IAEA Safety Standards

for protecting people and the environment

Safety of Conversion Facilities and Uranium Enrichment Facilities

Safety Guide

No. SSG-5 (Rev. 1)

IAEA
International Atomic Energy Agency

IAEA SAFETY STANDARDS AND RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

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

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

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

https://www.iaea.org/resources/safety-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.

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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 CONVERSION FACILITIES AND URANIUM ENRICHMENT FACILITIES

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

IAEA Safety Standards Series No. SSG-5 (Rev. 1)

SAFETY OF CONVERSION FACILITIES AND URANIUM ENRICHMENT FACILITIES

SPECIFIC SAFETY GUIDE

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Marketing and Sales Unit, Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
fax: +43 1 26007 22529
tel.: +43 1 2600 22417
email: sales.publications@iaea.org
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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.

Safety Requirements

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

Safety Guides

Safety Guides provide recommendations and guidance on how to comply with the safety requirements, indicating an international consensus that it

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

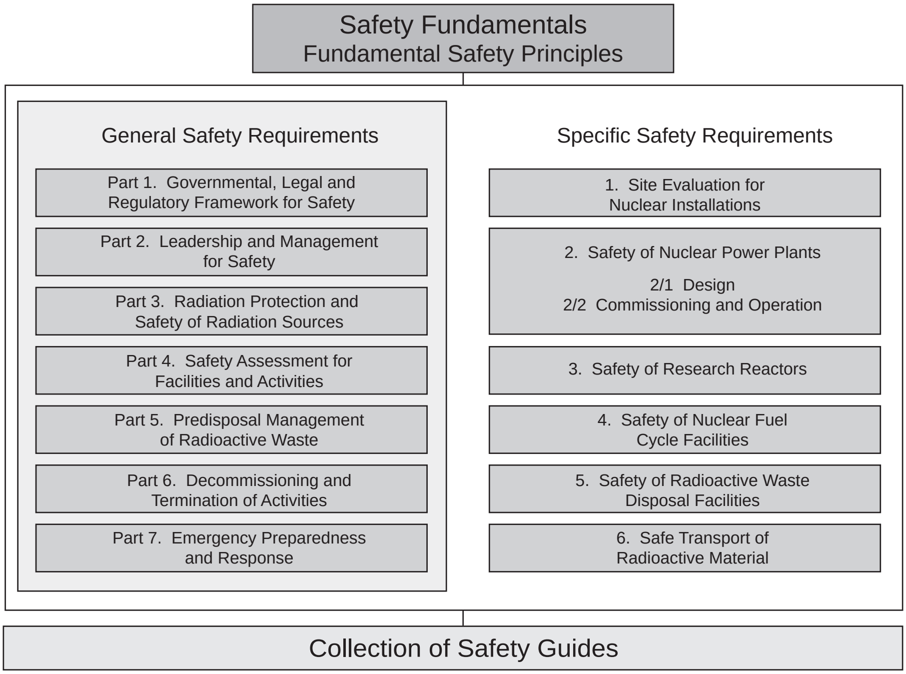

FIG. 1. The long term structure of the IAEA Safety Standards Series.

is necessary to take the measures recommended (or equivalent alternative measures). The Safety Guides present international good practices, and increasingly they reflect best practices, to help users striving to achieve high levels of safety. The recommendations provided in Safety Guides are expressed as ‘should’ statements.

APPLICATION OF THE IAEA SAFETY STANDARDS

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

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

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

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

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

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

DEVELOPMENT PROCESS FOR THE IAEA SAFETY STANDARDS

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

All IAEA Member States may nominate experts for the Safety Standards Committees and may provide comments on draft standards. The membership of 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.

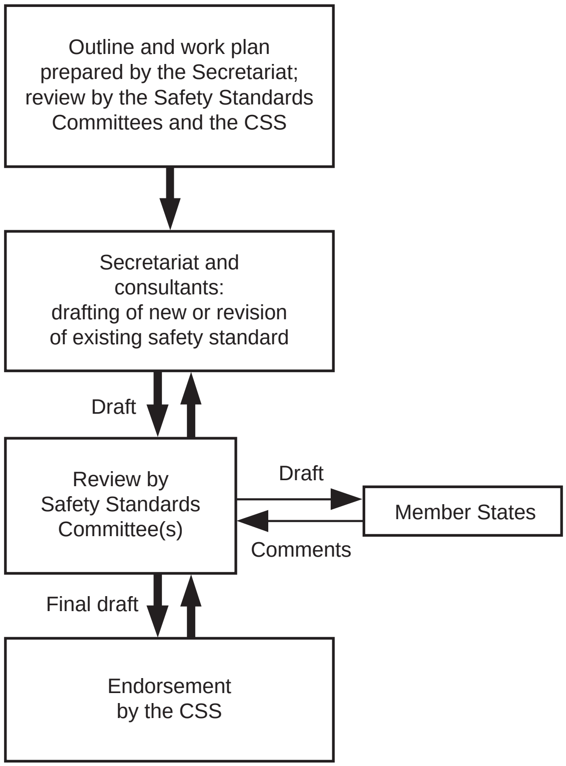

FIG. 2. The process for developing a new safety standard or revising an existing standard.

It articulates the mandate of the IAEA, the vision for the future application of the safety standards, policies and strategies, and corresponding functions and responsibilities.

INTERACTION WITH OTHER INTERNATIONAL ORGANIZATIONS

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

INTERPRETATION OF THE TEXT

Safety related terms are to be understood as defined in the IAEA 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 all the important areas of 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 conversion facilities and uranium enrichment facilities. Uranium and the waste generated in conversion facilities and uranium enrichment facilities are handled, processed, treated and stored at the facility. Conversion facilities and uranium enrichment facilities may process or use large amounts of hazardous chemicals, which can be toxic, corrosive, combustible and/or explosive.

1.3. The conversion process and the enrichment process can rely to a large extent on operator intervention and administrative controls to ensure safety, in addition to passive and active engineered safety measures. The potential hazard associated with these facilities includes a loss of the means of confinement resulting in a release of uranium hexafluoride (UF_6) and hazardous chemicals such as hydrogen fluoride and fluorine. In addition, for uranium enrichment facilities and conversion facilities that process uranium with a ^{235}U enrichment of more than 1%, criticality can also be a potential hazard.

1.4. This Safety Guide supersedes IAEA Safety Standards Series No. SSG-5, Safety of Conversion Facilities and Uranium Enrichment Facilities[1].

OBJECTIVE

1.5. The objective of this Safety Guide is to provide recommendations on site evaluation, design, construction, commissioning, operation and preparation for decommissioning of conversion facilities and uranium enrichment facilities to meet the applicable requirements established in SSR-4 [1].

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Conversion Facilities and Uranium Enrichment Facilities, IAEA Safety Standards Series No. SSG-5, IAEA, Vienna (2010).

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

SCOPE

1.7. The safety requirements applicable to fuel cycle facilities (i.e. facilities for uranium refining; conversion; enrichment; reconversion[2]; storage of fissile material; fabrication of fuel, including uranium and plutonium 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 conversion facilities or uranium enrichment facilities.

1.8. This Safety Guide deals specifically with the handling, processing, material transfer and storage of depleted, natural and low enriched uranium (LEU) that has a ^{235}U enrichment of no more than 6%, which could be derived from natural, high enriched, depleted or reprocessed uranium. Recommendations are also provided for auxiliary activities such as laboratory services. This Safety Guide also deals with the generation and management of radioactive wastes and effluents arising from the handling and processing of these materials.

1.9. The provisions for the conversion of uranium concentrate to UF_6 described in this publication are applicable to several different conversion processes that are currently used throughout the world on a large industrial scale. The provisions of this Safety Guide are applicable to the gas centrifuge enrichment process, which is currently the only process used for uranium enrichment on an industrial scale. This publication includes specific recommendations for ensuring criticality safety in a conversion facility or a uranium enrichment facility. It supplements more detailed recommendations on criticality safety provided in IAEA Safety Standards Series No. SSG-27 (Rev. 1), Criticality Safety in the Handling of Fissile Material [2].

1.10. The implementation of safety requirements on the legal and governmental framework and regulatory supervision (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 [3] is not addressed in this Safety Guide.

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[2] Also called ‘deconversion’.

1.11. This Safety Guide does not include recommendations on nuclear security. Recommendations on nuclear security for a conversion facility or uranium enrichment facility 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) [4] 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) [5]. However, this Safety Guide includes recommendations on managing interfaces between safety, nuclear security and the State system for nuclear material accounting and control.

STRUCTURE

1.12. Section 2 provides an overview of hazards in a conversion facility or uranium enrichment facility. Section 3 provides recommendations on the development of a management system for such facilities and the activities associated with it. Section 4 describes the safety aspects to be considered in the evaluation and selection of a site to avoid or minimize any environmental impact of operations. Section 5 addresses safety in the design stage; it provides recommendations on the conduct of the safety analysis for operational states and accident conditions and provides details on the safety aspects of radioactive waste management in a conversion facility or a uranium enrichment facility and on other design considerations. Section 6 addresses safety aspects in the construction stage. Section 7 addresses safety considerations in commissioning. Section 8 deals with safety in the stage of operation of the facility and provides recommendations on the management of operation, maintenance and periodic testing, control of modifications, criticality control, radiation protection, industrial safety, management of waste and effluents, and emergency preparedness and response. Section 9 provides recommendations on meeting the safety requirements for the preparation for decommissioning of a conversion facility or a uranium enrichment facility. Annexes I and II illustrate the typical process routes for a conversion facility and a uranium enrichment facility, respectively. Annexes III and IV provide examples of structures, systems and components important to safety and operational limits and conditions grouped in accordance with process areas, for conversion facilities and uranium enrichment facilities, respectively.

2. HAZARDS IN CONVERSION FACILITIES AND URANIUM ENRICHMENT FACILITIES

2.1. In conversion facilities and uranium enrichment facilities, large amounts of uranium compounds can be present. In conversion facilities the raw uranium mining product is processed to UF_6, and uranium exists in diverse chemical and physical forms (e.g. gaseous, liquid, solid, dissolved) and is used in conjunction with flammable or chemically reactive substances as part of the process. In uranium enrichment facilities, most of the uranium is in the form of UF_6.

2.2. For conversion facilities the main hazards are the following:

— Potential release of chemicals, especially hydrogen fluoride, fluorine and UF_6;
— External exposure from the handling of residues containing thorium and its decay products produced in fluorination reactors;
— External exposure from the handling of recently emptied cylinders, especially those used as containers for reprocessed uranium, where there is a buildup of ^{232}U.

2.3. For uranium enrichment facilities the main hazards are the following:

— Potential release of UF_6;
— Potential criticality event, since the enrichment of ^{235}U present in uranium enrichment facilities is greater than 1%;
— External exposure from the handling of recently emptied cylinders, and cylinders used as containers for reprocessed uranium, with a buildup of ^{232}U.

2.4. Generally, in a conversion facility or a uranium enrichment facility, only natural uranium or LEU that has a ^{235}U enrichment of no more than 6% is processed. The radiotoxicity of this uranium is low, and any potential off-site radiological consequences following an accident would be expected to be limited. However, the radiological consequences of an accidental release of reprocessed uranium would be likely to be greater, and this should be taken into account in the safety assessment if the licence held by the facility permits the processing of reprocessed uranium. Moreover, the chemical toxicity of uranium, which is a heavy metal, is rather high and its absorption can lead to serious health problems.

2.5. For enrichment levels below 6% and for non-reprocessed uranium, the chemical toxicity of UF_6 is more significant than its radiotoxicity. Along with UF_6, hydrogen fluoride is also present, which is a hazardous chemical substance. When UF_6 is released, it reacts with water in the air producing mainly hydrogen fluoride and water-soluble uranyl fluoride (UO_2F_2), which present additional safety hazards. Therefore, comprehensive safety analyses for conversion facilities and uranium enrichment facilities should also address the potential non-radiological hazards resulting from these chemicals.

2.6. In general, conversion facilities and uranium enrichment facilities do not pose a potential radiation hazard with a capacity to cause an accident with a significant off-site release of radioactive material (in amounts equivalent to a release to the atmosphere of ^{131}I from a nuclear power plant with an activity of the order of thousands of terabecquerels). However, certain accident conditions involving hazardous chemicals (e.g. a large release of hydrogen fluoride) can potentially result in adverse off-site consequences, including death or serious injuries.

2.7. For the application of the requirement that the concept of defence in depth be applied at the facility (see section 2 of SSR-4 [1]), the first two levels of defence in depth, if applied correctly to conversion facilities and uranium enrichment facilities, would be able to reduce the risks to appropriately low levels by means of design and appropriate operating procedures (see Sections 5 and 8). Nevertheless, the remaining levels of defence in depth should still be applied in accordance with a graded approach.

3. MANAGEMENT AND VERIFICATION OF SAFETY FOR CONVERSION FACILITIES AND URANIUM ENRICHMENT FACILITIES

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

3.2. Requirements for the management system are established in IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [6]. Associated recommendations are provided in IAEA Safety Standards Series Nos GS-G-3.1, Application of the Management System for Facilities and Activities [7]; GS-G-3.5, The Management System for Nuclear Installations [8]; GSG-16, Leadership, Management and Culture for Safety in Radioactive Waste Management [9]; and TS-G-1.4, The Management System for the Safe Transport of Radioactive Material [10].

3.3. Coordination of the nuclear safety and security interface in the establishment of the integrated management system should be ensured. The management system should consider the specific concerns of each discipline regarding the management of information. Potential conflicts between the need for transparency of information relating to safety matters and the need for protection of information for security reasons should be addressed.

3.4. In determining how the management system for the safety of conversion facilities and uranium enrichment facilities is to be developed and applied, a graded approach is required to be used (see Requirement 7 and para. 4.15 of GSR Part 2 [6]). This approach should be based on the relative importance to safety of each item or process.

3.5. The management system is required to support the development and maintenance of a strong safety culture, including in all aspects of criticality safety (see Requirement 12 of GSR Part 2 [6]).

3.6. In accordance with paras 4.15–4.23 of SSR-4 [1], the management system is required to address the following functional areas:

(a) Management responsibility, which includes the necessary support and commitment of the management to achieve the objectives of the operating organization.
(b) Resource management, which includes the measures necessary to ensure that the resources essential to the implementation of safety policy and the enhancement of safety and the achievement of the objectives of the operating organization are identified and made available.
(c) Process implementation, which includes the actions and tasks necessary to achieve the goals of the operating organization.
(d) Measurement, assessment, evaluation and improvement, which provide an indication of the effectiveness of management processes and work performance compared with objectives or benchmarks. It is through

measurement, assessment and evaluation that opportunities for improvement are identified.

MANAGEMENT RESPONSIBILITY

3.7. The prime responsibility for safety, including criticality safety, rests with the operating organization. In accordance with para. 4.11 of GSR Part 2 [6], the management system for conversion facilities and uranium enrichment facilities is required to clearly specify the following:

(a) The organizational structure;
(b) Functional responsibilities;
(c) Levels of authority.

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

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

> "[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 conversion facility or uranium enrichment facility.

3.10. The operating organization is required to ensure that safety assessments and analyses are conducted, documented and updated (see Requirement 24 and para. 4.65 of IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), Safety Assessment for Facilities and Activities [11], and Requirement 5 of SSR-4 [1]).

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

RESOURCE MANAGEMENT

3.12. The operating organization is required to provide adequate resources (both human and financial) for the safe operation of a conversion facility or uranium enrichment facility (see Requirement 9 of GSR Part 2 [6]), including resources for mitigating the consequences of accidents.

3.13. The management of the operating organization should undertake the following:

(a) Determine the necessary competence of personnel and provide training, as necessary;
(b) Prepare and issue specifications and procedures on safety related activities and operations;
(c) Support the conduct of and perform safety assessments, including modifications;
(d) Have frequent personal contact with personnel, including observing work in progress;
(e) Make provisions for adequate staffing[3], succession planning and retention of corporate knowledge.

3.14. Requirement 58 of SSR-4 [1] states that “**The operating organization shall ensure that all activities that may affect safety are performed by suitably qualified and competent persons.**”

3.15. In accordance with Requirement 58 and paras 9.39–9.47 of SSR-4 [1], the operating organization is required to ensure that these personnel receive training and refresher training at suitable intervals, appropriate to their level of responsibility. In particular, personnel involved in activities with fissile material,

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

radioactive material (including waste) and chemicals should understand the nature of the hazard posed by these materials and how these risks are controlled by the established safety measures, operational limits and conditions, and operating procedures.

3.16. Requirement 11 of GSR Part 2 [6] 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.**" In accordance with paras 4.33–4.36 of GSR Part 2 [6], the management system for a conversion facility or a uranium enrichment facility is required to include arrangements for procurement.

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

PROCESS IMPLEMENTATION

3.18. 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.**"

Paragraph 9.66 of SSR-4 states that "Operating procedures shall be developed for all safety related operations that may be conducted over the entire lifetime of the facility."

