of the reprocessing facility (e.g. process cells, high level liquid waste storage tanks).

5.189. Reprocessing facilities have long operating lifetimes; consequently, 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 the operation of remote repair equipment. In addition, designers should consider the generation and retention of three dimensional design data of the equipment and its location in hot cells.

5.190. An ageing management programme is required to be implemented by the operating organization of a reprocessing facility (see Requirements 32 and 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 the 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 IAEA Safety Standards Series No. SSG-38, Construction for Nuclear Installations [34].

6.2. A construction project for a reprocessing facility will involve a large number of designers and contractors, and it is likely that design, construction and early commissioning will take place simultaneously in different sections of the facility. The operating organization should ensure, as part of the management system, that the relevant recommendations in SSG-38 [34] are followed and that adequate procedures are implemented to minimize potential problems and deviations from the design intent as design and construction proceed.

6.3. The operating organization should consider optimizing 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 (in particular, 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 detection and alarm systems); the need to make, where justified, safety improvements and other improvements using proprietary designs and equipment; and the need to have access to the necessary experts for reviews. In all cases, the management system (see Section 3) 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, so 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 the site. This approach will also aid commissioning, operation, maintenance and decommissioning.

6.5. As reprocessing facilities are complex facilities, authorization by the regulatory body should be sought in several stages. Each stage may have a hold point at which approval by the regulatory body is 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 SSCs important to safety (e.g. verification of shielding efficiency, verification of geometry for criticality safety purposes, testing of welding) should be performed before construction and installation, when appropriate, since such testing 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 substandard components. Such items or components can have an impact on safety even years after the commissioning of the reprocessing facility (e.g. vessels constructed using substandard stainless steel) (see para. 8.8 of SSR-4 [1]).

6.8. The recommendations in paras 4.16(h), 5.27–5.30 and 5.39–5.41 of SSG-38 [34] on the care of installed equipment and the exclusion of foreign material[27] should be followed. After their installation, structures and components should be properly cleaned and suitable primer should be applied, 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 work is in progress should be isolated, as far as practicable, from other parts of the 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 the following:

(a) Applicable codes and standards;
(b) The organizational structure;
(c) Design change programme (configuration control);
(d) Procurement control (see also para. 4.22 of SSR-4 [1]);
(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 (see also para. 9.73 of SSR-4 [1]).

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

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. 8.26 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 relating 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 reprocessing facility before operation. The commissioning stage should also be an opportunity to promote and further enhance safety culture, including behavioural expectations and learning attitudes, throughout the entire organization. Such familiarization with the facility should include the following aspects:

(a) Campaigns of fuel reprocessing (see para. 8.27);
(b) Startup and rundown periods;
(c) Work conducted between campaigns, including maintenance work, that is not possible or is too hazardous to conduct during normal operation (e.g. significant modifications or equipment repair and replacement projects);
(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 necessary 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 the 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. These limits and values should be embedded in any instructions relating to safety, including emergency procedures. The effects of changing from one mode of operation to another (e.g. at the start and end of a campaign) should also be considered.

7.7. Where necessary (and in accordance with a graded approach[28]), commissioning tests for a reprocessing facility should be repeated a sufficient

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[28] In commissioning, a graded approach 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.

number of times under varying conditions to verify their reproducibility. Particular attention should be paid 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. For the commissioning of a reprocessing facility, temporary works (e.g. utility supplies, supports for items, access openings in building structures) and devices (e.g. temporary electrical or instrument supplies and connections to allow the testing of items in isolation or the injection of test signals) often need to be used. In such cases, the operating organization should undertake the following:

(a) Establish suitable controls over the use of temporary works and devices, including a programme for the control of modifications (see Requirement 61 of SSR-4 [1]), as necessary;
(b) Appoint an individual with responsibility for overseeing the application of the controls and a process for registering and approving the introduction of such temporary works and devices.

The controls should include a process for verification that all temporary works have been completed and that devices have either been removed at the end of commissioning or have been properly approved to remain in place (i.e. as a modification; see paras 8.44–8.52), with an adequate safety assessment performed and the results included in the safety case for operation.

7.9. Some commissioning activities (including the training of operating personnel) 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 SSCs important to safety. The operating organization should introduce controls as described in para. 7.8 for such activities, and all such activities and associated controls should be included in the management system for the reprocessing facility (see Section 3). 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, it should be ensured that, as far as practicable, they have identical characteristics to the material to be used during operations in order to achieve the purpose of commissioning. If the material's 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 instead of demineralized water), unless a full evaluation of the potential effects has been made.

7.11. Some stages of commissioning may be subject to approval by the regulatory body, both prior to starting and at completion (see also paras 8.1 and 8.11 of SSR-4 [1]). Where appropriate, the operating organization should define and agree with the regulatory body hold points (see para. 8.19 of SSR-4 [1]) and witness points, commensurate with the complexity and potential hazard of the commissioning activity, to ensure proportionate inspection during commissioning. The purpose of these 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 is required to establish and maintain effective communication with the regulatory body throughout the commissioning process (see para. 8.11 of SSR-4 [1]) 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, at 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);
(e) Confirmation of the performance of cooling systems for radioactive material (e.g. spent fuel, radioactive waste), as necessary.

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

7.13. Clear communication among management, supervisors and site personnel — between and within different shifts of personnel under operational states and accident conditions, and with the relevant emergency services — is a vital component of overall facility safety. Commissioning provides the opportunity for these lines of communication and associated equipment to be tested and for operating personnel 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 communication, pre-job briefing, post-job review, a questioning attitude, peer review). Commissioning should also be used to develop a standard format for logbooks and for 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 that "**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 of suppliers' training records.

7.16. The likelihood of any damage or modification to commissioned SSCs important to safety from subsequent construction and installation work should be considered. Reassurance or verification testing of commissioned SSCs 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 of arrangements for communication between the commissioning team and other groups in the facility. The safety committee should also advise on whether any SSCs important to safety and their support systems tested earlier in the programme require retesting prior to the next stage of commissioning. Such retesting may also be necessary in relation 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 of a reprocessing facility so that parts of the facility necessary to support the section being commissioned are able to provide this support at the appropriate time (or, if not, so that suitable alternative arrangements are made). This should involve consideration of ‘upstream’[29] sections of the facility (including those that supply utilities such as electrical power, steam, reagents, cooling water and compressed air), ‘downstream’[30] sections of the facility (including those for waste treatment, aqueous and aerial discharges, and environmental monitoring), and ‘support’[31] sections of the facility (including those containing 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 stages, depending on the objectives to be achieved. For a reprocessing facility, this may involve four stages, which are described in paras 7.20–7.37 of this Safety Guide.

