30 June 2020

IAEA SAFETY STANDARDS
for protecting people and the environment

Status: Step 7b
Incorporating comments from the Committees

Safety of Conversion Facilities and Uranium Enrichment Facilities (Revision of SSG-5)

DS 517

DRAFT SPECIFIC SAFETY GUIDE

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. This Safety Guide supersedes the Safety Guide on the Safety of Conversion Facilities and Uranium Enrichment Facilities that was issued as IAEA Safety Standard Series No. SSG-5 in 2010. It supplements and elaborates upon the requirements established in the Safety Requirements publication on the Safety of Nuclear Fuel Cycle Facilities, IAEA Safety Standards Series No. SSR-4 [1].

1.2. Uranium and waste generated in conversion facilities and enrichment facilities are handled, processed, treated and stored at the facility. Conversion facilities and enrichment facilities may process or use large amounts of hazardous chemicals, which can be toxic, corrosive, combustible and/or explosive. The conversion process and the enrichment process rely to a large extent on operator intervention and administrative controls to ensure safety, in addition to active and passive engineered safety measures. A significant potential hazard associated with these facilities is a loss of the means of confinement resulting in a release of uranium hexafluoride (UF_6) and hazardous chemicals such as hydrofluoric acid (HF) and fluorine (F_2). In addition, for enrichment facilities and conversion facilities that process uranium with a ^{235}U enrichment of more than 1%, criticality can also be a significant hazard.

1.3. The safety of conversion facilities and uranium enrichment facilities is addressed by means of their proper siting, design, construction, commissioning, and operation including management for safety, and decommissioning.

OBJECTIVE

1.4. The objective of this Safety Guide is to provide operating organizations, regulatory bodies, designers and other relevant organizations with recommendations and guidance on meeting the requirements established in SSR-4 [1] applicable to a conversion facility or a uranium enrichment facility.

SCOPE

1.5. The safety requirements applicable to fuel cycle facilities (i.e. facilities for uranium ore refining, conversion, enrichment, reconversion, interim 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 the 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 during their siting, design, construction, commissioning, operation and preparation for decommissioning.

1.6. 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. In conversion facilities for the conversion of uranium concentrate to UF_6, several different conversion processes are currently used throughout the world on a large industrial scale. At present enrichment facilities use mainly gas centrifuge process, however the provisions of this Safety Guide are applicable also to the gaseous diffusion process. This publication includes specific recommendations for ensuring criticality safety in a conversion facility or a uranium enrichment facility. These recommendations supplement more detailed guidance on criticality safety is provided in the IAEA Safety Standards Series No. SSG-27, Criticality Safety in the Handling of Fissile Material [2].

1.7. 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] are not addressed in this Safety Guide.

1.8. This Safety Guide does not include nuclear security recommendations for a conversion facility or uranium enrichment facility as established 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 in IAEA Nuclear Security Series No. 27-G, (Implementation of INFCIRC/225/Revision 5) [5].

STRUCTURE

1.9. This Safety Guide consists of nine sections and four annexes. Section 2 provides the general safety recommendations for a conversion facility or an enrichment facility. Section 3 of this publication provides guidance on the development of a management system for those 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 deals with safety in the design stage; it provides recommendations on safety analysis for operational states and accident conditions and discusses the safety aspects of radioactive waste management in the conversion facility or an enrichment facility and other design considerations. Section 6 addresses the safety aspects in the construction stage. Section 7 discusses safety considerations in commissioning. Section 8 deals with safety in the stage of operation of the facility: it provides recommendations on the management of operation, maintenance and periodic testing, control of modifications, criticality control, radiation protection, industrial safety, the management of waste and effluents, and emergency preparedness and response. Section 9 provides recommendations on meeting the safety requirements for the preparation for decommissioning of a conversion facility or an enrichment facility. Annexes I and II show the typical process routes for a conversion facility and an enrichment facility. 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 enrichment facilities, respectively.

2. GENERAL SAFETY RECOMMENDATIONS

2.1. In conversion facilities and enrichment facilities, large amounts of uranium compounds (in gaseous, liquid or solid state) are present in a dispersible form:

— In conversion facilities, uranium exists in diverse chemical and physical forms and is used in conjunction with flammable or chemically reactive substances as part of the process.
— In enrichment facilities, most of the uranium is in the chemical form UF_6.