3.19. The management system for a conversion facility (if applicable, see para. 5.37) or for a uranium enrichment facility should include management for criticality safety. Further recommendations on the management system for criticality safety are provided in SSG-27 (Rev. 1) [2].

3.20. Any proposed modifications to existing facilities or activities, or proposals for the introduction of new activities, are required to be assessed for their implications for existing safety measures and appropriately approved before implementation (see paras 9.57(b) and (c) 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(h) and 9.59 of SSR-4 [1]). The facility or activity documentation is required to be updated to reflect modifications (see paras 9.57(f) and (g) of SSR-4 [1]). The operating personnel, including supervisors, should receive adequate training on the modifications.

3.21. 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 the facility or duration of the activity involve different groups and interface with other areas such as those relating to nuclear security and to the system for nuclear material accounting and control. The 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 security should ensure that confidentiality of information is maintained. This includes the system of nuclear material accounting and control, for which information security should be coordinated in a manner ensuring that subcriticality is not compromised.

MEASUREMENT, ASSESSMENT, EVALUATION AND IMPROVEMENT

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

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

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

3.24. Requirement 73 of SSR-4 [1] states that "**The operating organization shall establish a programme to learn from events at the facility and events at other nuclear fuel cycle facilities and in the nuclear industry worldwide.**" Recommendations on operating experience programmes are provided in IAEA Safety Standards Series No. SSG-50, Operating Experience Feedback for Nuclear Installations [12].

VERIFICATION OF SAFETY

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

3.26. Requirement 6 of SSR-4 [1] states that "**An independent safety committee (or an advisory group) shall be established to advise the management of the operating organization on all safety aspects of the nuclear fuel cycle facility.**" The safety committee of a conversion facility or a uranium enrichment facility should have members or access to experts in areas of protection against toxic chemical hazards, criticality safety and radiation protection. Such experts should be available to the facility at all times during operation.

4. SITE EVALUATION FOR CONVERSION FACILITIES AND URANIUM ENRICHMENT FACILITIES

4.1. The site evaluation process for a conversion facility or a uranium enrichment facility will depend on a large number of variables. At the earliest stage of planning a facility, a list of these variables should be prepared and considered in accordance with their safety significance. The risks posed by possible significant external hazards (e.g. earthquakes, accidental aircraft crashes, fires, nearby explosions, floods, extreme meteorological conditions) will probably dominate in the site evaluation process and should be taken into account in the design of the facility. Requirements for site evaluation for a conversion facility or a uranium enrichment facility are established in IAEA Safety Standards Series No. SSR-1, Site Evaluation for Nuclear Installations [13] and further recommendations are provided in IAEA Safety Standards Series No. SSG-35, Site Survey and Site Selection for Nuclear Installations [14].

4.2. The scope of the site evaluation for a conversion facility or a uranium enrichment facility is established in Requirement 3 of SSR-1 [13] and Requirement 11 and paras 5.1–5.14 of SSR-4 [1] and should reflect the specific hazards listed in Section 2 of this Safety Guide.

4.3. The population density and population distribution in the vicinity of a conversion facility or a uranium enrichment 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/or hazardous chemicals (see Requirements 4 and 12 of SSR-1 [13]). Also, in accordance with Requirement 25 and paras 6.1 and 6.2 of SSR-1 [13], the dispersion in air and water of radioactive material released from the conversion facility or uranium enrichment 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. 5.3 of SSR-4 [1]) and should meet the applicable criteria established in national regulations.

4.4. Security advice is required to be taken into account in the selection of a site for a conversion facility or uranium enrichment facility (see para. 11.4 of SSR-4 [1]). The selection of a site should take into account both safety and security aspects and should be facilitated by both safety experts and security experts.

4.5. The operating organization should maintain a full record of the decisions taken on the selection of a site for a conversion facility or a uranium enrichment facility and the reasons behind those decisions.

4.6. The site characteristics should be reviewed periodically for their adequacy and persistent applicability during the lifetime of a conversion facility and uranium enrichment facility. Any changes to these characteristics that might require safety reassessment should be identified and evaluated (see para. 5.14 of SSR-4 [1]). This includes the case of an increase of the production capacity beyond the original envelope.

5. DESIGN OF CONVERSION FACILITIES AND URANIUM ENRICHMENT FACILITIES

SAFETY FUNCTIONS

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.**"

Maintaining subcriticality is applicable for facilities that process uranium with a ^{235}U enrichment of more than 1%.

5.2. The requirements on protection against internal radiation exposure are established in Requirement 34 and paras 6.120–6.122 of SSR-4 [1].

5.3. The requirements on the confinement of radioactive material and associated hazardous materials are established in Requirement 35 and paras 6.123–6.128 of SSR-4 [1].

5.4. The requirements on protection against external radiation exposure are established in Requirement 36 and paras 6.129–6.134 of SSR-4 [1]. Protective measures should be considered for processes or areas in conversion facilities and uranium enrichment facilities that could involve sources emitting high levels of gamma radiation, such as reprocessed uranium or newly emptied cylinders (e.g. exposure to decay products of ^{232}U and ^{238}U).

5.5. The requirements on maintaining subcriticality are established in Requirement 38 and paras 6.138–6.156 of SSR-4 [1]. Further recommendations on the design of conversion facilities and uranium enrichment facilities to ensure subcriticality are provided in section 3 of SSG-27 (Rev. 1) [2].

Design basis and safety analysis

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

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

5.8. The specification of a design basis (or equivalent) will depend on the design of the facility, the siting of the facility and regulatory requirements. However, particular consideration should be given to the following hazards in the specification of the design basis safety analysis:

(a) Hazards for conversion facilities:
    (i) Release of hydrogen fluoride or ammonia (NH_3) due to the rupture of a storage tank or piping;
    (ii) Release of UF_6 due to the rupture of a storage tank, piping or a hot cylinder;
    (iii) Fires resulting from exothermic reactions involving substances such as hydrogen and solvents;
    (iv) Internal and external hazards, including internal and external explosions (in particular, hydrogen explosions), internal and external fires, dropped loads and handling errors, extreme meteorological phenomena (in particular, earthquakes, flooding and tornadoes) and accidental aircraft crashes.
(b) Hazards for uranium enrichment facilities:
    (i) Release of UF_6 due to the rupture of a storage tank, piping or a hot cylinder;

(ii) Internal and external hazards, including internal and external explosions (in particular, hydrogen explosions), internal and external fires, dropped loads and handling errors, extreme meteorological phenomena (in particular, earthquakes, flooding and tornadoes) and accidental aircraft crashes.

5.9. These hazards would result primarily in chemicotoxic and radiological consequences for site personnel. However, they might also result in some adverse off-site consequences for the public or the environment.

5.10. The hazards listed in para. 5.8 might occur as a consequence of a postulated initiating event. Selected postulated initiating events for nuclear fuel cycle facilities are listed in the appendix of SSR-4 [1].

Structures, systems and components important to safety

5.11. 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."

Annexes III and IV to this Safety Guide present examples of structures, systems and components and representative events that might challenge the associated safety functions in conversion facilities and uranium enrichment facilities.

Confinement of radioactive material and toxic chemical material

5.12. To meet Requirements 34 and 42 of SSR-4 [1] on protection against internal radiation exposure and against toxic chemical hazards, the risk of releasing radioactive material and toxic chemical material from the conversion or enrichment process should be decreased by minimizing the following parameters as far as possible:

(a) The amount of liquid UF_6 in process areas (e.g. by limiting the size of crystallization (desublimation) vessels in both conversion facilities and uranium enrichment facilities);
(b) The amount of radioactive material and toxic chemical material unaccounted for in the process vessels;
(c) The duration of operation when UF_6 is at a pressure above atmospheric pressure;
(d) The capacity for storage of hydrogen fluoride, ammonia and hydrogen.

5.13. Conversion facilities and uranium enrichment facilities are required to be designed to minimize, to the extent practicable, contamination of the facility and releases of radioactive material to the environment, and to facilitate decontamination and eventual decommissioning of the facility (see Requirements 24, 25 and 33 of SSR-4 [1]).

5.14. To meet Requirement 10 and para. 6.21(a) of SSR-4 [1], in working areas where liquid UF_6 is processed or where there is a potential for significant airborne particulates, two static barriers and preferably a third barrier for the prevention of uncontrolled releases to the environment should be installed. Particular consideration should also be given to minimizing the use of flexible hoses and to ensuring their maintenance and periodic checking.

5.15. The use of an appropriate containment system should be the primary method for protection against the spreading of contamination from areas where significant quantities of either powder of uranium compounds or hazardous substances in a gaseous form are held (see Requirement 35 of SSR-4 [1]). To improve the effectiveness of static containment, a dynamic containment system providing negative pressure should be used, when practicable, through the creation of airflow towards the more contaminated parts of equipment or an area. The speed of the airflow should be sufficient to prevent the migration of radioactive material back to areas that are less contaminated. A cascade of reducing absolute pressures can thus be established between the environment outside the building and the hazardous material inside.

5.16. In the design of the ventilation and containment systems for areas that might contain elevated levels of airborne radioactive material during operation, account should be taken of criteria such as the following:

(a) The desired pressure difference between different parts of the premises;
(b) The air replacement ratio in the facility;
(c) The types of filters to be used;
(d) The maximum differential pressure across filters;
(e) The appropriate flow velocity at the openings in the ventilation and containment systems (e.g. the acceptable range of air speeds at the opening of a hood);
(f) The dose rate at the filters;
(g) The potential accumulation of nuclear fissile materials in ventilation elements (filters, ventilation ducts);
(h) The humidity and potential for moisture within the ventilation system;
(i) Predictive and preventive maintenance strategies.

5.17. To prevent the propagation of a fire through ventilation ducts and to maintain the integrity of firewalls, and as practicable in view of the potential of corrosion by hydrogen fluoride, ventilation systems should be equipped with fire dampers and should be constructed from non-flammable and non-corrosive materials.

5.18. Protection against chemical hazards should include the control of any route for chemicals into the workplace and to the environment.

Protection of workers

5.19. Requirements on the design of conversion facilities and uranium enrichment facilities to ensure radiation protection of workers are established in Requirement 8 of SSR-4 [1].

5.20. Conversion facilities and uranium enrichment facilities are required to be designed with appropriately sized ventilation and containment systems in areas of the facility identified as having potential for giving rise to significant concentrations of airborne radioactive material and other hazardous material (see para. 6.126 of SSR-4 [1]). The ventilation system should be used as one of the means of minimizing the radiation exposure of workers and exposure to hazardous material that could become airborne and so could be inhaled by workers. Where possible, the layout of ventilation equipment should be such that the flow of air is away from personnel workplaces and from personnel evacuation routes.

5.21. For normal operation, the need for the use of protective respiratory equipment is required to be avoided through careful design of the containment and ventilation systems (see para. 9.100 of SSR-4 [1]). For example, a glovebox, hood or special device should be used to ensure the continuity of the first confinement barrier rather than relying on the need for respiratory protection.

5.22. In areas that might contain airborne uranium in particulate form, primary filters should be located as close to the source of contamination as practicable. In designing ventilation systems, consideration should be given to preventing the potential for unwanted deposition of uranium due to insufficient air velocity or accumulation areas within the ducts. Means for periodic surveillance in areas where accumulation of airborne contamination could occur should be provided. Multiple filters in series should be used to avoid reliance on a single filter. In addition, duty and standby filters and/or fans should be provided to ensure the continuous functioning of the ventilation systems. If such filters and/or fans are not provided, it should be ensured that failure of the duty fan or filter will result in the safe shutdown of equipment in the affected area. Where possible, the reliance on a single filter (e.g. during other filter maintenance or replacement) should only occur during shutdown of main processes within the facility.

5.23. Monitoring equipment such as differential pressure gauges (e.g. on filters, between rooms or between a glovebox and the room in which it is located) and devices for measuring uranium or concentrations of hazardous substances in gaseous form in ventilation systems should be installed, as necessary.

5.24. Audio alarm systems should be installed to alert operators to fan failure and to high or low differential pressures. At the design stage, provision is also required to be made for the installation of equipment for monitoring airborne radioactive material and/or gas monitoring equipment (see para. 6.120 of SSR-4 [1]). Monitoring points should be chosen that would correspond most accurately to the exposure of personnel and would minimize the time for detection of any leakage (see para. 6.121 of SSR-4 [1]).

5.25. If fume hoods and gloveboxes are used (e.g. in laboratories), their design should be commensurate with the specific local hazards in the conversion facility or the uranium enrichment facility.

5.26. To facilitate decontamination and decommissioning of the facility, the walls, floors and ceilings in areas of the conversion facilities and uranium enrichment facilities where contamination could exist during normal operations should be made non-porous and easy to clean. This may be done by applying special coatings, such as epoxy, to such surfaces and by ensuring that no areas are difficult to access. In addition, all surfaces that could become contaminated should be made readily accessible to allow for periodic decontamination, as necessary.

Protection of the public and the environment

5.27. Paragraph 3.9 of IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [15] 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."

Further recommendations for performing environmental impact assessments of conversion facilities and uranium enrichment facilities are provided in IAEA Safety Standards Series No. GSG-10, Prospective Radiological Environmental Impact Assessment for Facilities and Activities [16].

5.28. The design should provide for adequate monitoring of the source of releases (gaseous emissions and liquid effluents) as well as for the monitoring of the receiving environment around the facility. The design should also provide for the identification of breaches to confirm there is no breach of confinement barriers, and the impact to the environment and the public complies with authorized limits.

5.29. The efficiency of filters and their resistance to chemicals (hydrogen fluoride and ammonia), moisture in the ventilation system, and high temperatures of the exhaust gases and fire conditions should be taken into consideration for assessment of releases to the environment.

5.30. The uncontrolled dispersion of radioactive or chemical substances to the environment as a result of an accident can occur if all the confinement barriers are impaired. Barriers may comprise the process equipment itself, or the room or building structure. The number of physical barriers for confinement should be adapted to the safety significance of the hazard. The minimum number of barriers is two, in accordance with Requirement 23 and para. 6.124 of SSR-4 [1]. The preferred number of barriers is three.

5.31. Ventilation of the containment systems, by the discharge of exhaust gases through a stack via gas cleaning mechanisms such as wet scrubbers in conversion facilities, or cold traps and dry chemical absorbers in uranium enrichment facilities, reduces the normal environmental discharges of radioactive or chemical (mainly hydrogen fluoride) material to very low levels. In such cases, the ventilation system may also be regarded as a confinement barrier.

Protection against external exposure

5.32. Relevant requirements on design provisions for protection against external radiation exposure are established in Requirement 36 and paras 6.129–6.134 of SSR-4 [1].

5.33. External exposure of workers should be controlled by means of an appropriate combination of requirements on distance, time and shielding. Owing to the low specific activity of naturally sourced material, the shielding provided by the vessels and pipe work of a conversion facility or a uranium enrichment facility will normally be sufficient to control occupational exposure adequately. However, in areas that are in close proximity to newly emptied UF_6 cylinders or bulk storage areas, installation of shielding or restrictions on occupancy should be considered.

5.34. When reprocessed uranium is processed, additional protective measures should be considered for protection of personnel, because of the higher gamma dose rates from ^{232}U decay products (^{208}Tl and ^{212}Bi) and residual fission products.

5.35. In selecting the areas for storage of tailings, requirements on distance, occupancy time and shielding should be considered to minimize the direct exposure of personnel to gamma and neutron radiation. In estimating the exposure, ‘sky shine’ (scattered gamma radiation in air) should also be taken into account.

Prevention of nuclear criticality

5.36. Prevention of nuclear criticality is an important topic with various aspects to be considered during the design of a conversion facility or uranium enrichment facility (see Requirement 38 of SSR-4 [1]). Paragraphs 5.37–5.44 provide recommendations on some of the main elements of criticality safety that are specific for conversion facilities or uranium enrichment facilities. Detailed recommendations on criticality safety are provided in SSG-27 (Rev. 1) [2].

5.37. If a conversion facility processes natural uranium, depleted uranium or uranium with less than 1% ^{235}U enrichment, a full criticality safety assessment is not necessary (see para. 6.138 of SSR-4 [1]). In such cases it should be demonstrated that there is no credible fault sequence in which uranium with equal to or higher than 1% ^{235}U enrichment is fed to the process as in, for example, the use of recycled uranium. For further recommendations, see para. 2.13 of SSG-27 (Rev. 1) [2].

5.38. Paragraphs 6.138–6.148 of SSR-4 [1] establish requirements for the prevention of criticality by means of design. For the prevention of criticality in conversion facilities and uranium enrichment facilities the following parameters should be subject to control:

(a) Mass and enrichment level(s) of fissile material present in a process.
(b) Geometry and interaction of processing equipment. Control can be achieved by limitation of the dimensions or shape (e.g. by means of safe diameters for storage vessels, control of slabs, appropriate distances in and between storage vessels). The loss of confinement or changes in the geometry due to leaks or breaks should also be taken into consideration.
(c) Concentration of fissile material in solutions (e.g. in the wet process for recovering uranium or during decontamination).
(d) Presence of reflectors or appropriate neutron absorbers.
(e) Degree of moderation. For example, this can be achieved by means of control of the ratio of hydrogen to ^{235}U in UF_6 cylinders and in centrifuge cascades, taking into account the hydrolysis products of UF_6 (uranyl fluoride, in particular) whose H/U ratio can be higher than the maximum retained for UF_6.