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

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

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

Stage 1: Construction testing

7.20. For some SSCs important to safety at a reprocessing facility, if verification of compliance might not be possible after construction and installation are complete, testing should be performed during the 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 testing during construction include seismically qualified supports or restraints, shielding or barrier walls (for homogeneity), pipe welds, vessels and other passive structures, underground cells (for leaktightness), and other systems and components important to safety. In many cases, this verification 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 SSCs may be performed at this stage, in accordance with regulatory requirements. Further recommendations are provided in SSG-38 [34].

Stage 2: Cold commissioning

7.22. During cold (or ‘inactive’) commissioning, the reprocessing facility’s systems are tested in the absence of radioactive material. The facility is tested systematically, as individual items of equipment and as systems in their entirety. Owing to the relative ease of taking corrective actions, as much verification and testing as practicable should be performed at this stage.

7.23. At this stage, operating personnel should take the opportunity to learn the details of the systems and to further develop and finalize operating procedures and associated documentation, including procedures relating to the operation and maintenance of the facility and those relevant to any anticipated operational occurrences, including emergencies. The leaktightness of containment systems (e.g. cells, gloveboxes, process vessels, piping) and the stability of control systems should be tested at this stage.

7.24. The completion of cold commissioning also provides the last opportunity to examine the reprocessing facility under inactive conditions. This is a valuable opportunity to simulate transients or the 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 management of such events by comparing the performance of the facility to that identified in calculations of simulated events.

7.25. This stage is also a final opportunity to ensure that all maintenance can be completed once the reprocessing 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 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.

7.26. To avoid potential errors in a reprocessing facility, its rooms, equipment, systems, components, cables and pipes should be given clear, consistent and unambiguous labels. Training materials and operational documentation should be checked for consistency with such labelling and finalized during cold commissioning.

7.27. It should also be confirmed that all physical connections within the reprocessing facility have been made as expected. This should involve checking 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: Warm commissioning

7.28. During warm (or 'uranium' or 'trace active') commissioning, natural or depleted uranium should be used[32] 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 into the reprocessing facility.

7.29. Safety tests performed during the warm commissioning stage should mainly be devoted to confinement checking. These tests should include checks for airborne radioactive material, smear checks on surfaces, and checks for gaseous discharges and liquid releases. Checks should also be made for unexpected accumulations of hazardous material.

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

7.30. 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.

7.31. This stage should also be used to provide measurable verification of certain parameters within the reprocessing facility that had previously only been calculated theoretically (in particular, in relation to discharges). The use of tracers[33] should also be considered, to enhance or allow such verification.

7.32. Prior to hot commissioning, emergency arrangements (on-site and off-site) for the reprocessing facility are required to be established, including procedures, training, sufficient numbers of trained personnel, and emergency drills and exercises (see paras 8.14 and 8.15 of SSR-4 [1]). The on-site and off-site emergency response capabilities should be demonstrated.

Stage 4: Hot commissioning

7.33. Before the start of hot (or 'active' or 'hot processing') commissioning, the authorization to operate the facility is generally issued by the regulatory body to the operating organization. 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 hot commissioning, as far as 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.

7.34. The full operational radiation protection programme (see Requirement 67 of SSR-4 [1]) should be implemented, including individual monitoring.

7.35. Unlike cold commissioning, hot commissioning involves major changes in the control arrangements for the reprocessing 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 hot commissioning before it is implemented. This should include actions to foster and promote a strong safety culture (see Requirement 12 of GSR Part 2 [11]) to contribute further to safe operation.

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

7.36. Hot commissioning should enable reprocessing to be progressively brought into full operation by steadily increasing both the quantity and the activity of the spent fuel fed into the reprocessing facility, as far as such an incremental approach is practicable.

7.37. 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, as required by para. 8.17 of SSR-4 [1]. 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

7.38. Requirements for commissioning reports[34] are established in paras 8.21–8.23 of SSR-4 [1].

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

7.40. A commissioning report is required to describe the commissioning tests that were performed to demonstrate the facility's compliance with the design, the design intent and the safety assessment, and it should summarize any necessary corrective actions (see para. 8.21 of SSR-4 [1]). Such corrective actions include making changes to the safety case and adding or changing safety features and work practices. All such changes should be treated as modifications (see paras 8.44–8.52 of this Safety Guide). 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.

7.41. The commissioning report should include a review of the results of radiation and contamination surveys performed in the facility and of sampling

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

and analytical measurements, particularly those relating to waste, effluent and environmental discharges.

7.42. To demonstrate the operating organization's readiness for operation, the commissioning reports for the reprocessing facility 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 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 (e.g. radiation and contamination surveys, decontamination, use of personal protective equipment, response to issues arising during tasks);
    (v) Emergency drills and exercises;
    (vi) Safety culture.

7.43. The commissioning report should highlight any notable deviation in the findings of the commissioning tests along with corrective measures taken. Any incidents or events that occurred during the commissioning of the reprocessing facility 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.

7.44. 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 SSCs 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 needed to be confirmed during commissioning should be reported. The commissioning data forms a baseline for monitoring the performance of the equipment and systems.

7.45. The safety committee is required to review the commissioning report (see para. 4.31(c) of SSR-4 [1]). The commissioning report should be approved by senior management in accordance with the management system, then submitted to the regulatory body, in accordance with regulatory requirements.

7.46. Where possible, lessons identified from the commissioning and operation of similar reprocessing facilities should be applied[35].

8. OPERATION OF NUCLEAR FUEL REPROCESSING FACILITIES

ORGANIZATION OF OPERATION OF A REPROCESSING FACILITY

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

8.2. Suitable arrangements are required to be made to collect, assess and propagate any lessons learned during the commissioning stage of the facility and, on an ongoing basis, during the operation stage (see Requirement 73 of SSR-4 [1] and paras 8.131–8.133 of this Safety Guide). Lessons learned from other organizations that operate reprocessing facilities should be included in this process. 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 a person responsible for the safe operation of the facility 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 period for manual intervention. Such persons 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:

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[35] See: http://finas.iaea.org

(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;[36]
   (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 the 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 are 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 be applied to key safety personnel and other personnel on the basis of this review.

8.5. A safety committee in a reprocessing facility (see Requirement 6 of SSR-4 [1]) is required to be 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]).

[36] 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. In staffing the facility, the operating organization 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 training and retraining needs for the facility (see paras 8.10–8.16).

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 backup 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 nuclear fuel cycle 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 [12].

8.11. The need for training all levels of management at a reprocessing facility should be considered. Personnel involved in the management and operation of the reprocessing facility should understand the complexity and the range of hazards present at the facility at a level of detail consistent with their level of responsibility. As stated in para. 9.38 of SSR-4 [1], "Certain operating positions may require formal authorization or a licence."

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

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

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

(a) Use of remote handling tools, 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 operations, training should include the following:

(a) Training for the control room operators;
(b) 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. The complementary training of safety and nuclear security personnel and their mutual participation in both safety and nuclear security exercises 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 or 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 at the facility. In this way, potential conflicts between safety and nuclear security can be resolved effectively without safety and security measures compromising each other.