2.2. For conversion facilities the main hazards are:

— Potential release of chemicals, especially HF, F_2 and UF_6;
— Controls to address this hazard will adequately protect also against internal radiation exposure.
— External exposure is a concern for the handling of residues containing thorium and its daughter products produced in fluorination reactors. External exposure is also a concern in 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 enrichment facilities the main hazards are:

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

2.4. Generally, in a conversion facility or an 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.

2.5. The chemical toxic hazards of uranium in a soluble form such as UF_6 is more significant than its radiotoxic hazards. Along with UF_6, large quantities of hazardous chemicals such as HF are present. Also, when UF_6 is released, it reacts with the moisture in the air to produce HF and soluble uranyl fluoride (UO_2F_2), which present additional safety hazards. Therefore, comprehensive safety analyses for conversion facilities and enrichment facilities should also address the potential hazards resulting from these chemicals.

2.6. Conversion facilities and enrichment facilities do not pose a potential radiation hazard with the 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 with an activity of the order of thousands of terabecquerels). However, certain accident conditions involving hazardous chemicals can potentially result in adverse off-site consequences (as for example large release of HF).

2.7. For the application of the requirement that the concept of defence in depth be applied at the facility (see Concept of defence in depth in Section 2 of Ref. [1]), the first two levels of defence in depth are the most important, as risks can be reduced to appropriately low levels by means of design and appropriate operating procedures (see Sections 5 and 8).

3. MANAGEMENT SYSTEM FOR CONVERSION FACILITIES AND URANIUM ENRICHMENT FACILITIES

MANAGEMENT SYSTEM

3.1. The following recommendations provide a means of meeting the requirements 4 and 5 of SSR-4 [1] for the management for and verification of safety for conversion facilities and uranium enrichment facilities. The following recommendations are supplementary to, and should be read in conjunction with, the recommendations provided in the IAEA Safety Standards Series No. GS-G-3.1, Application of the Management System for Facilities and Activities [6] and No. GS-G-3.5, The Management System for Nuclear Installations [7].

3.2. A documented management system that integrates the safety, health, environmental, security, quality, human-and-organizational-factor, societal and economic elements of the operating organization is required to be in place in accordance with IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [8] and Requirement 4 of SSR-4 [1].

3.3. The integrated management system should be established and put into effect by the operating organization, early in the lifetime of a conversion and uranium enrichment facility, to ensure that safety measures are specified, implemented, monitored, audited, documented and periodically reviewed throughout the lifetime of the facility or the duration of the activity.

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

3.5. In determining how the requirements of the management system for safety of conversion facilities and uranium enrichment facilities are to be applied, a graded approach based on the relative importance to safety of each item or process should be used.

3.6. The management system should provide structure and direction to the organization in a way that permits and promotes the development of a strong safety culture together with the achievement of high levels of safety performance.

3.7. The management system should address the following four functional areas: management responsibility; resource management; process implementation; and measurement, assessment, evaluation and improvement. In general:

— MANAGEMENT RESPONSIBILITY INCLUDES THE SUPPORT AND COMMITMENT OF MANAGEMENT NECESSARY TO ACHIEVE THE SAFETY OBJECTIVES OF THE OPERATING ORGANIZATION.
— RESOURCE MANAGEMENT INCLUDES THE MEASURES NECESSARY TO ENSURE THAT THE RESOURCES ESSENTIAL TO THE IMPLEMENTATION OF SAFETY STRATEGY AND THE ACHIEVEMENT OF THE OBJECTIVES OF THE OPERATING ORGANIZATION ARE IDENTIFIED AND MADE AVAILABLE.
— PROCESS IMPLEMENTATION INCLUDES THE ACTIVITIES AND TASKS NECESSARY TO ACHIEVE THE SAFETY GOALS OF THE ORGANIZATION.
— MEASUREMENT, ASSESSMENT, EVALUATION AND IMPROVEMENT PROVIDES AN INDICATION OF THE EFFECTIVENESS OF MANAGEMENT PROCESSES AND WORK PERFORMANCE COMPARED WITH OBJECTIVES OR BENCHMARKS; IT IS THROUGH MEASUREMENT AND ASSESSMENT THAT OPPORTUNITIES FOR IMPROVEMENT CAN BE IDENTIFIED.

MANAGEMENT RESPONSIBILITY

3.8. The prime responsibility for nuclear and radiation safety, including criticality safety, rests with the operating organization. The documentation of the management system of conversion facilities and uranium enrichment facilities should include description of the organizational structure, functional responsibilities and levels of authority. Provisions for ensuring effective communication and clear assignment of responsibilities should be provided to ensure that processes and activities which are important to safety are controlled and performed in a manner that ensures that safety objectives are achieved.