5.39. Paragraph 6.138 of SSR-4 [1] states (footnote omitted):

> "In areas of the facility where the quantity of fissile material involved is so low or the isotopic composition is such that it meets exemption criteria specified by, or agreed with, the regulatory body, then a full criticality safety assessment is not necessary. In all other cases, criticality safety shall be ensured by means of preventive measures that are, as far as reasonably achievable, established in the design. In this context, the area subject to criticality control may be an entire enrichment cascade, a building or the entire site."

5.40. For conversion facilities or uranium enrichment facilities, to the extent practicable, vessels which could contain fissile material should be made geometrically favourable and should be designed for the maximum authorized enrichment level, including a reasonable safety margin.

5.41. The criticality safety analysis should demonstrate that the design of equipment and the related safety measures are such that the values of controlled parameters are always maintained in the subcritical range. This should be achieved by determining the effective neutron multiplication factor (k_{eff}), which depends on the mass, the geometry, the distribution and the nuclear properties of uranium and all other materials with which it is associated, including low temperature effects (in the parts of the process operating at temperatures far below 0°C). The calculated value of k_{eff} (including all uncertainties and biases) should then be compared with the value specified by the design limit (which should be set in accordance with paras 2.8–2.12 of SSG-27 (Rev. 1) [2]).

5.42. Several methods that vary widely in basis and form can be used to perform the criticality safety analysis, such as the use of experimental data, reference books or consensus standards, hand calculations and calculations by means of deterministic or probabilistic computer codes. For more extensive recommendations on performing a criticality safety assessment, including recommendations on validation of computer codes, see section 4 of SSG-27 (Rev. 1) [2].

5.43. The criticality safety analysis should include the following:

(a) The use of a conservative approach, taking into account the following:
   (i) Uncertainties in physical parameters, the physical possibility of worst case moderation conditions and the potential for non-homogeneous distributions of moderators;
   (ii) The optimal geometry configuration of a system with fissile material;
   (iii) Plausible operational occurrences and their combinations if they cannot be shown to be independent;
   (iv) Operational states that might result from external hazards.
(b) The use of appropriate verified and validated computer codes that are validated together with the appropriate data libraries of nuclear reaction cross-sections, for the normal and credible abnormal conditions being analysed, while taking into account any bias and its uncertainties (see paras 4.22–4.29 of SSG-27 (Rev. 1) [2]).

5.44. The following parameters should be included in the scope of a criticality safety analysis for a conversion facility or a uranium enrichment facility (see para. 6.144 of SSR-4 [1]):

(a) Enrichment. The potential for uncertainties in the uranium enrichment of a fissile material should be considered if the maximum authorized enrichment level is not used in the criticality safety analysis (see para. 5.39).

(b) Mass. The mass margin should be sufficient to compensate for possible overbatching of uranium in normal operation (see also para. 3.18 of SSG-27 (Rev. 1) [2]).
(c) Geometry of processing equipment. The potential for changes in dimensions (e.g. bulging of slab tanks or slab hoppers) during operation is required to be in accordance with para. 6.144 of SSR-4 [1].
(d) Moderation. Hydrogenous substances (e.g. water, oil) are common moderators that are present in conversion facilities and uranium enrichment facilities or that might be present in accident conditions (e.g. water from firefighting). The subcriticality of a UF_6 cylinder should not rely only on moderation control.
(e) Reflection. Full water reflection should be assumed in the criticality safety analysis unless it is demonstrated that the worst case conditions relating to neutron reflection (e.g. by human bodies, organic materials, wood, concrete, the steel of the container) result in a lower degree of reflection. The degree of reflection in interacting arrays should be carefully considered since the assumption of full water reflection might provide a degree of neutronic isolation from interacting items. Consideration should be given to situations where material may be present that could lead to a greater increase of the neutron multiplication factor than in a full water reflection system (see para. 3.22 of SSG-27 (Rev. 1) [2]). Moderation control should ensure criticality safety for an individual UF_6 cylinder or an array of UF_6 cylinders for any conditions of reflection.
(f) Neutron interaction. Preference should be given to engineered spacing over spacing achieved by administrative means.
(g) Neutron absorbers. Paragraph 6.144(i) of SSR-4 [1] states that "when taken into account in the safety analysis, and if there is a risk for degradation, or if they could become broken or dislodged, the presence and the integrity of neutron absorbers shall be verifiable during periodic inspection." In accordance with para. 6.114(j), uncertainties in absorber parameters are required to be considered in the criticality calculations. The neutron absorbers that may be used in conversion facilities and uranium enrichment facilities include cadmium, gadolinium and boron in annular storage vessels or transfer vessels for liquids. Absorber parameters include thickness, density and nuclide composition.

PROVISIONS FOR HEAT REMOVAL

5.45. To meet Requirement 39 of SSR-4 [1], where the potential for exothermic reactions with large heat releases exists (as, for example, in the fluorination process in conversion facilities), facility design should consider appropriate cooling systems to remove heat from the chemical reactions and to ensure safe operation for all facility states.

5.46. Continuous monitoring of cooling systems should be ensured to prevent uncontrolled release of radioactive material.

5.47. The cooling water system design should have provisions for periodic inspections and maintenance to address corrosion and ageing management.

POSTULATED INITIATING EVENTS

5.48. Paragraph 6.60 of SSR-4 [1] states that: “The list of internal and external hazards, including human induced hazards (see Requirements 15 and 16), shall be used to select initiating events for detailed further analysis.” Paragraphs 5.49–5.95 provide recommendations on foreseeable internal and external hazards for conversion facilities and uranium enrichment facilities.

Internal hazards

Fire and explosion

5.49. An analysis of fire hazards and explosion hazards is required to be conducted for conversion facilities and uranium enrichment facilities to meet Requirement 22 and the requirements established in paras 6.77–6.79 of SSR-4 [1].

5.50. Fire in conversion facilities and uranium enrichment facilities could lead to the dispersion of radioactive material or toxic material by breaching the confinement barriers or could cause a criticality accident by affecting the system or the parameters used for the control of criticality (e.g. the moderation control system or the dimensions of the processing equipment). Special consideration should be given to the fire extinguishing media deployed and their potential moderation effect. In accordance with para. 6.146 of SSR-4 [1], the choice of fire extinguishing media (e.g. water or powder) and the safety of their use is required to be addressed with regard to criticality safety.

5.51. The fire hazards that are specifically encountered in a conversion facility such as from anhydrous ammonia (explosive and flammable), nitric acid (ignition in the case of organic materials) and hydrogen should be given due consideration.

Fire hazard analysis

5.52. As an important aspect of fire hazard analysis, areas of the facility that need special consideration should be identified. Fire hazard analyses of the facility should be performed for all areas with high risk fire sources such as areas where diffusers are located, areas with combustible materials (including low voltage cables) and premises where safety equipment is installed. Particular consideration during the fire hazard analysis should be given to the following:

(1) For conversion facilities:
  (a) Processes involving hydrogen, such as reduction of uranium oxide;
  (b) Workshops using flammable liquids (e.g. dodecane), such as purification units and laboratories;
  (c) The storage of reactive chemicals (e.g. ammonia, hydrogen, nitric acid, dodecane);
  (d) Areas with high fire loads, such as waste storage areas;
  (e) Waste storage and treatment areas;
  (f) Rooms housing safety related equipment (e.g. items such as air filtering systems, whose degradation might lead to radiological consequences that are considered to be unacceptable);
  (g) Transformers and rooms housing battery chargers;
  (h) Control rooms;
  (i) Vehicles such as UF_6 cylinder transporters and forklifts that use hydrocarbon fuel.
(2) For uranium enrichment facilities:
  (a) Areas with high fire loads, such as areas containing lubricating oil tanks, and vessels containing degreasing or decontamination solvents;
  (b) Diesel storage tanks;
  (c) Transformers and rooms housing battery chargers;
  (d) The storage of solvents;
  (e) Areas storing combustible waste before its conditioning;
  (f) Control rooms;
  (g) Vehicles such as UF_6 cylinder transporters and forklifts that use hydrocarbon fuel.

5.53. Fire hazard analysis for conversion facilities and uranium enrichment facilities should involve identification of the causes of fires, assessment of the potential consequences of fires and, where appropriate, estimation of the frequency or probability of occurrence of fires. It should be used to assess the inventory of fuels and initiation sources, and to determine the appropriateness and adequacy of measures for fire protection. Computer modelling of fires may sometimes be used in support of the fire hazard analysis.

5.54. The estimation of the likelihood of fires can be used as a basis for making decisions or for identifying weaknesses that might otherwise go undetected. Even if the estimated likelihood of fire may seem low, a fire might have significant consequences for safety and, as such, certain protective measures should be taken such as delineating small fire areas, to prevent fires or curtail a fire from spreading.

5.55. The analysis of fire hazards should also involve a review of the provisions made at the design stage for preventing, detecting and mitigating fires.

Fire prevention, detection and mitigation

5.56. Prevention is the most important aspect of fire protection. Facilities should be designed to limit fire risks by the incorporation of measures to ensure that fires do not break out. Mitigation measures should be put in place to minimize the consequences of a fire in the event that a fire breaks out despite preventive measures.

5.57. To accomplish the twofold aim of fire prevention and mitigation of the consequences of a fire, a number of general and specific measures should be taken, including the following:

(a) Separation of the areas where non-radioactive hazardous material is stored from the process areas.
(b) Minimization of the fire load of individual rooms.
(c) Selection of materials, including those for civil structures and compartment walls, penetrations and cables associated with structures, systems and components important to safety, in accordance with functional criteria and fire resistance ratings.
(d) Compartmentalization of buildings and ventilation ducts as far as possible to prevent the spreading of fires. Buildings should be divided into fire zones. Measures should be put in place to prevent or severely curtail the potential for the fire to spread beyond the fire zone in which the fire breaks out. The higher the fire risk, the greater the number of fire zones a building should have.
(e) Suppression or limitation of the number of possible ignition sources such as open flames or electrical sparks.

5.58. Paragraph 6.79 of SSR-4 [1] establishes requirements for the analysis with regard to fire extinguishing systems. Fire extinguishing devices, automatic or manually operated, with adequate extinguishing agents, should be installed in the zones where the outbreak of a fire is possible. The installation of automatic firefighting devices with water sprays should be assessed with care for areas where UF_6 is present, with account taken of the potential of hydrogen fluoride generation and criticality events for enriched uranium. Consideration should be given to minimizing the environmental impact of the water used to extinguish fires.

5.59. The design of ventilation systems should be given particular consideration with regard to fire prevention. Dynamic containment systems comprise ventilation ducts and filter units, which might constitute weak points in the fire protection system unless they are of suitable design. Fire dampers should be mounted in the ventilation system unless the likelihood of widespread fires is acceptably low. They should close automatically on receipt of a signal from the fire detection system or by means of temperature sensitive fusible links. Spark arrestors should be used to protect the filters, if necessary. The required operational performance of the ventilation system should be specified so as to comply with fire protection requirements.

5.60. Lines that cross the boundaries between fire areas or fire zones (e.g. electricity lines, gas and process lines) should be designed to ensure that fire does not spread.

Explosions

5.61. An explosion can be induced by fire or it can be the initiating event that results in a fire. Explosions could breach the barriers providing confinement and/or could affect the safety measures that are in place for preventing a criticality accident.

5.62. In conversion facilities and uranium enrichment facilities, the possible sources of explosions include the following:

(a) Gases (in conversion facilities: e.g. hydrogen or ammonia used in the reduction process; in uranium enrichment facilities: chemical oxidants such as fluorine, chlorine trifluoride or UF_6). Design provisions should be implemented to prevent an explosive mixture of the above chemical oxidants and of hydrocarbons or halohydrocarbons. Where the prevention of such an explosive mixture cannot be ensured, consideration should be given to the use of an inert gas atmosphere or dilution systems.
(b) Solid chemical compounds (in conversion facilities only: ammonium nitrate when in a high temperature environment). Monitoring of possible deposits should be implemented to prevent any accumulation of ammonium nitrate.

Flooding

5.63. Flooding in a conversion facility or a uranium enrichment facility might lead to the dispersion of radioactive material if the radioactive material is not kept in a confined state (e.g. yellow cake, ammonium diuranate (ADU) in conversion). For UF_6, which is always kept in a confined state, flooding would only result in a release of hazardous materials if there were a simultaneous loss of confinement. Flooding can potentially result in buoyancy induced failure of vessels, pipes and equipment, causing a loss of confinement.

5.64. In any case, flooding might lead to a change in criticality safety parameters such as reflection and/or moderation.

5.65. In facilities where vessels and/or pipes containing water are present (including any installed firefighting systems), the criticality safety analyses should take into account the presence of the maximum amount of water that could be contained within the room under consideration as well as the maximum amount of water in any connected rooms. Such rooms or premises should be clearly identified and personnel should be informed.

5.66. Walls (and floors if necessary) of rooms where flooding could occur should be capable of withstanding the water load, and safety related equipment should not be affected by flooding.

Leaks and spills

5.67. In addition to the loss of raw materials and their environmental impact, leaks from containment systems such as vessels, cylinders, pumps, valves and pipes can lead to the dispersion of radioactive material (e.g. uranium solutions and powders, gaseous or liquid UF_6) and toxic chemicals (e.g. hydrogen fluoride, fluorine, ammonia, chlorine trifluoride) and to the unnecessary generation of waste. Leaks of hydrogenous fluids (e.g. water, oil) can alter the neutron moderation and/or reflection and thereby reduce criticality safety. Leaks of flammable gases (e.g. hydrogen) or liquids can lead to explosions and/or fires. Leak detection systems should be deployed where leaks could occur.

5.68. For conversion facilities, uranium recovery locations and uranium enrichment facilities, vessels containing significant amounts of nuclear material, or hazardous chemicals, in solution form should be equipped with level detectors and alarms to prevent overfilling and with secondary confinement features such as bunds or drip trays of appropriate capacity. For fissile material the configuration is required to ensure criticality safety (see para. 6.143 of SSR-4 [1]).

5.69. The surfaces of floors and walls should be chosen to facilitate their cleaning, in particular in wet process areas. This will also facilitate the minimization of waste from decommissioning.

Loss of services

5.70. To meet the requirement established in para. 6.89 of SSR-4 [1], an emergency backup power supply that can be deployed in a timely manner to provide backup power, should be provided at least for the following systems and components:

(a) Criticality accident detection and alarm systems;
(b) Ventilation systems, if necessary, for the confinement of hazardous material;
(c) Detection and alarm systems for leaks of hazardous materials, including explosive gases;
(d) Some process control components (e.g. heating elements, valves);
(e) Fire detection and suppression systems;
(f) Monitoring systems for radiation protection and environmental protection;
(g) Lighting within the process facility.

5.71. For uranium enrichment facilities, a loss of electrical power might result in major operational consequences. In addition, there might be some safety implications from a loss of electrical power, such as the formation of solid uranium deposits. A backup electrical power system should be provided for the removal of the UF_6 from the cascade and its transfer to UF_6 cylinders or chemical absorber traps.

5.72. The licensing documentation (safety case) should address the remedial actions necessary for the facility, including the items identified in para. 5.70 to return to a safe operational state, unless the likelihood of an extended loss of power can be ruled out on probabilistic grounds.

5.73. The consequences of the loss of general supplies such as gas for instrumentation and control, cooling water for process equipment and ventilation systems, heating water, breathing air and compressed air for safety should be analysed at least for the following:

(a) Loss of gas supply to gas controlled safety valves and dampers: In accordance with the safety analysis, valves designed for fail-safe behaviour should be used.
(b) Loss of cooling or heating water: Adequate backup capacity or a redundant supply should be provided for in the design.

Processing errors

5.74. The following list gives examples of hazards to be considered during the safety assessment in relation to the loss or excess of process reagents and diluent gases:

(a) Incomplete chemical reactions in conversion facilities might lead to a release of hazardous chemicals.
(b) Overpressure in the equipment might cause an increase of the levels of airborne radioactive material and/or concentration of hazardous material in the working areas of the facility.
(c) Excess of fluorine in the fluorination process in conversion facilities might result in its release.
(d) Releases of large amounts of nitrogen might result in a reduction of the oxygen concentration in breathing air in the work areas of the facility.
(e) Loss of steam or hot water supply might result in the solidification of UF_6 in the piping and equipment.
(f) Failure of the air supply might result in the failure of safety related air operated valves.

Facility failures and equipment failures

5.75. To meet Requirement 40 of SSR-4 [1], particular consideration should be given to the confinement of highly corrosive and hazardous materials such as UF_6, fluorine and hydrogen fluoride in vessels, pipes and pumps, and to powder transfer lines where abrasive powder will cause erosion.