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 the operational limits and conditions to be developed for a nuclear fuel cycle facility. Operating personnel at a reprocessing facility 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 SSCs relevant to defining operational limits and conditions for each process area are presented in Annex II to this Safety Guide.

8.18. To ensure that, under normal circumstances, the reprocessing facility operates well within its operational limits and conditions (see Requirement 57 of SSR-4 [1]), limiting conditions for safe operation are required to be defined by the operating organization (see 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 set a sufficient safety margin while avoiding breaches of the limiting conditions for safe operation. All limits and conditions for a reprocessing facility should be clearly and consistently identified in the operating procedures (see Requirement 63 of SSR-4 [1]) and in directly relevant procedural steps.

8.19. The authority to make operating decisions should be assigned to suitable levels of management, depending on the operational limits and conditions and the potential safety implications of the decision. The management system (see Section 3) should specify the authority and responsibilities at each management level. If 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 should be applied to prevent a recurrence. In accordance with regulatory requirements, the regulatory body should be notified in a timely manner of such non-compliances and of any immediate actions taken and should be kept informed of the subsequent investigations and their outcome.

8.21. Operating procedures for the reprocessing facility are required to be developed (see Requirement 63 of SSR-4 [1]). These procedures should be developed to directly control all process operations at a reprocessing facility. These procedures should be user friendly and 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 should include simulations or exercises, where appropriate.

8.22. The documents prepared should systematically link to the safety case and the operational limits and conditions for the reprocessing facility, 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 the operational limits and conditions at all times.

SPECIFIC PROVISIONS FOR THE OPERATION OF A REPROCESSING FACILITY

8.23. 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 of the feed programme.

8.24. A reprocessing facility is 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, duration of cooling following discharge from a reactor) and safety related constraints at the facility.

8.25. 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 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.

8.26. 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. 5.141).

8.27. The 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, for maintenance, and for nuclear material accounting and control). It is safer to perform maintenance during inter-campaign periods, although the risks of contamination and occupational exposures do still increase as more maintenance work is undertaken. In addition, intensive maintenance periods might 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; this action may include specific training, the allocation of more experienced personnel to teams, and additional supervision of work (see also paras 8.30–8.37).

8.28. Systematic walkthroughs of the reprocessing facility — by operating personnel and by senior management — should be 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 walkthroughs should include a suitable level of independence (e.g. including personnel from other facilities on the site or off the site). Examples of aspects to be checked during a walkthrough 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) The completion of safety checks within the specified range of dates (e.g. on access equipment[37], lifting equipment, fire extinguishers and electrical equipment);
(c) The conditions at access points to supervised areas and controlled areas;
(d) The number and condition of areas where access is temporarily restricted (e.g. radiation areas, 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

8.29. Suitable controls should be established at a reprocessing facility to ensure, as far as practicable, that foreign material is excluded from the process. These controls should build on those developed during commissioning (see para. 7.7) and are particularly relevant for maintenance activities and for the supply and delivery of process reagents.

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

MAINTENANCE, CALIBRATION, PERIODIC TESTING AND INSPECTION AT A REPROCESSING FACILITY

8.30. Requirements relating to maintenance, periodic testing and inspection for nuclear fuel cycle facilities are established in Requirement 65 and paras 9.74–9.82 of SSR-4 [1].

8.31. 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.

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

8.33. Prior to any maintenance activities at a reprocessing facility, 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.

8.34. Maintenance (and any preparatory operations) that involves temporary changes to confinement and/or shielding at a reprocessing facility (including during any temporary or transient stages during the maintenance) should be thoroughly analysed beforehand to ensure that levels of contamination and occupational exposures will be acceptable. The analysis should specify appropriate safety measures and monitoring requirements (see paras 8.83 and 8.84).

8.35. During maintenance, the equipment being maintained should be isolated from other parts of the reprocessing facility that contain radioactive material, as far as practicable.

8.36. 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.

8.37. For maintenance tasks at a reprocessing facility with high anticipated doses (or high potential doses), consideration should be given to the use of mock-ups and/or computer generated 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.

8.38. A programme of periodic inspections of the reprocessing facility is required to be established to verify that the facility and the SSCs 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]).

8.39. 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 suppliers of reagents. The operating organization should satisfy itself that externally supplied or located equipment is properly calibrated at all times, in accordance with national or international standards, and that the records of calibration are traceable.

8.40. 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, on the basis of the safety analysis.

AGEING MANAGEMENT FOR A REPROCESSING FACILITY

8.41. 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 the ageing of SSCs, rather than a reactive approach responding to the failure of SSCs;
(d) Ensuring optimal operation of SSCs 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 could lead to premature degradation through enhancement of staff motivation, fostering of a culture for safety (including a sense of ownership and awareness), and understanding of the basic concepts of ageing management;
(g) Ensuring the availability and use of correct operating procedures, tools and materials, and ensuring the availability of a sufficient number of qualified personnel for a given task;
(h) Collecting feedback on operating experience to learn from relevant ageing related events.

8.42. The ageing management programme should consider physical ageing as well as non-physical ageing (i.e. obsolescence or becoming out of date in comparison with current knowledge, codes, standards and regulations, and technology).

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

(a) Systematic monitoring of the condition of SSCs;
(b) Regular visual inspections of SSCs (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

8.44. 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, including modification of configuration control. A work control system, quality assurance procedures and appropriate testing procedures, as necessary, should be used for the implementation of modifications (including temporary modifications) at a reprocessing facility.

8.45. The operating organization of a reprocessing facility 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.

8.46. Proposed modifications at a reprocessing facility 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 particularly important if the modification could have an effect on criticality safety. The level of detail of the safety assessments for modifications to a reprocessing facility 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]).

8.47. The safety committee of the reprocessing facility is required to review any proposed modifications that might have significance for safety (see para. 4.31(d) of SSR-4 [1]). Suitable records should be kept of the committee's decisions and recommendations.

8.48. Safety related documentation is required to be updated to reflect modifications (see para. 9.57(f) of SSR-4 [1]). The plans for each modification at a reprocessing facility should specify any documentation and training that will need to be updated (e.g. training programme, specifications, safety assessment, emergency plans, notes, drawings, engineering flow diagrams, process instrumentation diagrams, operating procedures).

8.49. Personnel involved in implementing a modification are required to be suitably trained and qualified (see para. 9.57(e) of SSR-4 [1]).

8.50. The management system for the reprocessing facility (see Section 3) should include a process for the overall monitoring of the progress of modifications and for ensuring 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 is declared fully operational again.

8.51. Modifications to the design, layout, organization or procedures at a reprocessing facility might adversely affect nuclear security. The possible effects of such modifications on nuclear security are required to be considered to verify that safety measures and security measures do not compromise each other (see Requirement 75 of SSR-4 [1]).