3.9. The management of the operating organization should ensure that all aspects of safety, including monitoring the performance of activities and processes are developed and documented. The management should also ensure that all personnel is adequately trained to perform assigned roles and should establish a system for keeping records that ensures control of performance and verification of activities that are important to safety. The records keeping system should provide for their identification, approval, review, filing, retrieval, and disposal.

RESOURCE MANAGEMENT

3.10. The operating organization should provide adequate resources (both human and financial) for the safe operation of the facility or activity as well as resources for mitigation of the consequences of accidents. The management of operating organization should:

- participate in the activities by determining the required personnel competence and providing training, as necessary;
- prepare and issue specifications and procedures on safety related activities and operations;
- support and participate in safety assessment of modifications;
- make provisions for adequate interfaces and frequent contact between operating personnel and plant managers, including observation of work in progress.

3.11. In meeting Requirement 58 of SSR-4 [1] the operating organization should ensure that operating personnel receive training and refresher training at suitable intervals, appropriate to their level of responsibility. In particular, operating personnel involved in activities with fissile material, radioactive materials including waste and with chemicals should understand the nature of the hazard posed by these materials and how the risks are controlled with the established safety measures and operational limits and conditions and operating procedures.

3.12. The management system should include procurement activities and should be extended to include vendors and sub-contractors. The operating organization should ensure, through audits, that suppliers of items important to safety have management systems that are adequate for ensuring safety of conversion facilities and uranium enrichment facilities.

PROCESS IMPLEMENTATION

3.13. All activities should be performed in accordance with approved procedures and instructions. The operating procedures should cover all facility states (see Definitions in SSR-4 [1]). The procedures should specify all parameters which are intended to control and the criteria to be fulfilled.

3.14. The management system of uranium conversion (if applicable) and uranium enrichment facilities should include also management for criticality safety. Further guidance on the management system for criticality safety is provided in IAEA Safety Standards Series No. SSG-27, Criticality Safety in the Handling of Fissile Material [2].

3.15. Any proposed modification to existing facilities or activities, or proposals for introduction of new activities, should be assessed for their implications on existing safety measures and appropriately approved prior to implementation. Modifications of safety significance should be subjected to safety assessment and regulatory review and appropriately approved before they are implemented. The modification process should also apply to procedures for design, fabrication, construction, commissioning and operation. The facility or activity documentation should be updated to reflect modifications, and the operating personnel, including supervisors, should receive adequate training on the modifications.

3.16. The activities for ensuring safety throughout the facility lifetime or activity duration involve different groups and interface with other areas such as those related to nuclear security and to the system for accounting for, and control of nuclear material. These activities should be identified, coordinated, planned, and conducted to ensure effective communication and clear assignment of responsibilities.

MEASUREMENT, ASSESSMENT, EVALUATION AND IMPROVEMENT

3.17. Audits performed by the operating organization as well as proper control of modifications to facilities and activities are particularly important for ensuring safety of conversion facilities and uranium enrichment facilities (para. 4.23 of SSR-4 [1]). In addition, independent audits should be also implemented. These audits should also cover measures for emergency preparedness and response. These audits should be carried out regularly and the results should be evaluated by the operating organization and corrective actions should be taken to implement recommendations and suggestions for safety improvements.

3.18. Deviation from operational procedures and unforeseen changes in operations or in operating conditions should be reported and authorized by the management. Such events should be promptly investigated by the operating organization to analyze the causes of the deviation, to identify lessons to be learned, and to determine and implement corrective actions to prevent recurrences. There is also a danger that conditions may change slowly over time in response to factors such as ageing of the facility or owing to increased production pressures.

3.19. The management system should include a means of incorporating lessons learned from operating experience and accidents at facilities in the State and in other States, to ensure continuous improvement in operational practices and assessment methodology. Guidance on and recommendations for establishing a system for the feedback of operating experience are provided in IAEA Safety Standards Series No. SSG-50, Operating Experience Feedback for Nuclear Installations Ref. [9].