5.76. The design should minimize the potential for mechanical impacts on containers of hazardous material caused by moving devices such as vehicles and cranes. The design should ensure that the movement of heavy loads by cranes above vessels and piping containing large amounts of hazardous and/or radioactive material is minimized, as a major release of hazardous or radioactive material could occur if the load were accidentally dropped.

5.77. Failure due to fatigue or chemical corrosion or lack of mechanical strength should be considered in the design of containment systems for hazardous and/or radioactive material.

5.78. To prevent failure of equipment containing hazardous materials (e.g. calciners or furnaces), effective programmes for maintenance, periodic testing and inspection should be established at the design stage.

External hazards

General

5.79. A conversion facility or a uranium enrichment facility should be designed in accordance with the nature and severity of the external hazards, either natural or human induced, identified and evaluated in accordance with the provisions of SSR-1 [13] and Requirement 16 of SSR-4 [1]. Detailed recommendations on external hazards are provided in IAEA Safety Standards Series Nos SSG-9 (Rev. 1), Seismic Hazards in Site Evaluation for Nuclear Installations [17]; SSG-18, Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations [18]; SSG-21, Volcanic Hazards in Site Evaluation for Nuclear Installations [19]; and SSG-68, Design of Nuclear Installations Against External Events Excluding Earthquakes [20]. Recommendations on specific external hazards for a conversion facility or a uranium enrichment facility are provided in paras 5.80–5.95.

Earthquakes

5.80. To ensure that the design of a conversion facility or a uranium enrichment facility provides the required degree of robustness, a detailed seismic assessment (see SSR-1 [13] and SSG-9 (Rev. 1) [17]) should be made, including the following seismically induced events:

(a) Loss of cooling.
(b) Loss of support services, including utilities.
(c) Loss of confinement functions (static and dynamic).
(d) Loss of safety functions for ensuring the return of the facility to a safe state and maintaining the facility in a safe state after an earthquake, including

structural functions and functions for the prevention of other hazards (e.g. fire, explosion, load drop, flooding).

(e) Loss of criticality safety functions such as geometry and/or moderation as a result of the following:
   (i) Deformation (geometry control);
   (ii) Displacement (geometry control, fixed neutron poisons);
   (iii) Loss of material (geometry control, soluble neutron poisons).

5.81. Depending on the site characteristics and the location of the conversion facility or uranium enrichment facility, as evaluated in the site evaluation (see Section 4), the effect of a tsunami and of soil liquefaction induced by an earthquake, and of other extreme flooding events, should be addressed in the facility design.

External fires and explosions and external toxic hazards

5.82. Hazards from external fires and explosions could arise from various sources in the vicinity of conversion facilities or uranium enrichment facilities, such as petrochemical installations; forests; pipelines and road, rail or sea routes used for the transport of flammable material such as gas or oil; and volcanic hazards.

5.83. To demonstrate that the risks associated with such external hazards are below acceptable levels, the operating organization should first identify all potential sources of hazards and then estimate the associated event sequences affecting the facility. The radiological or associated chemical consequences of any damage should be evaluated and it should be verified that they are within acceptance criteria. Toxic hazards should be assessed to verify that specific gas concentrations meet the acceptance criteria. It should be ensured that external toxic hazards would not adversely affect the control of the facility. The operating organization should conduct a survey of potentially hazardous installations and transport operations for hazardous material in the vicinity of the facility. In the case of explosions, risks should be assessed for compliance with overpressure criteria.

5.84. To evaluate the possible effects of flammable liquids, toxic spills, volcanic ashes, falling objects (such as chimneys), air shock waves and missiles resulting from explosions, their possible distance from the facility and hence their potential to cause physical damage should be assessed.

Extreme meteorological phenomena

5.85. A conversion facility or a uranium enrichment facility should be protected against extreme meteorological conditions as identified in the site evaluation (see

Section 4) by means of appropriate design provisions. These should generally include the following:

(a) The ability of structures important to safety to withstand extreme weather loads;
(b) The prevention of flooding of the facility, including adequate means to evacuate water from the roof in cases of extreme rainfall and to prevent failure of water pipes due to freezing;
(c) A safe state for the facility in accordance with the operational limits and conditions.

Tornadoes

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

5.87. High winds are capable of lifting and propelling objects as large as automobiles or utility poles. The possibility of impacts of tornado missiles such as these should be taken into consideration in the design stage for the facility, as regards both the initial impact and the effects of possible secondary fragments arising from collisions with and spallation from concrete walls or from other types of transfer of momentum.

Extreme temperatures

5.88. The potential duration of extreme low or high temperatures should be taken into account in the design of the main process equipment and support system equipment to prevent adverse effects such as the following:

(a) The crystallization of uranium nitrate solutions, or liquid or gaseous UF_6;
(b) The freezing of the cooling system used in desublimers (cold traps) such as those used in off-gas systems;
(c) The freezing of emergency oil used to blanket concentrated hydrogen fluoride solutions after a breach of a vessel;
(d) The liquefaction of solid UF_6 in piping.

5.89. If safety limits for humidity or temperature are specified in a building or a compartment, the air-conditioning system should be designed to perform efficiently also under extreme hot or wet weather conditions. The effect of condensation inside the facility should also be taken into consideration. For structures without expansion joints, the additional loads due to thermal expansion on structural systems should be considered in the design.

Snowfall and ice storms

5.90. The occurrence of snowfall and ice storms and their effects should be taken into account in the design of the facility and the safety analysis. Snow and ice are generally taken into account as an additional load on the roofs of buildings. The neutron reflecting effect and/or the interspersed moderation effect of the snow, if relevant, should be considered (e.g. for product cylinder storage areas).

Flooding

5.91. For any flood events such as extreme rainfall (for an inland site) or storm surge (for a coastal site) attention should be focused on potential leak paths (breaks in the confinement barrier) into structures, systems and components important to safety when these are vulnerable to damage. Equipment containing fissile material should be designed to prevent any criticality accident in the event of flooding. Electrical systems, instrumentation and control systems, emergency power systems (batteries and power generation systems) and control rooms should be protected by design.

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

5.93. Other effects of combined water levels (such as high tides or tsunamis) should be considered.

Accidental aircraft crashes

5.94. In accordance with the risks identified in the site evaluation (see Section 4), a conversion facility or a uranium enrichment facility should be designed to withstand the design basis impact.

5.95. For evaluating the consequences of impacts or the adequacy of the design to resist aircraft impacts, crash scenarios included in the design basis should be considered, which may demand the knowledge of such factors as the possible angle of impact, velocity of the aircraft or the potential for fire and explosion due to the aviation fuel load. In general, fire cannot be ruled out following an aircraft crash. Therefore, specific requirements for fire protection and for emergency preparedness and response should be established.

INSTRUMENTATION AND CONTROL

5.96. Instrumentation should be provided to monitor the relevant parameters and systems and general conditions of the facility over their respective ranges for: (a) normal operation; (b) anticipated operational occurrences; and (c) accident conditions, to ensure that adequate information can be obtained on the status of operations and the facility, and proper actions can be undertaken in accordance with the operating procedures.

5.97. Instrumentation should be provided for measuring all the main parameters whose variation might affect the safety of processes (e.g. pressure, temperature, flow rate). In addition, instrumentation should be provided for monitoring general conditions at the facility (e.g. radiation levels, releases of effluents, ventilation conditions), and for obtaining any other information about the facility necessary for its reliable and safe operation (e.g. presence of personnel, environmental conditions).

5.98. 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 should be designed to maintain process parameters within the operational limits and conditions or to bring the process to a predetermined safe state.

5.99. Appropriate information should be made available to the operator for monitoring the effects of automatic actions. The layout of instrumentation and the manner of presentation of information should provide the operating personnel with an adequate picture of the status and performance of the facility with consideration given to important parameters that should be recorded for future use. Devices should be installed that provide in an efficient manner visual and, as appropriate, audio indications of operational states that have deviated from normal conditions and that could affect safety. Provision should be made for the automatic measurement and recording of values of parameters that are important to safety and, where applicable, manual periodic testing should be used to complement automated continuous testing of conditions.

Control rooms and panels

5.100. Control rooms and human–machine interface panels should be provided to centralize the availability of information and monitoring of actions. Occupational exposure and safety of personnel should be considered when the location of control rooms in the facility is selected. Where applicable, it may be useful to have dedicated control rooms to allow for the remote monitoring of operations, thereby reducing exposures and risks to personnel. Particular consideration should be given to identifying those events, both internal and external to the control rooms, that might pose a direct threat to the operators and to the operation of control rooms. Ergonomic factors should be taken into account in the design of control rooms and the design of control room displays and systems.

Safety related instrumentation and control systems

5.101. Safety related instrumentation and control systems of a conversion facility or a uranium enrichment facility should include systems for the following:

(a) Criticality control and criticality detection and alarm:
   (i) Process controls, in particular for uranium enrichment facilities, include in-line devices for enrichment measurement to monitor the enrichment levels of products;
   (ii) Radiation detectors (gamma and/or neutron detectors) with audio and, where necessary, visual alarms for initiating immediate evacuation from the affected area, should cover all the areas where a significant quantity of fissile material is present (see para. 6.173 of SSR-4 [1]).
(b) Fire detection:
   (i) All rooms with fire loads or significant amounts of fissile and/or toxic chemical material should be equipped with fire alarms;
   (ii) Gas detectors should be used in areas where a leakage of gases (e.g. hydrogen) could produce an explosive atmosphere.
(c) Process control:
   (i) Parameters such as temperature, pressure, flow rate, concentration of chemicals and/or radioactive material, tank levels and cylinder weights should be monitored;
   (ii) Before heating a UF_6 cylinder, the weight of UF_6 should be measured and should be confirmed to be below the fill limit (e.g. by using a second independent weighing scale);

   (iii) If the system has the capability of reaching a temperature at which hydraulic rupture can occur, the temperature during heating should be limited by means of two independent systems.

(d) Control of ventilation: Mainly devices for measuring differential pressures across high efficiency particulate air (HEPA) filters and airflows.
(e) Control of gaseous and liquid effluents: Real time measurements should be provided if there is a foreseeable potential for exceeding regulatory limits; otherwise, retrospective measurements on continuously sampled filters and/or probes will generally be sufficient.
(f) Control of explosive mixtures: Real time measurements, controls and alarms are necessary if there is a foreseeable potential for exceeding regulatory and safety limits (e.g. devices for measuring the concentration of O_2 in the reduction kiln in conversion facilities).
(g) Control of occupational radiation exposure:
   (i) For monitoring external exposure, dosimeters with real time displays and/or alarms should be installed in areas where radioactive releases have the potential to occur, and especially in areas with inspection equipment such as X ray generators and radioactive sources;
   (ii) For monitoring internal exposure, continuous sampling of filters for retrospective measurement and/or real time measurement with alarms should be performed for the detection of releases of radioactive material.
(h) Control of asphyxiants: Presence and concentration of asphyxiants (e.g. nitrogen, ammonia, NO_x) in working areas where they might impact operational safety should be monitored.
(i) Control of chemical releases: Real time detection and alarm systems should be used in the process areas and/or laboratories where hydrogen fluoride, UF_6 and chlorine trifluoride above atmospheric pressure are present.

HUMAN FACTOR CONSIDERATIONS

5.102. The requirements relating to human factors engineering are established in Requirement 27 of SSR-4 [1].

5.103. Human factors in operation, inspection, periodic testing and maintenance should be considered at the design stage. Human factors to be considered for a conversion facility or a uranium enrichment facility should include the following:

(a) Possible effects on safety of unauthorized human actions (with account taken of ease of intervention by the operator and tolerance of human error);

(b) The potential for occupational exposure.

5.104. The design of the facility to take account of human factors is a specialist area. Experts and experienced operators should be involved from the earliest stages of design. Areas that should be considered include the following:

(a) Design of working conditions to ergonomic principles:
    (i) The operator–process interface, for example electronic control panels displaying all the necessary information and no superfluous information;
    (ii) The working environment, for example ensuring good access to and adequate space around equipment and suitable finishes to surfaces for ease of cleaning.
(b) Choice of location and clear labelling of equipment to facilitate maintenance, testing, cleaning and replacement.
(c) Provision of fail-safe equipment and automatic control systems for accident sequences for which reliable and rapid protection is required.
(d) Good task design and ease of implementing operating procedures, particularly during maintenance work, when automated control systems may be disabled.
(e) Minimization of the need to use additional means of personal radiation protection.
(f) Operating experience feedback relevant to human factors.

SAFETY ANALYSIS

5.105. Requirement 14 of GSR Part 4 (Rev. 1) [11] 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 conversion facilities and uranium enrichment facilities should include an analysis of various hazards for the whole facility and all activities.

5.106. The list of postulated initiating events identified should take into account all the internal and external hazards that can be used to develop the resulting event scenarios for the purpose of establishing the list of structures, systems and components important to safety. The functions of the structures, systems and components being relied upon for safety should not be adversely impacted by the event scenarios.

Safety analysis for operational states

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

(a) Calculations of the source term should use (i) the material with the highest specific activity for a given isotopic composition; (ii) the licensed inventory of the facility; and (iii) the maximum material throughput that can be processed by the facility. The poorest performances of barriers in normal operation should be used in the calculations. A best estimate methodology with the use of adequate margins may also be used.
(b) Calculations of the estimated doses due to occupational exposure should be made on the basis of the conditions at the most exposed workplaces and should use maximum annual working times. On the basis of data on dose rates collected during commissioning runs and, as necessary, the operational limits and conditions may include maximum annual working times for particular workplaces.
(c) Calculations of the estimated doses to the public (i.e. to the ‘representative person’) should be made on the basis of maximum estimated releases of radioactive material to the air and to water, maximum depositions to the ground, and direct exposure. Conservative models and parameters should be used to calculate the estimated doses to the public.

Safety analysis for accident conditions

Methods and assumptions for safety analysis for accident conditions

5.108. To estimate the on-site and off-site consequences of an accident, the entire range of physical processes that could lead to a release of radioactive material and any associated hazardous chemicals to the environment should be modelled in the accident analysis and the cases encompassing the worst consequences should be determined.

5.109. The consequences of design basis accidents for a conversion facility or a uranium enrichment facility would generally be limited to consequences for individuals on the site and close to the location of the accident. The consequences depend on various factors such as the amount and rate of the release of radioactive material and hazardous chemicals, the distance between the source of the release and the individuals exposed or affected, pathways for the transport of material to the individuals and the exposure times.

5.110. The acceptance criteria associated with the accident analysis should be defined in accordance with Requirement 16 of GSR Part 4 (Rev. 1) [11], and with respect to national regulations and relevant criteria.

5.111. To demonstrate the protection of workers, the public and the environment from accidents, the following two approaches, or another equivalent approach, should be considered in the safety assessment of conversion facilities and uranium enrichment facilities:

(1) The first approach involves the identification of structures, systems and components important to safety based on an analysis of all credible accidents that can exceed pre-established criteria for facility personnel, members of the public and the environment. It also involves demonstrating that these structures, systems and components can reduce the consequences and/or the likelihood of potential accidents below the pre-established criteria. This approach would also provide information for the development of emergency plans.
(2) The second approach starts with the selection of the limiting accident conditions, referred to as bounding or enveloping scenarios. It should then be demonstrated in a conservative way, with no account taken of any (active) structures, systems and components important to safety or administrative measures, that the consequences of these limiting accident conditions are within established facility independent acceptance criteria. This assessment is followed by a review of the possible accident sequences to identify provisions of design features and administrative measures, taking into account a graded approach in accordance with Requirement 11 of SSR-4 [1], to further reduce the consequences and/or the likelihood of potential accidents and to provide information for the development of emergency plans.

5.112. Accident consequences should be assessed in accordance with the requirements established in GSR Part 4 (Rev. 1) [11] and with relevant parts of its supporting Safety Guides.

5.113. Requirement 38 of SSR-4 [1] states that "**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.**" The potential occurrence of a criticality accident should be considered for uranium enrichment facilities and for conversion facilities that process uranium with a ^{235}U enrichment of more than 1% as part of the safety analysis for accident conditions. Particular consideration should be given to the potential occurrence of a criticality accident for facilities handling and processing various feed products, including reprocessed uranium.

5.114. In accordance with paras 6.149 and 6.150 of SSR-4 [1], the need for and suitability of mitigatory measures and the effectiveness of protective actions are required to be assessed for criticality accidents.

Analysis of design extension conditions

5.115. The safety analysis should identify design extension conditions, and their progression and consequences should be analysed in accordance with Requirement 21 of SSR-4 [1]. The objective is to identify and analyse additional accident scenarios to be addressed in the design of a conversion facility or uranium enrichment facility. 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."

5.116. Design extension conditions include events more severe than design basis accidents that could originate from extreme events, or combinations of such events, sequentially or simultaneously, which could cause damage to structures, systems and components important to safety or which could challenge the fulfilment of the main safety functions. The postulated initiating events provided in the appendix to SSR-4 [1] are required to be used, including combinations of initiating events as well as events with additional failures. Accidents that have more severe consequences as well as progressions of events that could potentially lead to a criticality event or to radiological or chemical releases should also be analysed to support emergency preparedness and response and assist in the development of emergency plans to mitigate the consequences of an accident.