8.52. The modifications made to a reprocessing facility (including modifications to the operating organization) should be reviewed on a regular basis to ensure that the cumulative effects of multiple modifications with minor safety significance do not have unforeseen effects on the overall safety of the facility. This review should be part of (or additional to) periodic safety review or an equivalent safety assessment process.

CONTROL OF CRITICALITY HAZARDS AT A REPROCESSING FACILITY

8.53. 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 on criticality safety in all facilities and activities are provided in SSG-27 (Rev. 1) [3].

8.54. 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 (see para. 9.89(a) of SSR-4 [1]);
(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 performed;
(e) Management of reflecting materials more efficient than water, such as additional shielding (where used);
(f) Management of mass in transfers of fissile material, where mass control is performed;
(g) Management of reagents or fluids that might cause dilution of a liquid poison and/or the precipitation of fissile material, where poison or concentration control is performed;
(h) Reliable methods for detecting the onset of any deviations from normal operation, particularly those parameters relied on for the avoidance of criticality;
(i) Periodic calibration or testing of systems for the control of criticality hazards;

(j) Emergency drills to prepare for the occurrence of criticality and/or the actuation of a criticality alarm.

8.55. 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]).

8.56. 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 any uncertainties associated with burnup measurements.

8.57. In chemical cycles at a reprocessing facility, particular care should be taken 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 or 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 internal doses.

8.58. 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 (see also para. 9.89(b) of SSR-4 [1]);
(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 (e.g. 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.

8.59. 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 attention should be paid to maintenance work and to inter-campaign periods, when material and residues from different campaigns might become mixed.

8.60. 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 learned.

RADIATION PROTECTION AT A REPROCESSING FACILITY

8.61. Requirements for radiation protection during the 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 Section 3 of GSR Part 3 [8]; recommendations on the implementation of requirements for the protection of workers are provided in IAEA Safety Standards Series No. GSG-7, Occupational Radiation Protection [35].

8.62. The operating organization of a reprocessing facility is required to ensure that doses are below authorized limits and are as low as reasonably achievable (see para. 9.91 of SSR-4 [1]). Furthermore, occupational exposures are required to be below the dose constraints set by the operating organization (see para. 9.93 of SSR-4 [1]). To ensure that these requirements are met, the operating organization of a reprocessing facility should establish a policy to ensure that protection and safety is optimized using a systematic approach.

8.63. 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, and the complexity and size of the reprocessing facility. 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; safety committee);
(b) Designation and functions of qualified experts (e.g. in radiation protection, internal and external dosimetry, workplace monitoring, ventilation, occupational health and radioactive waste management);
(c) Integration of radiation protection with other areas of health and safety (e.g. industrial hygiene, industrial safety, chemical safety, fire safety);
(d) Accountancy system for radiation generators and radioactive sources (providing their location, description, output, activity, and physical and chemical form, as appropriate);
(e) Designation of controlled areas and supervised areas;
(f) Local rules and procedures necessary for the protection and safety of 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, auditing and correcting identified deficiencies;
(l) Emergency procedures;
(m) Programme for workers' health surveillance.

8.64. Requirements for the designation of controlled areas and supervised areas are established in paras 3.88–3.92 of GSR Part 3 [8]. Consideration should also be given to the further classification of such designated areas in accordance with the radiation hazard. Such classification helps operating personnel in assessing the radiation risks associated with the 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, if necessary, adjusted to reflect the radiological conditions.

8.65. In areas of a reprocessing facility in which there is the potential for airborne 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 airborne contamination for the area. Mobile air samplers should be used near sources of contamination and at the boundaries of contamination zones as necessary, for example, 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.

8.66. The radiation protection programme should include provisions for detecting changes in the radiological status (e.g. hot spots, slow incremental increases or decreases in radiation or contamination levels) of equipment (e.g. pipes, vessels, drip trays, filters) or rooms, including through 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.

8.67. 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.

8.68. 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, preferably of limited duration.

8.69. 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 determined on the basis of the relative risk of radiation or contamination in the individual areas (see para. 3.97 of GSR Part 3 [8]). Radiation protection personnel should consider assigning a frequency for monitoring of each facility area based on easily identified boundaries. The use of photographs or drawings of the area or equipment should be considered in reporting the findings.

8.70. Radiation protection personnel (i.e. radiation protection managers, radiation protection officers and associated staff) should be involved in decision making associated with the optimization of protection and safety (e.g. the early detection and mitigation of hot spots) and proper housekeeping (e.g. waste segregation, packaging and removal).

8.71. Protection against internal exposure and external exposure should be provided during all operations at a reprocessing facility, 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.

8.72. 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.[38]

8.73. Regular contamination surveys of the reprocessing facility areas and equipment should be performed to confirm the adequacy of 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, which should be balanced against the normal exposure from routine operations.

8.74. Newly identified contamination zones within a reprocessing facility 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 checks at entry points and a dedicated, local ventilation system). A register should be maintained of such temporary contamination zones, barriers and enclosures. This register should be reviewed regularly by an appropriate level of management. The objective should be to reduce the number of temporary contamination zones either through decontamination or, where possible, through the elimination of the root cause, which might necessitate modifications to the reprocessing facility or its procedures.

[38] 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 accumulation of waste 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).

8.75. Appropriate means of timely and effective communications between operating personnel, radiation protection personnel, maintenance personnel and senior management should be established and maintained to ensure timely corrective actions.

8.76. 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."

8.77. Site personnel should be trained in the use of personal dosimeters and personal protective equipment (including putting them on and taking them off) 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 [8]).

8.78. Personnel and equipment should be checked for contamination before leaving contamination zones and should be decontaminated as necessary.

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

8.80. Intrusive maintenance[39] is considered a normal or regular occurrence in reprocessing facilities. The procedures for such work should include the following:

(a) An estimation, prior to the work, of the doses that are predicted to be received by all persons involved (including decontamination personnel).
(b) Preparatory activities to minimize individual and collective doses, including:
    (i) Identification of specific risks due to the intrusive nature of the maintenance;
    (ii) Operations to minimize the radiation source (inventory), such as flushing out and rinsing of parts of the process;

[39] 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.

(iii) Consideration of the use of mock-ups, remote devices, additional shielding, personal protective equipment, monitoring devices and dosimeters;
(iv) Identification of relevant procedures within the work permit, including procedures for optimizing protection and safety, such as use of personal protective equipment, monitoring devices and dosimeters, and time and dose limitations;
(v) Training of personnel on workflows and procedures in order to practise routines and to minimize radiation exposure.

(c) The measurement of doses during 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 occur continuously over the entire duration of the task.

8.81. 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:

(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[40] with a temporary ventilation system with filtration and/or exhaust to the facility's ventilation system;
    (ii) Barriers with appropriate additional monitors for measuring dose rates and/or airborne contamination and surface contamination.
(b) Personal protective equipment, 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 to monitor the radiological conditions and other safety related conditions. This individual should have the authority to halt the work and withdraw personnel in cases of unacceptable risk (e.g. oxygen deficiency, if air-fed equipment is in use). This individual should also provide assistance

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[40] An enclosure is a (usually temporary) combination of a static barrier (containment) supplemented by a dynamic barrier (ventilation) with appropriate entry facilities, which completely boxes in a work area and is sealed, as far as practicable, to local surfaces (e.g. walls, floors) 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 and easily decontaminable 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'.