4. SITE EVALUATION

4.1. The site evaluation process for a conversion facility or an enrichment facility will depend on a large number of variables, some of which are more important than others. At the earliest stage of planning a facility, a list of these criteria should be prepared and considered in accordance with their safety significance. Risks posed by possible significant external hazards (e.g. earthquakes, accidental aircraft crashes, hazards arising from nearby industries and transport routes, fires and extreme weather conditions) will probably dominate in the site evaluation process and need to be incorporated into the design of the facility. Requirements for site evaluation for a conversion facility or an enrichment facility are provided in IAEA Safety Standards Series No. SSR-1, Site Evaluation for Nuclear Installations [10] and further guidance is provided in IAEA Safety Standards Series No. SSG-35, Site Survey and Site

Selection for Nuclear Installations [11].

4.2. The scope of the site evaluation for a conversion facility or an enrichment facility are established by Requirement 3 of SSR-1 [10], Requirement 11 and paras. 5.1 to 5.14 of SSR-4 [1] and should reflect the specific hazards listed in Section 2 of this Safety Guide.

4.3. The density and distribution of population in the vicinity of a conversion facility or an enrichment facility and the direction of the prevailing wind at the site should be considered in the site evaluation process to minimize any possible health consequences for people in the event of a release of hazardous chemicals. The environmental impact from the facility under all plant states should be evaluated and should meet the applicable criteria.

4.4. Site selection should include assessment of safety risks related to external natural and human induced events.

4.5. To prevent potential conflicts safety and security interface should be considered systematically in the site evaluation and site selection process (requirement 75 of SSR-4 [1]).

4.6. Site evaluation and selection should be facilitated by experts from both safety and security disciplines. The selection of a site should take into account both safety and security aspects.

4.7. A full record should be kept of the decisions taken on the selection of a site for a conversion facility or an enrichment facility and the reasons behind those decisions.

4.8. The adequacy of the site evaluation should be reviewed periodically during the lifetime of the facility including in case of an increase of a production capacity beyond the original envelope (para 5.14 of SSR-4 [1]).

5. DESIGN

Specific engineering design guidance

5.1. The requirements on maintaining subcriticality are established in Requirement 38 and paras 6.138 – 6.156 of SSR-4 [1]. Further guidance on the design of conversion facilities and uranium enrichment facilities to ensure subcriticality is provided in Section 3 of SSG-27 [2];

5.2. The requirements on confinement for the prevention of releases that might lead to internal exposure and chemical hazards are established in Requirements 34 and 35 and the following paras. of SSR-4 [1];

5.3. The requirements on protection against external exposure are established in Requirement 36 and following paras. of SSR-4 [1]. Shielding should be considered for processes or areas that could involve sources of high levels of external gamma radiation, such as reprocessed uranium or newly emptied cylinders (e.g. exposure to daughter products of ^{232}U and ^{238}U).

Design basis and safety analysis

5.4. The definition of a design basis accident in the context of fuel cycle facilities can be found in Definitions of SSR-4 [1]. The safety requirements relating to design basis are established in Requirements 14 and 20 of SSR-4 [1].

Conversion facilities

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

(a) Nuclear criticality accidents, e.g. in a wet process area with a ^{235}U content of more than 1% (reprocessed uranium or unirradiated LEU)
(b) release of HF or ammonia (NH_3) due to the rupture of a storage tank;
(c) release of UF_6 due to the rupture of a storage tank, piping or a hot cylinder;
(d) fire originating from H_2 or solvents;
(e) loss of electrical power;
(f) internal and external events, including:
    i. Internal and external explosions (in particular hydrogen explosions);
    ii. Internal and external fire;
    iii. Dropped loads and associated handling events;
    iv. Natural phenomena (including earthquakes, flooding and tornadoes);
    v. Aircraft crashes.

5.6. Nuclear criticality (para. 5.5 a)) would generally be expected to result in limited or no off-site consequences unless the facility is in close proximity to occupied areas. Events listed in para. 5.5 (a)–(e)) are of major safety significance as they might result in chemical and radiological consequences for personnel. However, they may also result in some adverse off-site consequences for public or the environment.

5.7. The hazards listed in para. 5.5 may occur as a consequence of a postulated initiating event (PIE). Selected PIEs are listed in Appendix of SSR-4 [1].

5.8. The potential occurrence of a criticality accident should be considered for facilities that process uranium with a ^{235}U enrichment of more than 1%. Particular consideration should be given to the potential occurrence of a criticality accident for facilities treating various feed products including reprocessed uranium.

Enrichment facilities

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

(a) The rupture of an overfilled cylinder during heating (feed area);

(b) The rupture of a cylinder containing liquid UF_6 or the rupture of piping containing liquid UF_6 (depending on the facility design for product take-off);

(c) A large fire, especially for diffusion facilities;

(d) Natural phenomena such as earthquakes, flooding or tornadoes;

(e) An aircraft crash;

(f) Nuclear criticality.