5.117. Additional safety features or increased capability of safety systems, identified during the analysis of design extension conditions, should be implemented in the facility, where practicable.

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

5.119. Examples of design extension conditions that are applicable to conversion facilities and uranium enrichment facilities can be found in Ref. [21].

5.120. Analysis of design extension conditions should also demonstrate that the conversion facility or uranium enrichment facility can be brought into a state where the confinement function and subcriticality can be maintained in the long term (see also SSG-27 (Rev. 1) [2]).

Assessment of possible radiological or chemical consequences

5.121. The main steps for the assessment of possible radiological or chemical consequences in the safety analysis should include the following:

(a) Analysis of the actual site conditions (e.g. meteorological, geological and hydrogeological site conditions) and conditions expected in the future, including internal and external initiating events with the potential for adverse effects.
(b) Specification of facility design information and facility configurations, with the corresponding operating procedures and administrative controls for operations.
(c) Identification of individuals and population groups (for facility personnel and members of the public) who could possibly be affected by radiation risks and/or associated chemical risks arising from the operation of the facility.
(d) Identification and analysis of conditions at the facility, including internal and external initiating events that could lead to a release of material or energy with the potential for adverse effects, the time frame for emissions and the exposure time, in accordance with reasonable scenarios.
(e) Quantification of the consequences for the individuals and population groups identified in the safety assessment.
(f) Identification and specification of the structures, systems and components important to safety that may be credited to reduce the likelihood and to mitigate the consequences of accidents. The structures, systems and components important to safety that are credited in the safety assessment should be qualified to perform their functions in accident conditions.

(g) Characterization of the source term (e.g. material, mass, release rate, temperature).
(h) Identification and analysis of pathways by which material that is released could be dispersed in the environment.
(i) Considerations for the interface between safety and nuclear security.

5.122. The analysis of the conditions at the site involves a review of the meteorological conditions (e.g. wind speed, stability class, building wake effects), and of the geological and hydrological conditions at the site (e.g. surface water flow rate) that might influence facility operations or might play a part in transporting material or transferring energy that might be released from the facility.

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

5.124. The identification of personnel and members of the public (i.e. the representative person) who might potentially be affected by an accident involves a review of descriptions of the facility and of demographic information.

5.125. Further recommendations on the assessment of potential radiological impact to the public can be found in GSG-10 [16]. Useful guidelines for assessing the acute and chronic toxic effects of chemicals used in conversion facilities and uranium enrichment facilities are provided in Ref. [22].

EMERGENCY PREPAREDNESS AND RESPONSE

5.126. A comprehensive hazard assessment should be performed in accordance with Requirement 4 of IAEA Safety Standards Series No. GSR Part 7, Preparedness and Response for a Nuclear or Radiological Emergency [23], before the commissioning of the facility. The results of the hazard assessment should provide a basis for identifying the emergency preparedness category relevant to the facility and the on-site areas and, as relevant, off-site areas where protective actions and other response actions may be warranted in the case of a nuclear or radiological emergency. Further recommendations are provided in IAEA Safety Standards Series No. GS-G-2.1, Arrangements for Preparedness for a Nuclear or Radiological Emergency [24].

5.127. The operating organization of a facility is required to establish emergency arrangements that take into account the potential hazards at the facility (Requirements 47 and 72 of SSR-4 [1]). The emergency plan and the necessary equipment and provisions should be determined on the basis of selected scenarios for design extension conditions and beyond design basis accidents (or the equivalent). The conditions under which an off-site emergency is required to be declared for a facility should include criticality accidents, widespread fires in the UF_6 storage area, and earthquakes.

MANAGEMENT OF RADIOACTIVE WASTE

5.128. The general requirements for optimization of protection and safety for waste and effluent management and the formulation of a waste strategy are established in IAEA Safety Standards Series No. GSR Part 5, Predisposal Management of Radioactive Waste [25] and recommendations are provided in IAEA Safety Standards Series Nos GSG-3, The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste [26], GSG-1, Classification of Radioactive Waste [27], SSG-41, Predisposal Management of Radioactive Waste from Nuclear Fuel Cycle Facilities [28] and GSG-16 [9]. Recommendations on aspects that are particularly relevant or specific to conversion facilities and uranium enrichment facilities are provided in paras 5.129–5.132.

5.129. In accordance with Requirement 24 of SSR-4 [1], the generation of radioactive waste is required to be kept to the minimum practicable in terms of both activity and volume, by means of appropriate design measures. The operating organization of conversion facilities and uranium enrichment facilities should to the extent practicable recover uranium and reuse chemicals to minimize the generation of waste.

5.130. In the design stage, including in the design for uranium recovery, a review of various techniques should be undertaken to identify the most appropriate technique to minimize waste generation. Safety related factors should also be taken into account in selecting the most appropriate technique.

5.131. In the case of conversion facilities and uranium enrichment facilities, the nuclear material to be recovered is uranium, both from scraps and as secondary outputs from ventilation filters or from cleaning the facility. The process of recovering uranium from scraps may include dissolution and solvent extraction, which generate liquid effluents. An appropriate balance should be sought between the benefits of recovering useful material, the solid and liquid waste generated and the environmental impact.

5.132. Appropriate quality controls should be applied throughout the management of waste from all waste streams. Recommendations on the management system for radioactive waste management are provided in GSG-16 [9].

MANAGEMENT OF GASEOUS AND LIQUID EFFLUENTS

5.133. Conversion facilities and uranium enrichment facilities should be designed so that the need for discharges is avoided. If discharges cannot be avoided, the operating organization should ensure that discharge limits can be met in normal operation and that accidental releases to the environment are prevented.

5.134. Liquids from operating processes should be monitored, treated and managed as necessary to reduce the discharges of radioactive material and hazardous chemicals.

5.135. Where necessary, equipment should be installed to reveal potential failure of treatment systems, such as differential pressure gauges to identify failed filters. If required by the safety analysis or the relevant authorization, discharge monitoring should be provided via continuous sampling of the activity or gas concentration, coupled with continuous measurement of the discharge flow rate.

5.136. In addition to the utilization of the best available techniques to remove suspended solids, residual radionuclides in effluents discharged to the environment should be in soluble form, as far as possible, to allow effective dispersal in the aquatic system without coagulation, deposition and buildup of the radionuclides that could result in the need for environmental cleanup activities.

OTHER DESIGN CONSIDERATIONS

5.137. To meet Requirement 7 of SSR-4 [1], at an early stage in the facility design, selection of equipment and materials should be such as to ensure confinement, limit the accumulation of uranium and increase the ease of cleaning and/or surface decontamination. With regard to inadvertent accumulation of uranium in process lines, ventilation systems and containers, special consideration should be given to operating experience feedback (see Ref. [29]).

5.138. For specific process areas, consideration should be given to the means by which the facility can be shut down safely in an emergency.

5.139. Minimization of the storage of hazardous materials on the site should be considered in the design.

5.140. Selection of materials for civil structures and equipment should be done with respect to their chemical and thermal compatibility, considering the chemicals used in the facility processes.

Design provisions for on-site transfer of radioactive material and hazardous materials

5.141. Requirements for control over the transfer of radioactive material and other hazardous materials are established in Requirement 28 and paras 6.111–6.112 of SSR-4 [1].

5.142. The design of the facility and the production processes should take into account the number of on-site transfers of radioactive material and other hazardous materials across different safety related zones (e.g. contamination zones, criticality controlled areas).

5.143. For incoming containers containing radioactive material or other hazardous materials, sufficient technical provisions for checking their integrity should be considered during the design stage.

5.144. All containers used for transfer of radioactive material and other hazardous materials on the site should be considered in the safety analysis.

5.145. For cases where misidentification of containers could pose a hazard, provisions for easy identification of the content should be used (e.g. use of unique colours, shapes and/or valves).

5.146. Technical provisions for inspection and maintenance of containers that are classified as items important to safety should be available. All containers should be controlled by a computer based system (e.g. to monitor the actual status, position and technical conditions of the containers).

5.147. The analyses of handling arrangements should cover the following:

(a) Transport routes and intersections within the facility;

(b) Technical limits of the transport vehicles;
(c) Handling failures during transport.

Design of the storage area for UF_6 cylinders

5.148. Provision should be made for avoiding any deep corrosion of cylinders that could result in a loss of confinement of UF_6 (especially for the storage of depleted UF_6 over long periods of time).

5.149. The design of storage areas should allow easy access to conduct periodic inspections and testing of cylinders and should minimize occupancy (to limit occupational exposure).

5.150. Flammable material should not be stored close to any storage area for UF_6 cylinders.

5.151. A large aircraft crash into the storage area for UF_6 cylinders is generally not considered a design basis accident. However, this scenario may need to be considered in the design extensions conditions analysis. In accordance with specific site considerations, engineered provisions such as drainage or rafts may minimize the potential of a significant pool fire.

5.152. Special consideration should be given to the storage of cylinders with reprocessed uranium (including cylinders with heels) which represent higher radiation risk to personnel.

AGEING MANAGEMENT CONSIDERATIONS

5.153. In accordance with Requirement 32 of SSR-4 [1], the design of the facility is required to take into account the ageing effects and the degradation mechanisms of systems, structures and components important to safety to ensure their reliability and availability during the lifetime of the facility.

5.154. The design should allow all systems, structures and components important to safety to be easily inspected in order to detect their ageing (static containment deterioration, corrosion) and to allow their maintenance or replacement if needed.

5.155. An ageing management programme should be implemented at the design stage to ensure that provisions are in place for timely maintenance of systems, structures and components important to safety and for anticipating equipment replacements.

5.156. The effectiveness of the ageing management programme for the facility should be reviewed and assessed periodically.

6. CONSTRUCTION OF CONVERSION FACILITIES AND URANIUM ENRICHMENT FACILITIES

6.1. Requirements for the construction of conversion facilities and uranium enrichment facilities are established in Requirement 53 and paras 7.1–7.7 of SSR-4 [1]. General recommendations on the construction and construction management of nuclear installations are provided in IAEA Safety Standards Series No. SSG-38, Construction for Nuclear Installations [30].

6.2. For conversion facilities and uranium enrichment facilities, the criteria used for the construction of the building and the fabrication of the process equipment and components used in the facility and for their installation, should be the same as or more stringent than those used for the non-nuclear chemical industry, and should be specified as part of the design (e.g. seismic design).

6.3. The extent of regulatory involvement in construction should be commensurate with the hazards posed by the facility over its lifetime.

6.4. In addition to the construction programme (see Requirement 53 of SSR-4 [1]) and the management process by which the operating organization maintains control over construction, frequent visits to the construction site should be used to provide feedback of information to the construction contractor to avoid future operational problems.

6.5. Uranium enrichment facilities are complex mechanical facilities and, as such, modularized components should be used in their construction. This enables equipment to be tested and proven at manufacturers' premises before its installation at the uranium enrichment facility. This will also aid commissioning, maintenance and decommissioning of the facility. Components and cables in a uranium enrichment facility should be clearly labelled, owing to the complexity of the control systems.

6.6. Preferably, construction work should be completed before commissioning of the facility or its parts. In cases where the construction and commissioning or operational stages overlap, appropriate precautions should be considered in order to minimize the potential adverse impact of construction activities on safety. Consideration should also be given to the protection of equipment that has already been installed.

6.7. All structures and components, after their installation, should be properly cleaned and painted with suitable primer followed by appropriate surface treatment.

6.8. The effect of nearby activities handling corrosive substances should also be considered.

6.9. Contractors engaged in the construction work should be properly assessed for their integrity and competency in adhering strictly to design requirements and quality requirements to ensure the future safety of the facility.

7. COMMISSIONING OF CONVERSION FACILITIES AND URANIUM ENRICHMENT FACILITIES

7.1. The requirements for commissioning are established in Requirement 54 and paras 8.1–8.23 of SSR-4 [1].

7.2. The operating organization should make the best use of the commissioning stage to become completely familiar with the facility. This stage should also be an opportunity to promote and further enhance safety culture, including positive behaviours and attitudes, throughout the entire organization.

7.3. For a conversion facility or a uranium enrichment facility, the commissioning should be divided into two main stages:

(1) Cold commissioning (i.e. commissioning before the introduction of uranium into the facility). In this stage, the facility's systems are systematically tested, both the individual items of equipment that they comprise and the systems in their entirety. As much verification and testing as possible should be performed because of the relative ease of taking corrective actions in this stage. However, given the low radiation levels in a conversion facility or a uranium enrichment facility, it would also be acceptable to conduct some of

these activities in the subsequent stage. The operating organization should take the opportunity to finalize the set of operational documents and to train the personnel in the safety requirements, operating procedures (including those for maintenance) and emergency procedures. At the end of this stage, the operating organization should provide to the regulatory body evidence of conformity of the facility to design requirements and safety requirements and operational readiness for active commissioning.

(2) Hot commissioning (i.e. commissioning with the use of uranium). In this stage, the safety systems and measures for confinement and for radiation and chemical protection should be tested. Testing in this stage should consist of (i) checks for airborne radioactive material and checks of levels of exposure at the workplace; (ii) smear sampling of surfaces; (iii) checks for gaseous and liquid discharges; and (iv) checks for the unexpected accumulation of material. Testing in this second stage should be performed with the use of natural or depleted uranium to prevent risks of criticality, to minimize occupational exposure and to reduce the possible need for decontamination.

7.4. During cold commissioning, the operating organization should verify (by a ‘smoke test’ or other equivalent method) that the location of key radiological instruments is correctly designed (i.e. that the airflows within the plant are as estimated by the calculations during the design stage).

7.5. During commissioning and later during operation of the facility, the estimated doses to personnel that were calculated should be compared with the actual doses or dose rates. If, in operation, the actual doses are higher than the calculated doses, corrective actions should be taken, including making any necessary changes to the licensing documentation (i.e. the safety analysis report) or adding or changing safety features or work practices.

7.6. To minimize the contamination of equipment during commissioning, process testing with uranium should be used where necessary to evaluate the performance of instruments for the detection of radiation or to evaluate the processes for the removal of uranium.

7.7. Sufficient operating personnel, suitably qualified and with the necessary training, should be available at each stage of commissioning.

7.8. Where possible, lessons identified from the commissioning and operation of similar conversion facilities or uranium enrichment facilities should be sought out and applied.

8. OPERATION OF CONVERSION FACILITIES AND URANIUM ENRICHMENT FACILITIES

ORGANIZATION OF THE OPERATION OF CONVERSION FACILITIES AND URANIUM ENRICHMENT FACILITIES

8.1. The main hazards of a conversion facility or a uranium enrichment facility described in Section 2 should be taken into account in meeting the safety requirements established in section 9 of SSR-4 [1].

8.2. The internal safety committee in a conversion facility or a uranium enrichment facility should be created from the safety committee established for commissioning (see also para. 3.26 of this Safety Guide and para. 4.29 of SSR-4 [1]).

STAFFING OF A CONVERSION FACILITY OR URANIUM ENRICHMENT FACILITY

8.3. 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.**"

8.4. 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." The programme for the operation and utilization of the conversion facility or uranium enrichment facility should be periodically reviewed and updated to ensure that it is consistent with and supports long term objectives.

8.5. The staffing 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.

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

8.7. The operating organization should establish the necessary arrangements to ensure the safety of personnel and the safe operation of the conversion facility or uranium enrichment 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

8.8. The safety requirements relating to the qualification and training of facility personnel are established in Requirements 56 and 58 of SSR-4 [1]. Detailed recommendations are provided in paras 4.6–4.25 of GS-G-3.1 [7].

8.9. The operating personnel of a conversion facility or a uranium enrichment facility should receive specific training in the mitigation of chemical effects and the detection of overexposure (see para. 9.41 of SSR-4 [1]).

8.10. In addition to the specific training required in para. 9.49 of SSR-4 [1], the training on prevention and mitigation of fires and explosions that could result in a release of radioactive material should be provided. Such training should cover: (a) an H_2 explosion in a reduction furnace in a conversion facility; and (b) a lubrication oil fire in a uranium enrichment facility. In addition, personnel should be provided periodically with basic training in nuclear and radiation safety.

8.11. Complementary training of safety personnel and security personnel and their mutual participation in exercises of both types should be part of the training programme to effectively manage the interface between safety and security. In particular, personnel with responsibilities and expertise in safety analysis and safety assessment as well as in operational safety, including radiation protection personnel and nuclear criticality safety personnel, should be provided with a working knowledge of the security requirements of the facility, and security experts should be provided with a working knowledge of the safety considerations of the facility, so that potential conflicts between safety and security can be resolved effectively.

OPERATIONAL DOCUMENTATION

8.12. Requirement 57 and paras 9.27–9.37 of SSR-4 [1] require that operational limits and conditions be developed for a conversion facility or a uranium enrichment facility. The safety significance of the operational limits and conditions as well as of the action levels and conditions should be well understood by the personnel operating the facility. The set of action levels should be defined and maintained by the operating organization.