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

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 a conservative assessment of the hazard and operational experience, until the risk assessment can be reviewed and refined with sources of new data.

8.82. Requirement 37 of SSR-4 [1] states that "**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.**"

8.83. The extent and type of workplace monitoring at a reprocessing facility should be commensurate with the expected dose rates and levels of airborne contamination and surface contamination and with 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 (i.e. alpha, beta, gamma or neutron) expected to be present within the reprocessing facility.

8.84. 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 active (e.g. electronic) dosimeters for beta, gamma and neutron radiation, as appropriate;
(b) Area gamma monitors and criticality detectors;
(c) Extremity dosimeters (e.g. to measure doses to the fingers or head in highly non-uniform radiation fields);
(d) Eye lens dosimeters;
(e) Mobile airborne activity monitors with immediate, local alarms (for maintenance work areas, tents and temporary enclosures, and airlocks);
(f) Mobile air samplers.

8.85. In the event of abnormal dose rates or contamination levels being detected in a room or area, checks of the personnel present in the area should be performed and decontamination or medical intervention should be implemented accordingly. Such interventions are outside the scope of this Safety Guide.

8.86. Further recommendations on occupational radiation protection and the assessment of internal exposure and external exposure, including recommendations on decontamination, are provided in GSG-7 [35].

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

8.87. 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].

8.88. 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 non-radiological hazards that could be present in a reprocessing facility is extensive and includes the following:

(a) Conventional hazardous chemicals being used in the process or in storage;
(b) Electrical works;
(c) Fire and explosion;
(d) Superheated water and steam;
(e) Hazards resulting in asphyxiation and anoxia;
(f) Dropped loads;
(g) Elevated working places (potential for falls);
(h) Noise;
(i) Dust.

8.89. The exposure of personnel to chemical hazards should be assessed using a method similar to that for the assessment of radiation exposure, and the assessment should be based on 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 relevant regulatory authority. Limiting values for exposure to various chemical hazards are provided in Ref. [28].

8.90. 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 processes conducted at elevated temperatures and to the hazards associated with the use of organic solvents in the extraction stages.

8.91. In the reprocessing facility and associated 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 chemicals that can be used. Where necessary, local enclosures and ventilation and personal protective equipment should be specified and provided. Consideration should be given to the need for breathing apparatus, equipment for dealing with chemical spills, and suitable protective clothing for dealing with chemical emergencies.

8.92. 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 with an indication of the potential hazards that the chemical poses.

8.93. Site personnel should be informed about the chemical hazards within the reprocessing facility. 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]) to enable them to adequately identify and respond to problems that might lead to accidents.

8.94. As required by regulatory requirements, a health surveillance programme should be set up to routinely monitor the health of those personnel at a reprocessing facility who might be exposed to harmful chemicals. The surveillance programme should address short term effects (acute exposure) and long term effects (chronic exposure).

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

8.96. Flammable, combustible, explosive and strongly oxidizing materials are used in reprocessing facilities (e.g. organic solvents in the extraction stage; 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 that the impact of the incident can be minimized.

8.97. To minimize the fire hazard of pyrophoric metals (e.g. zirconium or uranium particles) at a reprocessing facility, 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.

8.98. The procedures and training for responding to fires in areas containing fissile material should pay particular attention to the prevention of criticality and the prevention of any unacceptable reduction of criticality safety margins. Further recommendations are provided in SSG-27 (Rev. 1) [3].

8.99. 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 that need to be taken when performing such activities.

8.100. The prevention and control of the accumulation of waste (both contaminated and ‘clean’ waste) should be rigorously enforced to minimize the fire load (fire potential) in all areas of the reprocessing facility. Auditing for waste accumulation 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.

8.101. To ensure the efficiency and operability of fire protection systems, suitable procedures, training and exercises are required to be implemented (see para. 9.109 of SSR-4 [1]). These include the following:

(a) Periodic testing, inspection and maintenance of devices associated with fire protection systems (e.g. fire detectors, sprinklers, fire extinguishers, fire dampers, hydrants, firewater pumps);
(b) General and detailed (location specific) instructions and related training for firefighters;
(c) Firefighting plans;
(d) Fire response drills, including the involvement of off-site emergency services (see also para. 9.112 of SSR-4 [1]);
(e) Training for operating staff and emergency workers.

MANAGEMENT OF RADIOACTIVE WASTE AND EFFLUENTS AT A REPROCESSING FACILITY

8.102. Requirements relating to the management of radioactive waste and effluents in the operation of a nuclear fuel cycle facility are established in Requirement 68 and paras 9.102–9.108 of SSR-4 [1].

8.103. All operating personnel at a reprocessing facility should be trained in the waste management hierarchy (i.e. eliminate, reduce, reuse, recycle and dispose; see para. 4.6 of GSR Part 5 [2]), the waste management programme for the facility and the relevant procedures. Waste minimization targets should be set and regularly reviewed, and a system for continuous improvement (i.e. minimization of waste volumes and waste activity in relation to the work performed) should be implemented.

8.104. All waste generated at a reprocessing facility should be treated and stored in accordance with pre-established criteria, taking into account any national waste classification schemes. Waste management involves consideration of 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 to be retrievable (see paras 9.104 and 9.106 of SSR-4 [1]).

8.105. 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 through the reuse, recycling and decontamination of materials). Trends in the generation of radioactive waste at a reprocessing facility 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.

8.106. The accumulation of radioactive waste on the site of a reprocessing facility 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.

8.107. 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 characterization should include a determination of the waste's physical, chemical and radiological properties to allow its subsequent management (i.e. appropriate pretreatment, 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 temporary storage or disposal, as appropriate. Particular care should be taken to segregate waste containing fissile material and to ensure criticality safety for such waste (see also paras 9.84 and 9.85 of SSR-4 [1]).

8.108. Consideration should be given to segregating solid waste at a reprocessing facility in accordance with its origin, which can be indicative of its potential radioactive 'fingerprint'[41] and thus can provide information that can be used to determine the most suitable routes for processing, storage and disposal. The radioactive fingerprint, in conjunction with rapid, local radiological measurements (e.g. total beta and gamma activity), should be used as sorting criteria at the location where the waste is generated. This approach permits the waste to be rapidly segregated and the appropriate waste handling techniques to be chosen. This approach should be used to optimize protection and safety in the initial handling of the waste, in the subsequent detailed characterization of the waste and, if necessary, in the sorting of the waste in dedicated waste handling areas. Remote or automatic equipment should be used to the extent practicable.

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

8.110. Decontamination methods should be adopted at a reprocessing facility to 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.