5.10. These hazards would result primarily in radiological consequences for site personnel, however may also result in some adverse off-site consequences for public or the environment. The last type of hazard on the list would generally be expected to result in limited or no off-site consequences unless the location of the accident is in close proximity to populated areas.

5.11. The hazards listed in para. 5.9 may occur as a consequence of a PIE. Selected PIEs are listed in Appendix of SSR-4 [1].

Structures, systems and components important to safety

5.12. The likelihood of design basis accidents (or equivalent) should be minimized, and any radiological and associated chemical consequences should be controlled by means of structures, systems and components important to safety (Requirement 13 of SSR-4 [1]) and appropriate administrative measures (operational limits and conditions – Requirement 57 of SSR-4 [1]). Annexes III and IV contain examples of structures, systems and components and representative events that may challenge the associated safety functions.

SAFETY FUNCTIONS

Prevention of criticality

5.13. The following paragraphs highlight some of the main elements that are specific for facilities covered by this Safety Guide. There are other topics related to criticality safety (Requirement 38 of SSR-4 [1]) that are relevant for uranium conversion or enrichment facilities and are not adequately covered by this Safety Guide. The principal guidance is obtained in SSG-27 [2].

5.14. If a conversion (or deconversion) facility processes natural uranium, depleted uranium, or uranium with less than 1% ^{235}U enrichment criticality safety would not need to be taken into consideration. In such cases it should be demonstrated that there is no credible fault sequence in which uranium with higher ^{235}U enrichment is fed to the process (see para. 6.138 of SSR-4 [1]). For further guidance see the exemption criteria in para 2.8 of SSG-27 [2].

5.15. Paras 6.138 - 6.148 of SSR-4 [1] list the requirements for the prevention of criticality by design.

For the prevention of criticality in conversion facilities and enrichment facilities the following parameters should be subject to control:

- Mass and degree of enrichment of fissile material present in a process: for conversion facilities, in vessels or mobile transfer tanks, or analytical laboratories; for enrichment facilities, in effluent treatment units or analytical laboratories;
- Geometry and/or interaction (limitation of the dimensions or shape) of processing equipment, e.g. by means of safe diameters for storage vessels, control of slabs and appropriate distances in and between storage vessels. The loss of confinement/geometry due to leaks or breaks should also be accounted for;
- Concentration of fissile material in solutions, e.g. in the wet process for recovering uranium or decontamination;
- Presence of reflectors or appropriate neutron absorbers, e.g. neutron poisoning of cooling water in gaseous diffusion enrichment facilities;
- Degree of moderation, e.g. by means of control of the ratio of hydrogen to ^{235}U in UF_6 cylinders and in diffusion cascades.

5.16. Paragraph 6.138 of SSR-4 Ref. [1] requires that preference be given to achieving criticality safety by design rather than by means of administrative measures. As an example, to the extent practicable, vessels which could contain fissile material should be made geometrically safe and should be designed for the maximum authorized enrichment level including a reasonable safety margin.

5.17. Several methods 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 guidance on performing a criticality safety assessment, including guidance on validation of computer codes see section 4 of SSG-27 [2].

5.18. The aim of the criticality safety analysis is to demonstrate that the design of equipment together with the related safety measures are such that the values of controlled parameters are always maintained in the subcritical range. This is generally achieved by determining the effective multiplication factor (k_{eff}), which depends on the mass, the distribution and the nuclear properties of uranium and all other materials with which it is associated. The calculated value of k_{eff} (including all uncertainties and biases) is then compared with the value specified by the design limit (which should be set in accordance with Paras 2.4 - 2.7 of SSG-27 [2]).

5.19. The methods of calculation vary widely in basis and form, and each has its place in the broad range of situations encountered in the field of nuclear criticality safety. The criticality safety analysis should involve:

- The use of a conservative approach (with account taken of uncertainties in physical parameters and of the physical possibility of worst-case moderation conditions);
- The use of appropriate and qualified 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. (see 4.20-4.25 of SSG-27 [2]).