8.13. Operational documentation should be prepared that lists all the operational limits and conditions under which the facility is operated. Annexes III and IV give examples of parameters that can be used for defining the operational limits and conditions in the various processing areas of the facility.

8.14. In accordance with para. 9.31 of SSR-4 [1], limits on operating parameters are required to be established for a conversion facility or a uranium enrichment facility. Examples of such limits are the following:

(a) The maximum enrichment of uranium allowed at the facility;
(b) The feed specification limits;
(c) The maximum allowed inventories for processes and for the facility;
(d) Minimum staffing requirements and availability of specific expertise (e.g. nuclear criticality expert).

8.15. Consideration should be given to ensuring that uranium is present only in areas designed for the storage or handling of uranium. To meet the requirements established in Requirement 64 and in para. 6.121 of SSR-4 [1], programmes should be put in place for routine monitoring of surface contamination and airborne contamination, and for ensuring an adequate level of housekeeping.

8.16. Operating procedures should be developed to control process operations directly. The procedures should include directions for attaining a safe state of the facility for all anticipated operational occurrences and accident conditions. Procedures of this type should include the actions needed to ensure criticality safety, fire protection, emergency planning and environmental protection.

8.17. The operating procedures for the ventilation system should be specified for fire conditions, and periodic testing of the ventilation system and fire drills should be performed.

MAINTENANCE, CALIBRATION, PERIODIC TESTING AND INSPECTION

8.18. The safety requirements relating to maintenance, calibration, periodic testing and inspection of conversion facilities and uranium enrichment facilities are established in Requirement 65 and paras 9.74–9.82 of SSR-4 [1].

8.19. Maintenance activities in a conversion facility or a uranium enrichment facility should be pre-authorized on the basis of a safety assessment in line with the established management system.

8.20. Before maintenance is performed in areas where fissile material is located (or near such areas), criticality safety personnel should be consulted (see also para. 5.54 of SSG-27 (Rev. 1) [2]).

8.21. Maintenance activities using radioactive sources or X ray generators (e.g. those used for the inspection of welds or flow gauges) should be coordinated with radiation protection personnel, especially when performed by subcontractors.

8.22. When performing maintenance in a conversion facility or a uranium enrichment facility, particular consideration should be given to the potential for surface contamination or airborne radioactive material, and to specific chemical hazards such as hazards due to uranium compounds, hydrogen fluoride, fluorine, hydrogen and nitric acid.

8.23. Maintenance should follow good practices, with particular consideration given to the following:

(a) Work control (e.g. handover and handing back of documents, visits to job sites, changes to the planned scope of work; suspension of work, ensuring safe access);
(b) Equipment isolation (e.g. disconnection of equipment from power supply, heat and pressure piping; venting and purging of equipment);
(c) Testing and monitoring (e.g. checks before commencing work, monitoring during maintenance, checks for recommissioning);

(d) Safety precautions for work (e.g. specification of safety precautions, ensuring the availability of fully functional personal protective equipment and ensuring its use, emergency plans);
(e) Reinstallation of equipment (e.g. reassembly, reconnection of pipes and cables, testing, cleaning of job site, monitoring after recommissioning);
(f) Verification that after maintenance is performed the work area and equipment have been restored to normal safe conditions.

8.24. Changing equipment configurations during maintenance might result in abnormal settings and potential occurrence of unexpected operational modes with no prior safety analysis or operational limits and conditions. This should be prevented by consulting criticality safety personnel before maintenance is performed on installations that may contain enriched uranium or are located near a storage area of enriched uranium.

8.25. All temporary changes to the facility configuration during maintenance activities should be coordinated between safety specialists and security specialists to avoid potential conflicts (e.g. loss of electrical power supply on some safety systems, opening of barriers and doors). Compensatory measures should be implemented as necessary. Particular attention should be given to changes that could affect the systems or structures needed for the neutron isolation of adjacent fissile units. When changes affect these systems or structures temporarily, it should be ensured that these systems or structures continue to deliver their required safety function when reinstated.

8.26. Compliance of the operational performance of the ventilation systems with fire protection requirements should be verified on a regular basis.

8.27. A programme for calibration and periodic inspections of the facility should be established. Its purpose is to verify that the facility and its structures, systems and components are operating in accordance with the operational limits and conditions. Suitably qualified and experienced personnel should perform calibrations and periodic inspections.

8.28. Places in the process line identified by the operating organization as places with potential for accumulation of uranium compounds should be periodically inspected.

8.29. Long term deterioration of UF_6 cylinders and corrosion damage to the plugs and valves due to both internal and external influences are recognized as possible sources of leakage problems. An inspection programme should be established at long term storage facilities to monitor and record the level of corrosion (particularly at plugs and valves and along the skirt welds).

AGEING MANAGEMENT

8.30. The operating organization should take into account the following in implementing an ageing management programme in accordance with Requirement 60 of SSR-4 [1]:

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

8.31. The ageing management programme should consider the technical as well as the non-technical aspects of ageing, and its effectiveness should be regularly assessed and reviewed.

8.32. The periodic tests and inspections should be completed by regular checks performed by the operating personnel, such as the following:

(a) Monitoring of deterioration (e.g. measurement of metallic impurities in fluoric acid);
(b) Regular visual inspections of uranium powder pipes;

(c) Monitoring of operating conditions (e.g. taking heat images of electrical cabinets, checking temperatures of ventilator bearings).

CONTROL OF MODIFICATIONS

8.33. 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 for a conversion facility or a uranium enrichment facility should include a standard process for all modifications (see para. 3.20). The work control system, quality assurance procedures and appropriate testing procedures of the facility should be used for the implementation of modifications.

8.34. All proposed modifications should contain a description of the modification and why it is being made, provide the basis for safety assessment of the modification, identify all the aspects of safety that might be affected by the modification, and demonstrate that adequate and sufficient safety provisions are in place to control the potential hazards.

8.35. The operating organization should prepare procedural guidelines and provide training to ensure that the responsible personnel have the necessary training and authority to ensure that modification projects are carefully considered (see paras 9.57(e) and 9.58 of SSR-4 [1]). The safety of modifications should be assessed for potential hazards during installation, commissioning and operation.

8.36. Proposed modifications should be scrutinized by and be subject to approval by qualified and experienced persons to verify that the arguments used to demonstrate safety are suitably robust. This is particularly important if the modification could have an effect on criticality safety. The depth of the safety arguments and the degree of scrutiny to which they are subjected should be commensurate with the safety significance of the modification (see also para. 9.59 of SSR-4 [1]).

8.37. In accordance with para. 4.31(d) of SSR-4 [1], the safety committee is required to review the proposed modifications. Suitable records should be kept of its decisions and recommendations.

8.38. The modification should also specify which documentation will need to be updated as a result of the modification (e.g. training plans, specifications, the safety assessment, notes, drawings, engineering flow diagrams, process instrumentation diagrams, operating procedures). Procedures for the control of documentation should be put in place to ensure that documents are changed within a reasonable time period following the modification. Personnel should be informed and trained accordingly before operation commences.

8.39. An adequate management process should be used as an overall means of monitoring the progress of modifications through the system and as a means of ensuring that all modification proposals receive an equivalent and sufficient level of scrutiny. The modification documentation should also specify the functional checks that should be performed before the modified system may be declared fully operational again.

8.40. Modifications performed on design, layout or procedures of the facility might adversely affect security equipment and vice versa. For example, the malfunction of safety equipment might damage nearby security equipment. Therefore, before approval and implementation, any proposed changes to the facility or to management arrangements should be reviewed, assessed and endorsed to ensure that all applicable safety requirements and criteria are met. In addition, the interface with security should be evaluated to verify that safety measures and security measures do not compromise each other (see Requirement 75 of SSR-4 [1]).

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

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

CONTROL OF NUCLEAR CRITICALITY HAZARDS

8.43. The requirements for criticality safety in conversion facilities and uranium enrichment facilities are established in Requirement 66 and paras 9.83–9.85 and 9.88 of SSR-4 [1], and general recommendations are provided in SSG-27 (Rev. 1) [2]. In conversion facilities and uranium enrichment facilities that process uranium with a ^{235}U enrichment of more than 1%, it is particularly important that the procedures for controlling criticality hazards are strictly applied.

8.44. Operational aspects of the control of criticality hazards in conversion facilities and uranium enrichment facilities should be taken into consideration, including the following:

(a) Prevention of unexpected changes in conditions that could increase the probability of a criticality accident, for example, unplanned accumulation of uranium compounds (e.g. in ventilation ducting), inadvertent precipitation of material containing uranium in storage vessels or loss of neutron absorbers;
(b) Control of the enrichment level to detect deviations that could lead to enrichment above the maximum enrichment used in criticality safety analysis, both steady state and transients, before a significant amount of material above this limit has accumulated;
(c) Management of moderating materials; for example, undertaking checks before an empty cylinder is used in the facility to receive material enriched by ^{235}U above 1%, to ensure that no hydrogenous material (e.g. water, oil or plastics) is present in the cylinder;
(d) Management of mass in transfer of uranium (e.g. using procedures, mass measurement, systems and records) for which safe mass control is used;
(e) Reliable methods for detecting the onset of any of the conditions described in points (a)–(d);
(f) Periodic calibration or testing of systems for the control of criticality hazards;
(g) Evacuation drills to prepare for the occurrence of a criticality event and/or the actuation of an alarm.

8.45. For any wet cleaning process, a safe uranium holdup limit should be defined. It should be verified that the uranium holdup is below this safe limit before the wet cleaning process can be started (see also para. 9.88(b) of SSR-4 [1]).

RADIATION PROTECTION

8.46. The requirements for radiation protection in operation are established in Requirement 67 and paras 9.90–9.101 of SSR-4 [1] and in GSR Part 3 [15]; recommendations are provided in IAEA Safety Standards Series No. GSG-7, Occupational Radiation Protection [31]. The operating organization should have a policy to optimize protection and safety and is required to ensure that doses are below national dose limits and within any dose constraints set by the operating organization (see para. 9.91 of SSR-4 [1]). The policy should address the minimization of exposure to radiation by all available physical means and by administrative arrangements, including the use of time and distance during operations and maintenance activities.

8.47. In a conversion facility or a uranium enrichment facility, the main radiological hazard under accident conditions for both the personnel and members of the public is from the inhalation of airborne material containing uranium compounds. In conversion facilities, insoluble compounds of uranium such as uranium dioxide and triuranium octoxide pose a particular hazard because of their long biological half-lives (and therefore effective half-lives)[4]. In accordance with para. 9.99 of SSR-4 [1], close attention is required to be paid to the confinement of uranium powders and the control of contamination in the workplace. In uranium enrichment facilities, most uranium compounds have a short biological half-life. The chemical hazards for the uranium compounds found in conversion facilities and uranium enrichment facilities dominate the radiological hazards.

8.48. In conversion facilities and uranium enrichment facilities, in normal operation, the main characteristic that needs to be taken into account in the development of measures for radiation protection is that the external and internal dose rates are relatively low. A nuclear criticality accident is the only event in which a high external dose rate would be encountered.

8.49. Interventions for maintenance and/or modifications are major activities that require justification and optimization of protective actions, as specified in GSR Part 3 [15]. The procedures for intervention should include the following:

(a) Estimation of the exposure before an intervention in areas such as those for the processing and handling of ashes containing thorium gamma emitters arising from the fluorination reactor in conversion facilities.
(b) Preparatory activities to minimize the doses due to occupational exposure, including the following:
    (i) Specifically identifying the risks associated with the intervention;
    (ii) Specifying in the work permit the protective measures for the intervention such as for the individual as well as collective means of protection (e.g. use of masks, clothing and gloves, time limitation).
(c) Measurement of the occupational exposure during the intervention.

[4] The biological half-life is the time taken for the amount of a material in a specified tissue, organ or region of the body (or any other specified biota) to halve as a result of biological processes. The effective half-life is the time taken for the activity of a radionuclide in a specified place to halve as a result of all relevant processes.

(d) Implementation of feedback of information for identifying possible improvements.

8.50. The risks of exposure of members of the public should be minimized by ensuring that, as far as reasonably practicable, radioactive material is kept away and/or removed from ventilation exhaust gases to prevent it being discharged to the atmosphere.

8.51. The monitoring results from the radiation protection programme should be compared with the operational limits and conditions, and corrective actions are required to be taken if necessary (see para. 9.34 of SSR-4 [1]). Furthermore, these monitoring results should be used to verify the dose calculations made in the initial environmental impact assessment.

8.52. Internal exposure should be controlled by the following means:

(a) Performance targets should be set for all parameters relating to internal exposure (e.g. levels of contamination).
(b) Enclosures and ventilation systems should be routinely inspected, tested and maintained to ensure that they continue to fulfil their design requirements. Regular flow checks should be performed at ventilation hoods and entrances to confinement areas. Pressure drops across air filter banks should be checked and recorded regularly. Surveillance of the ventilation system should be conducted to detect any unwanted accumulation of fissile and radioactive material.
(c) A high standard of housekeeping should be maintained at the facility. Cleaning techniques that do not give rise to airborne radioactive material should be used (e.g. the use of vacuum cleaners with HEPA filters).
(d) Regular contamination surveys of areas of the facility and equipment should be performed to confirm the adequacy of cleaning programmes.
(e) Contamination zones should be delineated and clearly indicated.
(f) Continuous air monitoring should be performed to alert facility operators if levels of airborne radioactive material exceed predetermined action levels.
(g) Mobile air samplers should be used where there are possible sources of contamination, as necessary.
(h) An investigation should be conducted promptly in response to the detection of high levels of airborne radioactive material.
(i) Personnel and equipment should be checked for contamination and should undergo decontamination, if necessary, before leaving contamination zones. Entry to and exit from the work area should be controlled to prevent the

spread of contamination. In particular, changing rooms and decontamination facilities should be provided.

(j) Temporary means of ventilation and means of confinement should be used when intrusive work increases the potential for causing contamination by airborne radioactive material (e.g. activities for vessel connection and/or disconnection, periodic testing, inspection and maintenance).
(k) Personal protective equipment should be made available for dealing with releases of chemicals (e.g. acid gas) or radioactive material from the normal means of confinement in specific operational circumstances (e.g. during disassembly or cleaning of process equipment).
(l) Personal protective equipment should be maintained in good condition, should be cleaned as necessary and should be inspected.
(m) Any personnel with wounds should protect them with an impervious covering for work in contamination zones.

8.53. In vivo monitoring and biological sampling should be made available as necessary for monitoring doses due to occupational exposure. Since most of the uranium present in conversion facilities and uranium enrichment facilities is in soluble form, the frequency of sample collection and the sensitivity of analytical laboratory equipment should be appropriate to detect and estimate any uptake of uranium for routine or emergency purposes.

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

8.55. For exposures which are expected to be low, the method for assessing doses due to internal exposure may 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 should be reviewed as appropriate by the regulatory body.

8.56. On completion of maintenance work, the area concerned should be decontaminated, if necessary, and air sampling and smear sampling of surfaces should be performed to confirm that the area can be returned to normal use.

8.57. In addition to industrial safety requirements for entry into confined spaces, if entry is necessary into vessels that have contained uranium, radiation dose rate surveys should be performed inside the vessel to determine whether any restrictions on the allowed working time are required.

8.58. Preference should be given to estimating the internal dose received by members of the public using environmental monitoring data. However, internal doses may also be estimated by using qualified dispersion models and dose models in conjunction with reliable data on effluents.

8.59. There are limited operations in a conversion facility or a uranium enrichment facility where specific measures for controlling external exposure are required. Typically, these will be areas where the following activities take place:

(a) Operations involving recently emptied cylinders;
(b) Storage of bulk quantities of uranium;
(c) Handling of UF_6 cylinders;
(d) Handling of ashes from fluorination.

8.60. The control of external exposure should account for the dose from neutrons as necessary, especially in areas where UF_6 is stored in bulk (neutrons are emitted from spontaneous fission and alpha-neutron reactions). In addition, newly emptied UF_6 cylinders might also result in external gamma radiation doses that need to be controlled. Much more extensive controls for limiting external exposure will be needed in the processing of reprocessed uranium than in the processing of natural uranium.

8.61. Radioactive sources are also used in a conversion facility or a uranium enrichment facility for specific purposes (e.g. radioactive sources are used for checking uranium enrichment).

8.62. External exposure should be controlled by:

(a) Ensuring that significant amounts of uranium and recently emptied cylinders are remote or appropriately shielded from areas of high occupancy;
(b) Ensuring that radioactive sources are changed by suitably qualified and experienced persons;
(c) Performing routine surveys of radiation dose rates.

8.63. Additional controls should be considered if reprocessed uranium is used as a feedstock at the facility. Such material has a higher specific activity than uranium from natural sources and thus has the potential to increase substantially both external and internal exposures. It could also introduce additional radionuclides into the waste streams. A comprehensive assessment of doses due to occupational exposure and exposure of the public should be conducted before the first introduction of uranium from other than natural sources.