8.111. As far as reasonably achievable, decontamination should be used to minimize the environmental impact and maximize the recovery of nuclear material.

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[41] 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.

Decontamination of alpha contaminated (e.g. plutonium) waste should be as complete as economically practicable in order to reduce, and ideally minimize, the impact of long lived alpha emitting radionuclides on the environment, provided that recovery routes are available for the decontamination waste stream.

8.112. Clearance procedures for radioactive waste should be provided in accordance with regulatory requirements. These procedures should be used as fully as practicable to minimize the volumes of radioactive waste and thus the size of disposal facility necessary.

8.113. Information about the radioactive waste that is necessary for the safe management and eventual disposal of the waste 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]).

8.114. Reprocessing facilities usually have several discharge points that correspond, either separately or collectively, to the authorized limits on discharges for the facility. The operating organization should establish an appropriate management structure to operate and control each of these discharge points, as well as the overall discharges.

8.115. 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]). Where possible, for reprocessing facilities, effluent streams should be monitored 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.

8.116. As described in para. 5.174, 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 requirements might not be met.

8.117. The operating organization should establish a list of performance indicators to assist in the monitoring and review of programmes for the minimization of discharges. The indicators should be established in relation to maximum upper limits; for example, monthly goals for discharges to the environment.

8.118. Periodic estimates of the impact on the public of radioactive discharges from the reprocessing facility (i.e. based on the estimated dose to the representative person) 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.

8.119. Radioactive gaseous discharges from a reprocessing facility 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 indicated by the safety analysis) is required to be tested (see para. 6.103 of SSR-4 [1]), and this testing should be defined in the operational limits and conditions.

8.120. All liquids collected from the site of the reprocessing facility (e.g. surface water or groundwater near buildings) that have to be discharged into the environment should be assessed and managed in accordance with regulatory requirements for exemption or clearance or in accordance with discharge authorizations. 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.

8.121. An authorization for liquid discharges from a reprocessing facility usually specifies an annual quantity of specified radionuclides and, if necessary, the physical and chemical characteristics of the effluent. It may also prescribe further conditions designed to minimize the environmental impact, for example, discharge at high tide or above a minimum river flow. Operational procedures should be implemented to meet the requirements of the authorization.

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

EMERGENCY PREPAREDNESS AND RESPONSE FOR A REPROCESSING FACILITY

8.123. General requirements for emergency preparedness and response are established in GSR Part 7 [20]. Supporting recommendations on emergency arrangements are provided in GS-G-2.1 [33] and in IAEA Safety Standards Series No. GSG-2, Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency [36]. 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].

8.124. As part of emergency preparedness, arrangements are required to be developed for coordination between the operating organization and the local, regional and national emergency response organizations (see para. 3.1 and Requirement 22 of GSR Part 7 [20]). 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 [20] and para. 9.130 of SSR-4 [1]).

8.125. Suitable, reliable and diverse means of communication are required to be established with local authorities and response organizations (see para. 5.43 of GSR Part 7 [20]).

8.126. Requirement 10 of GSR Part 7 [20] states:

> "**The government shall ensure that arrangements are in place to provide the public who are affected or are potentially affected by a nuclear or radiological emergency with information that is necessary for their protection, to warn them promptly and to instruct them on actions to be taken.**"

8.127. The operating organization of a reprocessing facility is required to ensure the availability of personnel with specific expertise on assessing the magnitudes of hazards and the possible development of hazardous conditions in the facility, as well as the availability and reliability of all supplies, equipment, communication systems, plans, procedures and other arrangements necessary for effective response in an emergency (see para. 5.31 of GSR Part 7 [20] and 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 (see also para. 6.21 of GSR Part 7 [20]).

8.128. The emergency plan and procedures for a reprocessing facility 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.

8.129. In accordance with para. 4.14(b) of GSR Part 7 [20], emergency plans, security plans and contingency plans are required to be developed in a coordinated manner. This coordination should take into account the responsibilities of personnel with responsibilities for safety and of personnel with responsibility for nuclear security, to ensure that in the case of an event at a reprocessing facility 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 [20]). 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 practised and evaluated by security forces and emergency workers. From these exercises or evaluations, lessons should be identified and recommendations should be made to improve the overall response to a potential event.

8.130. For establishing procedures for access control during emergencies at a reprocessing facility, when there is a necessity for rapid access and egress of personnel, safety and security specialists should cooperate closely. Safety and nuclear security objectives should both be sought during emergencies to the extent possible, in accordance with regulatory requirements.

FEEDBACK ON OPERATING EXPERIENCE AT A REPROCESSING FACILITY

8.131. Requirements for feedback on operating experience at a nuclear fuel cycle facility are established in Requirement 73 and paras 9.133–9.137 of SSR-4 [1]. Recommendations on programmes for operating experience feedback are provided in SSG-50 [17].

8.132. The programme for feedback on operating experience at a reprocessing facility is required to cover experience and lessons learned 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, if applicable, at other nuclear installations. The programme is required to include a reporting system and consideration of technical, human and organizational factors (see paras 9.134 and 9.135 of SSR-4 [1]).

8.133. 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 in the Fuel Incident Notification and Analysis System (FINAS) database[42].

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 [37]. Requirements for preparation for the decommissioning of a reprocessing facility are established in Requirement 74 and paras 10.1–10.13 of SSR-4 [1]. The operating organization of a reprocessing facility is required to allocate adequate financial resources for safe decommissioning where these are not provided by the government (see para. 4.2(e) of SSR-4 [1]).

9.2. At the end of the facility's operations stage, the reprocessing facility should be safely shut down and the hazardous inventory and corrosive materials should be removed as far as practicable. The operational experience gained through the ageing management programme (see paras 5.187–5.190 and 8.41–8.43) should be used to ensure that the SSCs in the facility have sufficient residual life to support safe post-operational cleanup and safe decommissioning. During the period between shutdown of operations and decommissioning, the implications for safety of the reprocessing facility are required to be assessed and managed (see para. 10.9 of SSR-4 [1]). Safety measures should be implemented, as appropriate, to maintain the reprocessing facility in a safe and stable state, including measures to prevent criticality and the spread of contamination and fire, and to maintain

[42] http://finas.iaea.org

appropriate radiological monitoring. The need to revise the safety assessment for the facility in its shutdown state should be considered. The application of knowledge management methods to retain the knowledge and experience of operating personnel in a durable and retrievable form should also be considered.

9.3. The decommissioning plan is 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 [37] and paras 10.1, 10.2 and 10.9 of SSR-4 [1]) to take into account new information and emerging technologies. The aim should be to ensure the following:

(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 anticipated radioactive waste remains compatible with available (or planned) temporary storage capacities and disposal facilities, including any transport and treatment.

9.4. 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 and for which subcriticality is controlled by geometry, moderation or absorption (see paras 10.11–10.13 of SSR-4 [1]).