INDUSTRIAL AND CHEMICAL SAFETY

8.64. The requirements relating to industrial and chemical safety are established in Requirement 70 of SSR-4 [1].

8.65. The industrial and chemical hazards present in conversion facilities and uranium enrichment facilities may be summarized as follows:

(a) Chemical hazards due to the presence of UF_6, hydrogen fluoride (including hydrogen fluoride produced through hydrolysis of UF_6 in contact with air moisture), fluorine, nitric acid, ammonia and uranium compounds;
(b) Explosion hazards due to hydrogen, ammonia, ammonium nitrate, methanol, solvents and oxidants present in diffusion cascades;
(c) Asphyxiation hazards due to the presence of nitrogen or carbon dioxide.

8.66. The presence of hydrogen fluoride in conversion facilities represents the main hazard for the protection of personnel, the public and the environment. Special consideration should be given to the storage, handling and processing of hydrogen fluoride on the site (e.g. during transfer of large volumes of hydrogen fluoride from storage tanks to the process area). Industry specific national requirements should be applied, as appropriate.

8.67. The threshold of hydrogen fluoride that a human can detect by smelling is lower than the occupational exposure levels that can result in acute health effects but higher than the levels causing reversible negative health effects. Fixed or mobile means of hydrogen fluoride detection should be provided in the most exposed areas of the facility. In addition, releases of UF_6 generate colourless gaseous hydrogen fluoride and a visible white cloud of uranyl fluoride particulates. For releases of UF_6 and for releases of other chemicals that result in visible clouds, periodic training should be given to all site personnel to follow the approach ‘see, evacuate or shelter, and report’ but higher than the levels causing reversible negative health effects. Fixed or mobile means of hydrogen fluoride detection should be provided in the most exposed areas of the facility.

8.68. The exposure of personnel to chemical hazards should be assessed using a method similar to that for the assessment of radiation doses and 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 regulatory body. The acceptable levels of exposure for various chemical hazards in a conversion facility or a uranium enrichment facility can be found in SSG-68 [20].

8.69. The selection of personal protective equipment should be commensurate to the hazard present (e.g. acid filters for protective equipment for acids, particulate filters for particulates, combination filters where both hazards are present).

8.70. Fire hazard analyses should be conducted periodically to incorporate changes that might adversely affect the potential for and spread of fires (see paras 5.52–5.55).

8.71. A health surveillance programme should be set up, in accordance with national regulations, for routinely monitoring the health of personnel who might be exposed to uranium and associated chemicals (e.g. hydrogen fluoride, beryllium, ammonia, nitric acid, sulphuric acid, potassium hydroxide, sodium hydroxide). Both the radiological and the chemical effects of uranium should be considered, as necessary, as part of the health surveillance programme.

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

OVERFILLING OF CYLINDERS

8.73. Fill limits for cylinders should be established to ensure that, when UF_6 expands (by around 35%) on liquefaction, hydraulic rupture does not occur. Further heating after liquefaction could result in hydraulic rupture.

8.74. In a conversion facility or a uranium enrichment facility, the weight of a cylinder being filled should be monitored to reduce the potential for overfilling, generally by means of weighing scales.

8.75. In the event of an overfilled cylinder, UF_6 in excess should be transferred by sublimation only (e.g. by evacuation to a cooled low pressure receiving vessel).

8.76. If the system has the capability of reaching a temperature where hydraulic rupture can occur, the temperature during heating should be limited by means of two independent systems.

HANDLING OF CYLINDERS CONTAINING LIQUID UF_6

8.77. Movement of cylinders containing liquid UF_6 should be minimized. Cylinders containing liquid UF_6 should be moved only using an appropriately qualified apparatus that has been designated as important to safety. Relevant administrative operational limits and conditions should be established for the movement and storage of cylinders containing liquid UF_6 (e.g. predetermined paths, maximum allowed heights, speeds and distances during movement, dedicated storage areas, minimum cooling times, use of valve protectors, restrictions on load movement above hot cylinders).

ON-SITE HANDLING OF SOLID UF_6

8.78. The length of time needed for the cooling of a cylinder containing liquid UF_6 should be sufficient to ensure that all the liquid UF_6 has solidified.

8.79. Cylinders containing solid UF_6 should be moved only using an appropriately qualified apparatus that has been designated as important to safety.

8.80. Consideration should be given to the impact of a fire on a cylinder containing solid UF_6 (e.g. a fire involving a transporter for UF_6 cylinders). In case a cylinder containing UF_6 is directly affected by a fire, its cooling should be considered in accordance with facility procedures to reduce the potential for rupture.

STORAGE OF TAILINGS

8.81. Site licences generally define a site limit for the total amount of tailings of UF_6 (depleted uranium hexafluoride) that may be stored. Therefore, a plan for disposition of tailings should be prepared well before this limit is reached, to ensure that future generation of tailings does not exceed the site limit. Tailings of UF_6 stored in the long term should be deconverted to a chemically more stable form of uranium (e.g. an oxide of uranium).

8.82. A recording and tracking system should be used to make periodic inspections of uranium accounting and ensure cylinder integrity.

8.83. Periodic inspections of the tailings storage area should be conducted to check standards of housekeeping and ensure that the fire load in the storage area does not exceed the load considered in the facility safety assessment.

MANAGEMENT OF RADIOACTIVE WASTE AND EFFLUENTS

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

8.85. Radioactive gases and chemicals should be treated, where appropriate, by means of HEPA filters and chemical scrubbing systems. Performance standards should be set to specify performance levels at which filters or scrubber media should be changed. After filter changes, tests should be performed to ensure that new filters are correctly seated and yield a removal efficiency as assumed in the analyses.

8.86. Radioactive liquids from operating processes should be treated effectively. Chemicals should be recovered and reused, where possible. This is particularly important for hydrogen fluoride and ammonium nitrate produced in the deconversion process. Care should be taken to ensure that any radiological contamination in material being recycled is below the national threshold limits so that these chemicals are suitable for reuse in other industrial applications.

8.87. The generation of solid radioactive waste should be minimized by removing as much outer packing as possible before material is transferred to radiologically controlled areas. The operating organization should use the best available techniques in minimizing the generation of radioactive waste (including incineration, metal melting and compaction). As far as reasonably practicable and in accordance with national regulations, radioactive material should be treated to allow its further use. Cleaning methods that minimize the generation of waste should be adopted at the facility.

8.88. In conversion facilities, ashes resulting from the fluorination of uranium should be treated to recover the uranium content. The remaining material (oxides of ^{234}Th, ^{230}Th and ^{228}Th if reprocessed uranium is used) should be stored safely. To limit exposure, the treatment of ashes should be postponed to benefit from the decay of ^{234}Th and ^{228}Th.

EMERGENCY PREPAREDNESS AND RESPONSE

8.89. The requirements for emergency preparedness and response are established in Requirement 72 and paras 9.120–9.132 of SSR-4 [1] and in GSR Part 7 [23], and recommendations are provided in GS-G-2.1 [24] and in IAEA Safety Standards

Series No. GSG-2, Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency [32]. The conditions at a conversion facility or a uranium enrichment facility that might require an off-site emergency response to be initiated include large releases of UF_6, hydrofluoric acid, fluorine and ammonia and also criticality accidents, fires (e.g. in the solvent extraction units of a conversion facility) and explosions, and loss of services (see para. 9.126(a) of SSR-4 [1]).

8.90. As part of emergency preparedness, arrangements should be developed for the interfaces with local, regional and national response organizations. These arrangements should be tested periodically to ensure effective operation during an emergency. Clear communication and authorization protocols should be established with local authorities to ensure that the response organization can respond effectively to an emergency at the facility.

8.91. The operating organization should ensure availability of personnel with specific expertise on the nature and extent of hazards 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. 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.

8.92. As specified in GSR Part 7 [23], emergency plans, security plans and contingency plans should be developed in a coordinated manner, considering all responsibilities of the facility personnel and security forces, to ensure that all crucial functions can be performed in a timely manner in the case of an event when the simultaneous response of both groups is needed. Emergency response plans should consider nuclear security events as possible initiators of an emergency as well as their implications on emergency situations, and these plans should be coordinated with the security response. Strategies for rapidly determining the origin of events and deploying appropriate first responders (i.e. emergency response 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 response personnel, with a focus on coordinated command and control interfaces and communications. The response to such events should be jointly exercised and evaluated by security forces and emergency response personnel. From these exercises or evaluations, lessons should be identified and recommendations should be made to improve the overall response to a potential event.

8.93. For establishing access control procedures for an emergency, when there is a necessity for rapid access and egress of personnel, safety specialists and security specialists should cooperate closely. Both safety objectives and security objectives should be met in an emergency, in accordance with regulatory requirements. When this is not possible, the best solution that takes into account both objectives should be pursued.

FEEDBACK OF OPERATING EXPERIENCE

8.94. Requirements on feedback of operating experience are established in paras 9.133–9.137 of SSR-4 [1]. Further recommendations on the operating experience programme are provided in SSG-50 [12].

8.95. The programme for the feedback of operating experience at conversion facilities and uranium enrichment facilities should cover experience and lessons identified from events and accidents at the facility as well as from other nuclear fuel cycle facilities worldwide and other relevant non-nuclear accidents. It should also include evaluation of trends in operational disturbances, trends in malfunctions, near misses and other incidents that have occurred at conversion facilities and uranium enrichment facilities and, as far as applicable, at other nuclear installations. The programme should include consideration of technical, organizational and human factors.

9. PREPARATION FOR DECOMMISSIONING OF CONVERSION FACILITIES AND URANIUM ENRICHMENT FACILITIES

9.1. Requirements for the preparation for safe decommissioning of a conversion facility or a uranium enrichment facility are established in paras 10.1–10.13 of SSR-4 [1] and general safety requirements for the decommissioning of facilities are established in IAEA Safety Standards Series No. GSR Part 6, Decommissioning of Facilities [33].

9.2. Special measures should be implemented during the preparatory work for decommissioning to ensure that criticality control is maintained when handling equipment containing nuclear material whose subcriticality is controlled by geometry, moderation or poisoning. Care should also be taken over possible changes in the fissile material form.

9.3. In addition to the general preparations for decommissioning described in IAEA Safety Standards Series No. SSG-47, Decommissioning of Nuclear Power Plants, Research Reactors and Other Nuclear Fuel Cycle Facilities [34], the following preparatory steps specific to conversion facilities and uranium enrichment facilities should be followed:

(a) A post-operational cleanout should be performed to remove all the UF_6 and the bulk amounts of uranium compounds and other hazardous materials from the process equipment:
    (i) In conversion facilities, the first step is to perform dry mechanical cleaning, to minimize the generation of liquid waste. The uranium resulting from the dry mechanical cleaning process should be recovered.
    (ii) In centrifuge uranium enrichment facilities, gaseous UF_6 is pumped out and recovered in cold traps. In addition, flushing with an inert gas (e.g. nitrogen) should be used to remove the residual UF_6 and hydrogen fluoride.
(b) Any ground (surface and subsurface), groundwater, parts of buildings and equipment contaminated with radioactive material or chemical material and their levels of contamination should be identified by means of comprehensive site characterization.
(c) Risk assessments and method statements for the licensing of the decommissioning process should be prepared.

9.4. The decommissioning plan for conversion facilities and uranium enrichment facilities should be developed following the recommendations provided in SSG-47 [34]. Specific consideration should be given to the following elements:

(a) Description of the facility status at the beginning of decommissioning, including the list of systems that should be operational;
(b) Determination of methods of decontamination of the facility to reach the levels required by the regulatory body for cleanup operations or the lowest reasonably achievable level of residual contamination;
(c) Preparation of risk assessments and method statements for the decommissioning process;
(d) Preparations for the dismantling of process equipment.

9.5. The developed decommissioning plan and the safety assessment should be periodically reviewed and updated throughout the commissioning and operation stages of the facility (see Requirements 8 and 10 of GSR Part 6 [33]) to take into account new information and emerging technologies to ensure the following:

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

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Annex I

TYPICAL PROCESS ROUTES IN A CONVERSION FACILITY

I–1. This annex shows the typical process routes in a conversion facility.

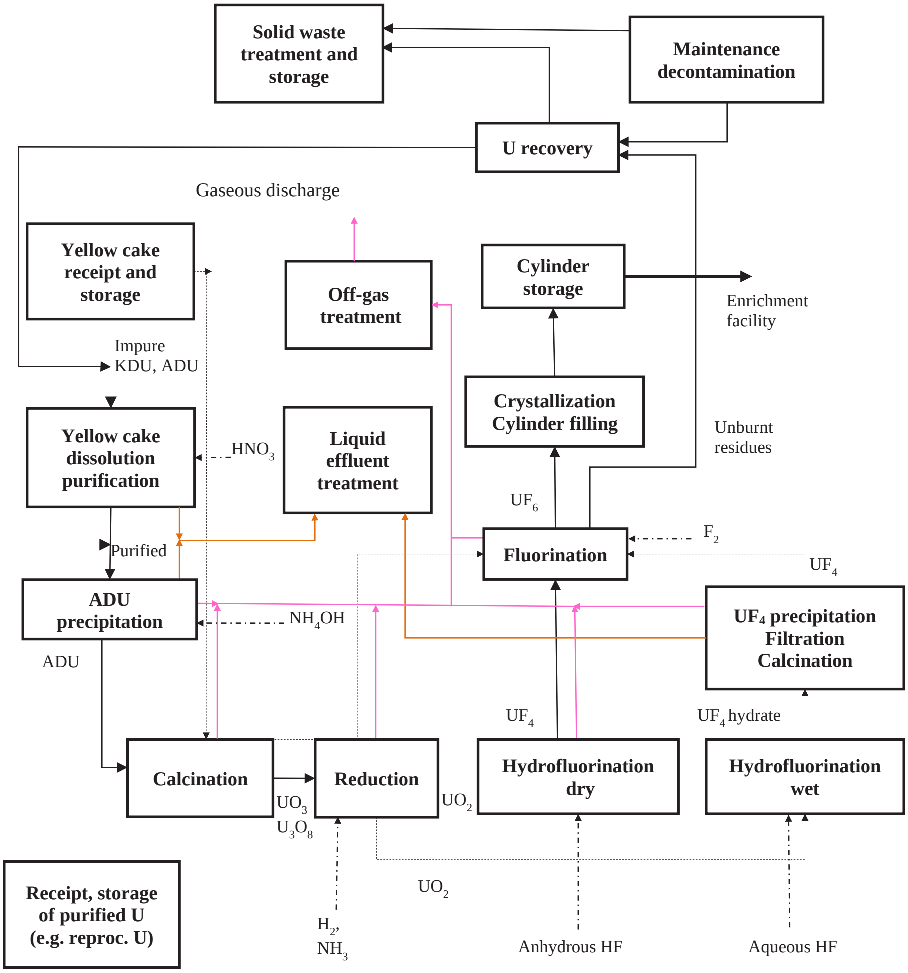

FIG. I–1. Typical process routes in a conversion facility. ADU — ammonium diuranate; KDU — potassium diuranate.

Annex II

TYPICAL PROCESS ROUTES IN A URANIUM ENRICHMENT FACILITY

II–1. This annex shows the typical process routes in a uranium enrichment facility.

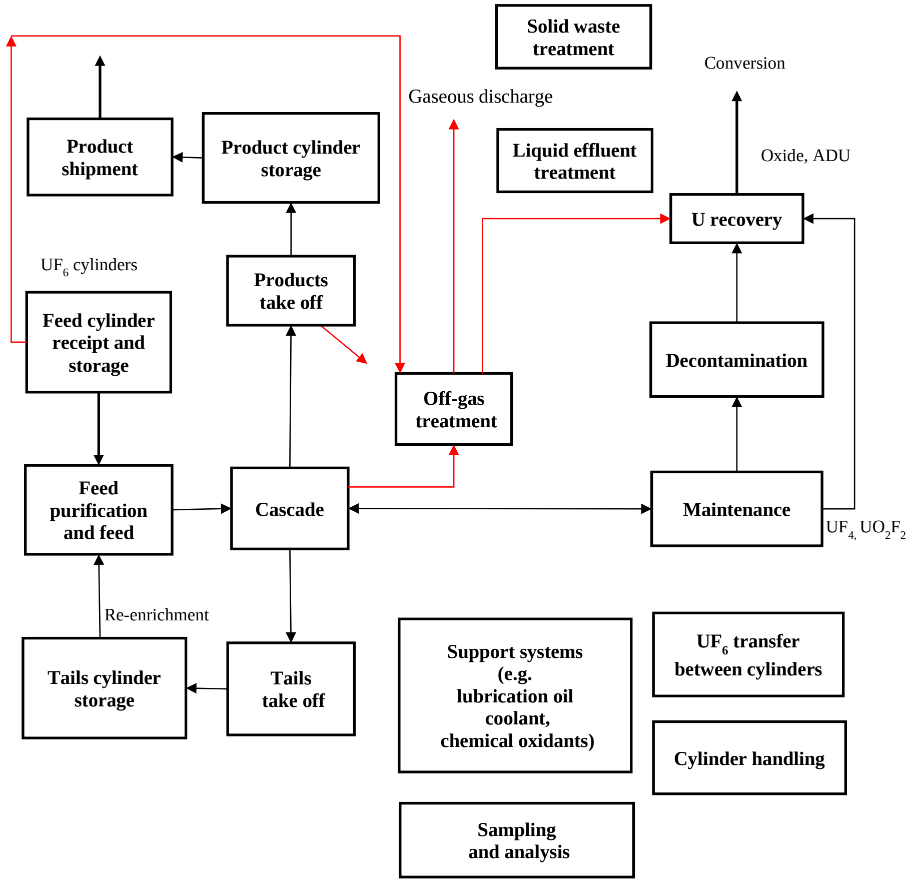

FIG. II–1. Typical process routes in a uranium enrichment facility. ADU — ammonium diuranate.

Annex III

EXAMPLES OF STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY, ASSOCIATED EVENTS AND OPERATIONAL LIMITS AND CONDITIONS FOR CONVERSION FACILITIES

III–1. This annex provides examples of structures, systems and components important to safety, associated events and operational limits and conditions for conversion facilities. A safety function, as used in Table II–1, can serve one or more of the following purposes:

(1) Maintaining subcriticality;
(2) Confinement to protect against internal exposure and chemical hazards;
(3) Protection against radiation exposure.

TABLE III–1. EXAMPLES OF STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY, ASSOCIATED EVENTS AND OPERATIONAL LIMITS AND CONDITIONS FOR CONVERSION FACILITIES.

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Receipt and storage of anhydrous HF	— Flexible hoses and transfer devices — Automatic shut-off valves — Refrigerated storage tanks — Oil spreader	Release of HF	(2)	— Storage room temperature — Oil temperature
HF transfer	Transfer pipes	Release of HF	(2)	
Receipt and storage of NH_3	— Flexible hose and transfer devices — Automatic shut-off valves — Storage vessels	Release of NH_3		
Receipt of H_2	— Flexible hose and transfer devices — Automatic shut-off valves	Explosion	(2)	
Production of anhydrous F_2	— Electrolysis cells — Piping — H_2 detectors	— Explosion — Release of HF and F_2	(2)	— H_2 concentration in air room — F_2 and HF content in gases

TABLE III–1. EXAMPLES OF STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY, ASSOCIATED EVENTS AND OPERATIONAL LIMITS AND CONDITIONS FOR CONVERSION FACILITIES. (cont.)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Receipt and storage of yellow cake	Powder containers	Release of uranium	(2)	— Mass — Enrichment — Concentration
Dissolution of yellow cake	Dissolver and facilities for off-gas treatment	Release of uranium and nitrogen oxide (NO_x)	(2)	Concentration of nitrogen oxide in gaseous effluent
Purification	— Fire detectors — Flameproof apparatus	Fire	(2)	
Receipt of uranium nitrate (enriched uranium)	Checking device for ^{235}U content	Processing of uranium beyond safety limits	(1)	— Enrichment — Concentration
Intermediate storage of uranium nitrate	— Tank — Drip tray — Leak detector	Breach of tank	(2)	Integrity of tank, valves and lines
ADU precipitation	— Vessels — Filter — Drying device	Release of uranium	(2)	Integrity of tank, valves and lines

TABLE III–1. EXAMPLES OF STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY, ASSOCIATED EVENTS AND OPERATIONAL LIMITS AND CONDITIONS FOR CONVERSION FACILITIES. (cont.)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Calcination	Kiln	Release of uranium	(2)	— Integrity of kiln — Relative pressure of room or kiln — Concentration of nitrogen oxide in gases.
Reduction	Rotary kiln or flowing bed reactor	Release of uranium	(2)	Relative pressure of kiln versus of room
Reduction	— Reduction furnace — In-line oxygen monitor — H_2 detection devices in rooms	— Explosion — Release of uranium powder	(2)	— O_2 amount — H_2 concentration — Relative pressure kiln versus room
Reduction	Off-gas treatment units	Release of uranium powder	(2)	Uranium concentration
Dry hydrofluorination	— Hydrofluorination reactor — Facilities for off-gas treatment	Release of HF	(2)	— HF — Uranium content in gases

TABLE III–1. EXAMPLES OF STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY, ASSOCIATED EVENTS AND OPERATIONAL LIMITS AND CONDITIONS FOR CONVERSION FACILITIES. (cont.)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Dry hydrofluorination	Shielding	Increase in dose rate	(3)	Thickness
Wet hydrofluorination	— Hydrofluorination reactor — Facilities for off-gas treatment	Release of HF	(2)	— HF — Uranium content in — gases
Fluorination	— Fluorination reactor — Washing column for off-gas treatment	Release of F_2, HF and UF_6	(2)	— F_2 — Uranium content in gases
Crystallization and cylinder filling	— High pressure measuring device — Cylinder and valve — Weight measuring device — UF_6 level detector in intermediate product take-off tank to confirm transfer into cylinders — Pipes, vessels and valves containing UF_6 — UF_6 release detection system	Release of UF_6 (breach of confinement): — Defective cylinder leads to breach — Overfilling — UF_6 left in process gas lines leading to a release of UF_6 — Release of liquid UF_6	(2)	— Pressure — Visual cylinder inspection — Weight limits

TABLE III–1. EXAMPLES OF STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY, ASSOCIATED EVENTS AND OPERATIONAL LIMITS AND CONDITIONS FOR CONVERSION FACILITIES. (cont.)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Crystallization and cylinder filling	— Vessels — Piping	Release of UF_6	(2)	Integrity of tank, valves and lines
Crystallization and cylinder filling	Leak detection	Release of uranium and HF	(2)	HF concentration
Handling and storage of cylinders	UF_6 cylinders	Release of uranium and HF	(2)	Thickness
Handling and storage of cylinders	Means of transfer, cranes, etc	— Breach of cylinder — Valve wrenching	(2)	Position of valve protector
Recovery of uranium - Solvent extraction	— Vessels and drip trays — Leak detectors	— Breach of vessels — Spills of solutions of radioactive material	(2)	Integrity of vessels and valves
Recovery of uranium -Solvent extraction	Mixer settlers or extraction columns	— Fire — Releases	(2)	Temperature
Intermediate storage of unburnt residues	Shielding	Increase in dose rate	(3)	Thickness

TABLE III–1. EXAMPLES OF STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY, ASSOCIATED EVENTS AND OPERATIONAL LIMITS AND CONDITIONS FOR CONVERSION FACILITIES. (cont.)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Off-gas treatment	Aerosol and gas measuring devices	Release of HF, F_2 and uranium	(2)	Uranium content in released air
Off-gas treatment	— Columns — Piping	Release of uranium and HF	(2)	HF content in released air
Treatment of radioactive liquids	— Tank — Piping — Measuring devices for radioactive and chemical impurities — Exhaust pipe	Release of uranium and other impurities	(2)	— Uranium concentration — Uranium content in released water
Building	Areas for nuclear and chemical activities	Loss of integrity	(2)	Leaktightness
Pipes containing water or solutions	Piping	Loss of integrity	(1)	Thickness

Annex IV

EXAMPLES OF STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY, ASSOCIATED EVENTS AND OPERATIONAL LIMITS AND CONDITIONS FOR URANIUM ENRICHMENT FACILITIES

IV–1. This annex provides examples of structures, systems and components important to safety, associated events and operational limits and conditions for uranium enrichment facilities. A safety function, as used in Table II–1, can serve one or more of the following purposes:

(1) Criticality prevention;
(2) Confinement of radioactive material;
(3) Protection against external exposure.

TABLE IV–1. EXAMPLES OF STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY, ASSOCIATED EVENTS AND OPERATIONAL LIMITS AND CONDITIONS FOR URANIUM ENRICHMENT FACILITIES

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Receipt and storage of feed cylinders	— Weighing scales — Cylinder and valve — Isotope measuring device	— Breach during the heating — Defective cylinder leads to breach — Criticality event in the process	(1), (2)	— Limit on cylinder weight — Visual inspection of cylinders — Limit on feed enrichment
Feed purification	— Pressure measuring device for cold cylinders — Temperature measuring device of UF_6 — Pressure measuring device of UF_6 — UF_6 leak detectors — Shielding (if reprocessed uranium) — Feed connector and piping — UF_6 cylinder — Autoclave isolation valve system	— Explosion (F_2) — Heating trip,cylinder breach — Heating trip, cylinder breach — Personnel exposure — Personnel exposure — Release into the second confinement barrier	(1), (2), (3)	— Pressure and temperature limits — Detection limits for UF_6 detectors — Visual inspection and pressure test of the feed connectors — Pressure check of feed cylinder — Remove light gases to the required level for centrifuge uranium enrichment facilities

TABLE IV–1. EXAMPLES OF STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY, ASSOCIATED EVENTS AND OPERATIONAL LIMITS AND CONDITIONS FOR URANIUM ENRICHMENT FACILITIES (cont.)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Cascade	— Vessels, valves and pipes when UF_6 pressure is above atmospheric pressure — Leak detectors when UF_6 pressure in the facility is above atmospheric pressure — Pressure and temperature measuring devices to control mass flows and to detect leakages or generation of reaction products — Enrichment measuring device — Pressure measuring device for product flow — Isolation — Process motor trip device — Neutron poison concentrations in cooler water — Compressor trip	— Release of uranium and HF — Increase enrichment and in leakages — Criticality — Release of UF_6.	(1), (2)	— Detection limits for UF_6 detectors — Pressure and temperature limits — Specific enrichment limits — Poison concentration levels — Detection of UF_6

TABLE IV–1. EXAMPLES OF STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY, ASSOCIATED EVENTS AND OPERATIONAL LIMITS AND CONDITIONS FOR URANIUM ENRICHMENT FACILITIES (cont.)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Cascade	— Heat exchanger tubes in contact with UF_6 — Temperature and pressure measuring devices	— Reaction of UF_6 with water leading to buildup of uranic deposits — Introduction of moderator of the introduction of halohydrocarbons leading to an explosion	(1), (2)	— Maintenance of the integrity of the tubes — Pressure and temperature limits.
Cascade	In-line analysers to monitor for hydrocarbons or halohydrocarbon and for detecting ingress of oil or halohydrocarbons	Reaction of UF_6 with oil leading to criticality and/or explosion	(1), (2)	Limit on hydrocarbon concentrations

TABLE IV–1. EXAMPLES OF STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY, ASSOCIATED EVENTS AND OPERATIONAL LIMITS AND CONDITIONS FOR URANIUM ENRICHMENT FACILITIES (cont.)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Product take-off	— Low pressure and temperature measuring devices — High pressure measuring device — Cylinder and valve — Weighing scales — UF_6 level detector in intermediate product take-off tank to confirm correct transfer into cylinders — Pipes, vessels and valve containing UF_6 — UF_6 release detection system	— Moderation control to prevent HF condensation — UF_6 release (breach of confinement); — Defective cylinder leads to breach — Overfilling — UF_6 left in process gas lines leading to release of UF6 — Release of liquid UF_6	— (1), (2)	— Vapour pressure of HF — Pressure — Visual empty cylinder inspection — Weight limit

TABLE IV–1. EXAMPLES OF STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY, ASSOCIATED EVENTS AND OPERATIONAL LIMITS AND CONDITIONS FOR URANIUM ENRICHMENT FACILITIES (cont.)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Off-gas treatment	— Cold traps and/or chemical traps — Temperature measuring device for cold traps — Measuring device for effluents discharged to atmosphere	— Release of uranium to secondary confinement barrier or atmosphere — External radiation dose from any accumulated isotopes of uranium or uranium decay products	(1), (2), (3)	Temperature measuring device of cold traps

TABLE IV–1. EXAMPLES OF STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY, ASSOCIATED EVENTS AND OPERATIONAL LIMITS AND CONDITIONS FOR URANIUM ENRICHMENT FACILITIES (cont.)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Tailings take-off	— High pressure measuring device Cylinder and valve — Weighing scales — UF_6 level detector in intermediate product take-off tank to confirm adequate transfer into cylinders — Pipes, vessels and valve containing UF_6 — UF_6 release detection system	— Release of UF_6 (breach of confinement) — Defective cylinder leads to breach — Overfilling — UF_6 left in process gas lines leading to release of UF_6 — Release of liquid UF_6	(2)	— Pressure — Visual empty cylinder inspection — Weight limit
Maintenance	Geometrically favourable containers for the collection of residues	— Criticality — Operator exposure	(1), (2)	Safely subcritical dimensions of the containers
Decontamination	— Various criticality controls (e.g. on mass, geometry, concentration) — Level controls on tanks	— Criticality — Process liquor spill — Operator exposure	(1), (2)	Limits on concentration and mass

TABLE IV–1. EXAMPLES OF STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY, ASSOCIATED EVENTS AND OPERATIONAL LIMITS AND CONDITIONS FOR URANIUM ENRICHMENT FACILITIES (cont.)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Uranium recovery	— Various criticality controls (e.g. on mass, geometry, concentration) — Level controls on tanks — Storage of liquors and/or recovered uranium in favourable geometry tanks or containers	— Criticality — Process liquor spill — Operator exposure	(1), (2)	— Limits on concentration and mass — Safely subcritical dimensions of the containers
Off-gas treatment	— Differential pressure — Activity measurements and alarms — HF concentration measurements — Favourable geometry scrubbers	— Blocked or torn filters: failure of ventilation or discharge to atmosphere — Criticality	(1), (2)	— High and low pressure alarms — Safely subcritical dimension of apparatus

TABLE IV–1. EXAMPLES OF STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY, ASSOCIATED EVENTS AND OPERATIONAL LIMITS AND CONDITIONS FOR URANIUM ENRICHMENT FACILITIES (cont.)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Sampling and transfer of liquid UF_6	— Pressure measuring device for the cold cylinder — Temperature measuring device in the cylinder during heating — Pressure measuring device of UF_6 — UF_6 leak detectors — Pipes, vessels and valve containing UF_6	— Explosion (F_2) — Cylinder breach — Cylinder breach — Personnel exposure — Release into the second confinement barrier	(1), (2), (3)	— Pressure and temperature limits — Detection limits for UF_6 detectors Visual inspection and pressure test of connectors
Cylinder handling	— Valve protectors for liquid UF_6 — Devices for moving cylinders containing liquid UF_6, such as cranes, carts and transporters	Release of uranium and HF	(2), (3)	Procedures
Radioactive waste treatment	Treatment facilities	— Release of uranium — Release of chemicals — Fire	(1), (2)	

TABLE IV–1. EXAMPLES OF STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY, ASSOCIATED EVENTS AND OPERATIONAL LIMITS AND CONDITIONS FOR URANIUM ENRICHMENT FACILITIES (cont.)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Radioactive waste treatment	Measuring devices for uranium content	Degradation of criticality safety margin (mass)	(1)	
Radioactive waste treatment	Radioactive waste storage	Fire	(1), (2)	
Building	Areas for nuclear and chemical activities	Loss of integrity	(2)	Leaktightness
Ventilation system	Fan and filters for input air	Fire	(2)	— Differential pressure on filters — Flow stages of pressure in the building — Vacuum in the sampling lines
Ventilation system	Ventilation control system	Release of uranium	(2)	Differential pressure on filters
Ventilation system	Filters inside the process areas		(1), (2)	Differential pressure on filters

TABLE IV–1. EXAMPLES OF STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO SAFETY, ASSOCIATED EVENTS AND OPERATIONAL LIMITS AND CONDITIONS FOR URANIUM ENRICHMENT FACILITIES (cont.)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Ventilation system	Ducts for air and process gas	Degradation of criticality safety margin (mass)	(1)	Mass of uranium (e.g. pre-filters)
Ventilation system	Final filter stage for waste air	Fire	(2)	Differential pressure on filters
Ventilation system	Measurement devices for radioactivity in waste air	Release of uranium	(2)	Uranium concentration release
Treatment and release of water	Tank	Release of uranium	(1), (2)	Level measuring device
Treatment and release of water	Measurement devices for radioactivity in water	Release of uranium	(2), (1)	Sampling and analyses before release
Power supply system	Emergency power supply system	Loss of criticality safety and radiation protection control	(2)	Maximum time for power supply reconstitution

CONTRIBUTORS TO DRAFTING AND REVIEW

Amalraj, J.	Canadian Nuclear Safety Commission, Canada
Bogdanova, T.	Federal Environmental, Industrial and Nuclear Supervision Service, Russian Federation
Casoli, B.	Institute for Radiological Protection and Nuclear Safety, France
Costa, C.G.S.	Brazilian Nuclear Industries, Brazil
Faraz, Y.	Nuclear Regulatory Commission, United States of America
Groche, K.	Consultant, Germany
Khotylev, V.	Canadian Nuclear Safety Commission, Canada
Michaelson, T.	International Atomic Energy Agency
Rovny, J.	International Atomic Energy Agency
Shokr, A.	International Atomic Energy Agency
Visser, T.	URENCO, Netherlands

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