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Annex I

MAIN PROCESS ROUTES AT A REPROCESSING FACILITY

I–1. The main processes in the reprocessing facility include head end operations, separation of plutonium and uranium, plutonium finishing and uranium finishing. Further details on these processes are given in Figs I–1 to I–4.

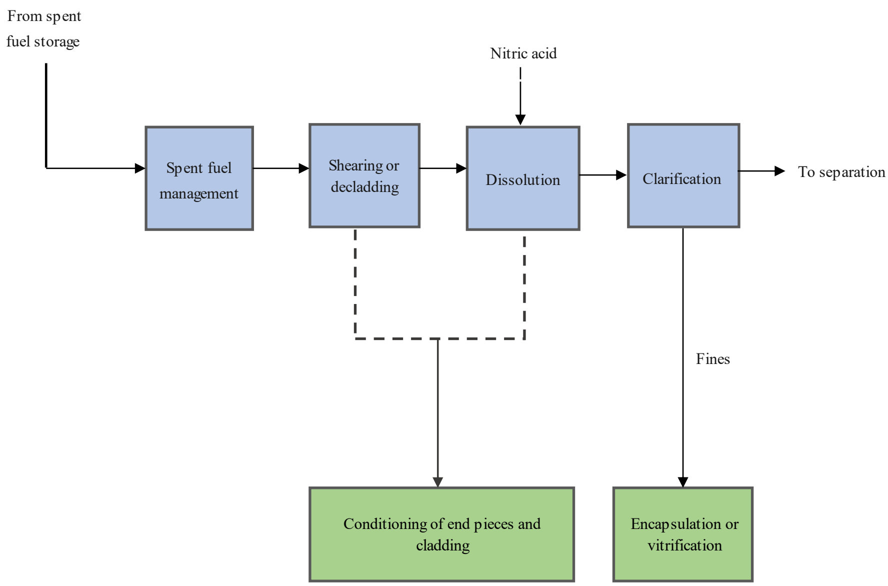

FIG. I–1. Main process routes at the head end of a reprocessing facility.

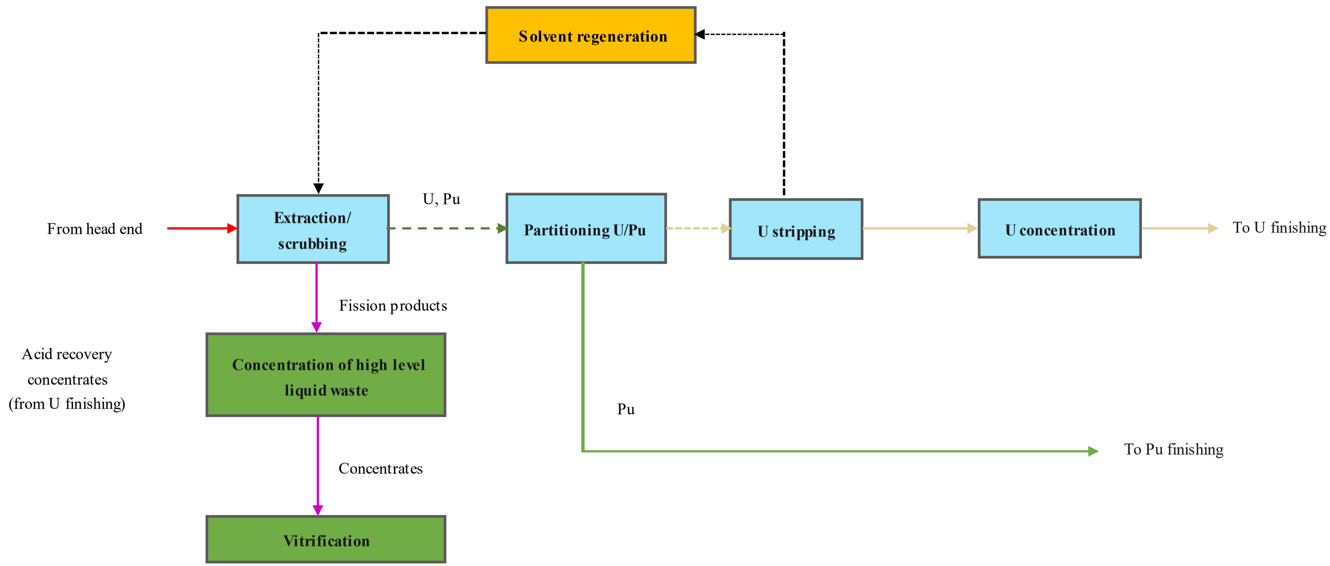

FIG. I–2. Separation of uranium and plutonium at a reprocessing facility.

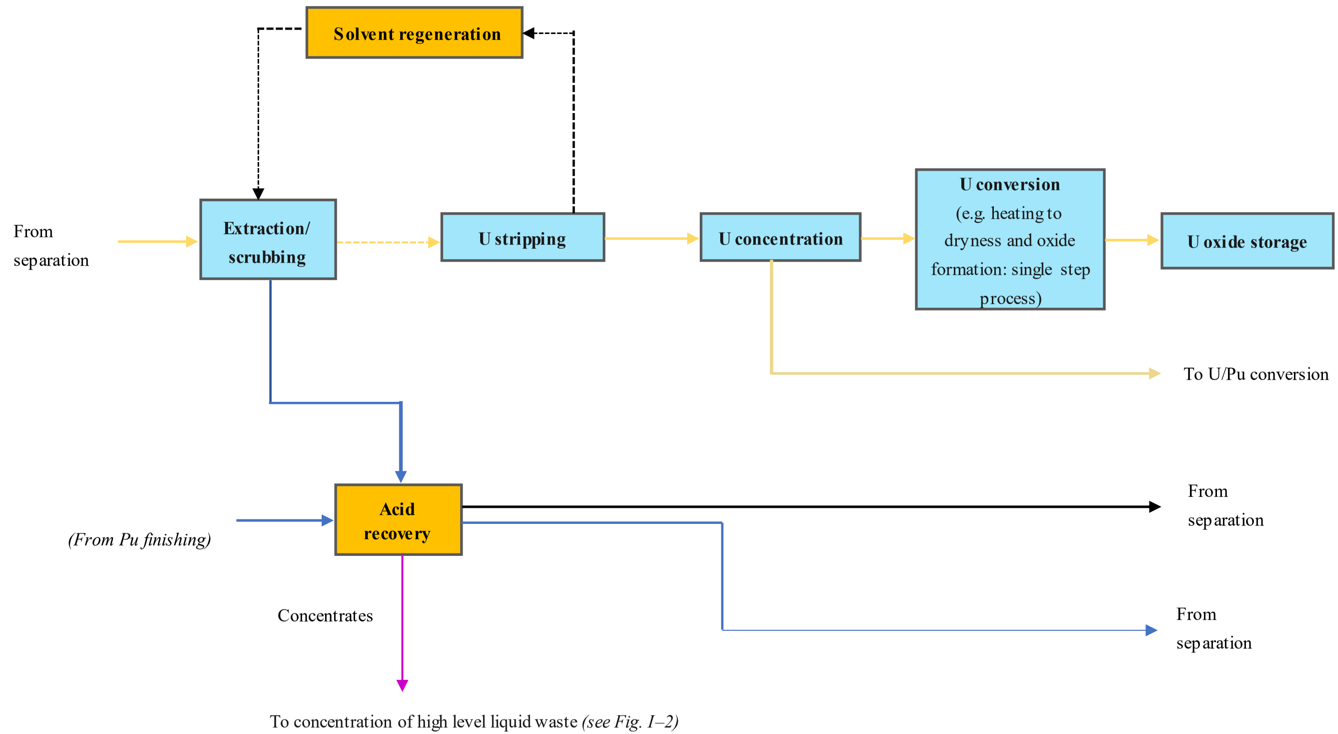

FIG. I–3. Uranium finishing at a reprocessing facility.

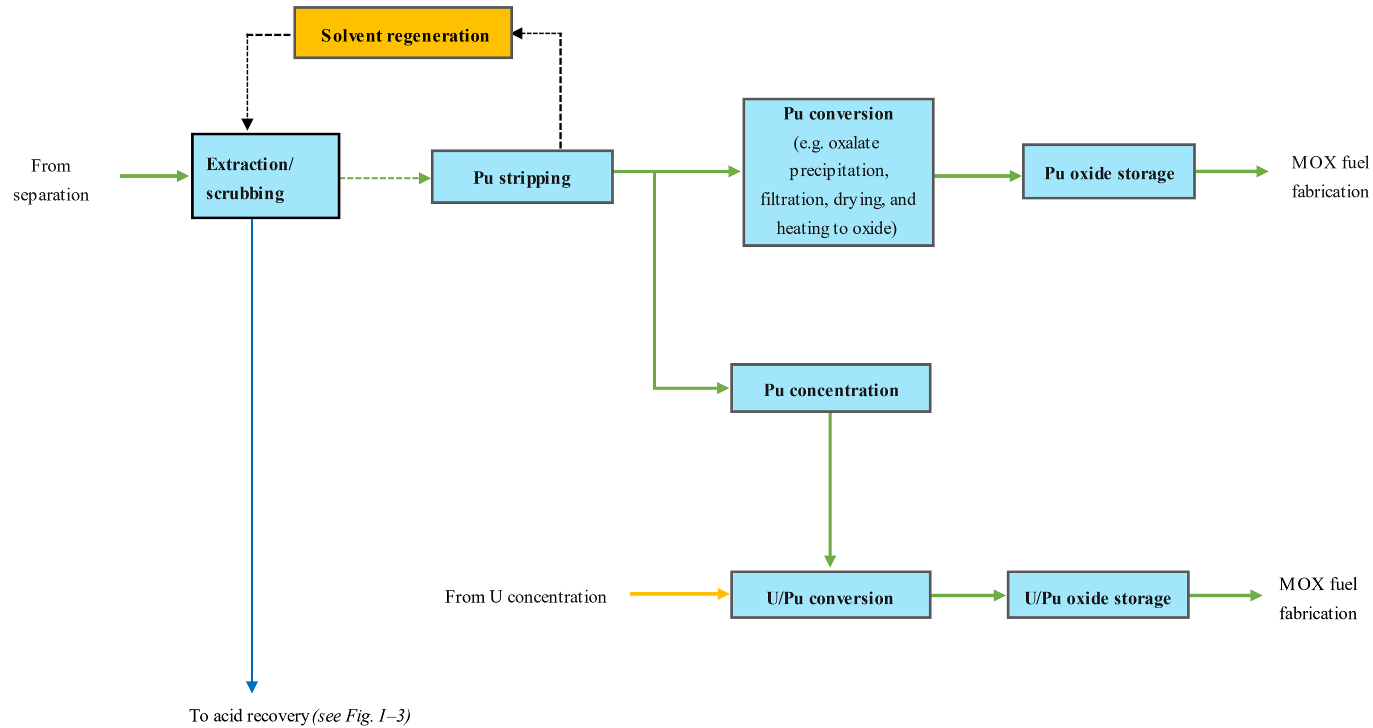

FIG. I–4. Plutonium finishing at a reprocessing facility. MOX: mixed oxide.

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

II–1. The main safety functions for a reprocessing facility are as follows:

(1) Prevention of criticality.
(2) Confinement of radioactive material:
    (a) Integrity of barriers;
    (b) Cooling and the removal of decay heat;
    (c) Prevention of radiolysis and of generation of other hazardous explosive or flammable materials.
(3) Protection against radiation exposure.

Tables II–1 to II–4, grouped in accordance with the processes identified in Annex I, present examples of the process areas, structures, systems and components important to safety, and representative events in a reprocessing facility that could challenge the associated safety functions. Examples of the parameters used for defining operational limits and conditions for these process areas are also provided in these tables.

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, 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 necessary)	Criticality event	1	Neutron poison concentration
Clarification	(See the process area ‘Vessel’)		3	

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
Clarification	Analytical measurement system	Criticality event in the final storage vessel	1	Hydrogen:plutonium ratio
	Filter cleaning, centrifuge cleaning systems	Potential release of radioactive material	3	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
Vessel	Vessels containing radioactive solution	Leakage of radioactive 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 radioactive solution
	Heating supply system (if any)	Overheating, boiling, crystallization, corrosion	2a, 2b, 2c	Flow rate of heating fluid; temperature of radioactive solution
	Supply system in air for dilution of radiolysis gases (if any)	Explosion (hydrogen)	2c	Flow rate of diluting air for dilution

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	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

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

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
Uranium/ plutonium partitioning	Criticality event detection system	Criticality event (mitigation)	1	Criticality alarm system
Stripping/ concentration of uranium	Temperature control system	Explosion (red oil)	2c	Temperature
	Process parameters control system	Explosion (red oil)	2c	Administrative controls
Solvent regeneration	Temperature control system	Explosion (hydrazine)	2c	Temperature
		Fire (organic material)	2a	
	Analytical measurement system	Explosion (hydrazine)	2c	Administrative controls
		Fire (organic material)	2a	
High level liquid waste concentration	(See the process area ‘Vessel’ in Table II–1)		3	
	Temperature control system	Explosion (red oil)	2c	Temperature
	Control system for the destruction of nitrates	Overpressure	2c	Administrative controls

TABLE II–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
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

TABLE II–3. URANIUM FINISHING AT A REPROCESSING FACILITY (*see Fig. I–3*)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Uranium 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 FINISHING 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 flow rate
	Storage rack	Criticality	1	Geometry (design, commissioning)
Solvent regeneration	Temperature control system	Fire (organic material)	2a	Temperature
	Analytical measurement system	Fire (organic material)	2a	Administrative controls

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