5.20. The following parameters should be included in the scope of a criticality safety analysis for a conversion facility or an enrichment facility:

- *Mass.* The mass margin should be more than 100% of the maximum value attained in normal operation (to compensate for possible ‘double batching’, i.e. the transfer of two batches of fissile material instead of one batch in a process) or equal to the maximum physical mass that could be present in the equipment. (see also para. 3.17 of SSG-27 [2])
- *Geometry of processing equipment.* The potential for changes in dimensions during operation should be considered (e.g. bulging of slab tanks or slab hoppers).
- *Neutron interaction.* Preference should be given to engineered spacing over spacing achieved by administrative means.
- *Moderation*. Hydrogenous substances (e.g. water and oil) are common moderators that are present in conversion facilities and enrichment facilities or that may be present in accident conditions (e.g. water from firefighting); the subcriticality of a UF_6 cylinder should rely only on moderation control.
- *Reflection.* Full water reflection should be assumed in the criticality analysis unless it is demonstrated that the worst-case conditions relating to neutron reflection (e.g. by human bodies, organic materials, wood, concrete, 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 may 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 (para. 3.22 of SSG-27 [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.
- *Neutron absorbers.* When taken into account in the safety analysis, and if there is a risk of degradation, the presence and the integrity of neutron absorbers shall be verifiable during periodic testing. Uncertainties in absorber parameters should be considered in the criticality calculations. The neutron absorbers that may be used in conversion facilities and enrichment facilities include cadmium, gadolinium or boron in annular storage vessels or transfer vessels for liquids. Absorber parameters include thickness, density andnuclide composition.

Confinement to protect against internal exposure and chemical hazards

5.21. In meeting the requirements 34 and 42 of SSR-4 [1] on protection against internal radiation exposure and against toxic chemicals, the following parameters should be minimized as far as possible:

— The amount of liquid UF_6 in process areas, e.g. by limiting the size of crystallization (desublimation) vessels in both conversion and enrichment facilities;
— The amount of nuclear material unaccounted for in the process vessels;
— The duration of operation when UF_6 is at a pressure above atmospheric pressure;
— The capacity for storage of HF, NH_3 and H_2.

5.22. Conversion facilities and enrichment facilities should 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.

5.23. In the 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 (Requirement 35 of SSR-4 [1]). Particular consideration should also be given to minimizing the use of flexible hoses and to ensuring their maintenance and periodic checking.

5.24. 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. 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.

5.25. In the design of the ventilation and containment systems for areas that may contain elevated levels of airborne radioactive material during operation, account should be taken of criteria such as: (i) the desired pressure difference between different parts of the premises; (ii) the air replacement ratio in the facility; (iii) the types of filters to be used; (iv) the maximum differential pressure across filters; (v) 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); and (vi) the dose rate at the filters.

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

Protection of personnel

5.27. The ventilation system should be used as one of the means of minimizing the radiation exposure of personnel and exposure to hazardous material that could become airborne and so could be inhaled by personnel. Conversion facilities and enrichment facilities should 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 (Requirement 8 of SSR-4 [1]). Wherever possible, the layout of ventilation equipment should be such that the flow of air is from the operation gallery towards the equipment.

5.28. Where possible the need for the use of protective respiratory equipment should be avoided through careful design of the containment and ventilation systems. For example, a glovebox, hood or special device should be used to ensure the continuity of the first containment barrier rather than rely on the need for respiratory protection.

5.29. In areas that may contain airborne uranium in particulate form, primary filters should be located as close to the source of contamination as practicable unless it can be shown that the design of the ventilation ducts and the air velocity are sufficient to prevent unwanted deposition of uranium powder in the ducts. 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 ventilation systems. If this is not the case, it should be ensured that failure of the duty fan or filter will result in the safe shutdown of equipment in the affected area.

5.30. Monitoring equipment such as differential pressure gauges (on filters, between rooms or between a glovebox and the room in which it is located) and devices for measuring uranium or gas concentrations in ventilation systems should be installed as necessary. Alarm systems should be installed to alert operators to fan failure or high or low differential pressures. At the design stage, provision should also be made for the installation of equipment for monitoring airborne radioactive material and/or gas monitoring equipment. 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]).

5.31. 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 HF, ventilation systems should be equipped with fire dampers and should be constructed from non-flammable and non-corrosive materials.

5.32. 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 enrichment facility.

5.33. To facilitate decontamination and the decommissioning of the facility, the walls, floors and ceilings in areas of the conversion facilities and enrichment facilities where contamination is likely to exist should be made non-porous and easy to clean. This may be done by applying special coatings, such as epoxy, to such surfaces and 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

5.34. The design should provide for the minimization of releases to environment during normal operation by application of best available technology.

5.35. The uncontrolled dispersion of radioactive or chemical substances to the environment as a result of an accident can occur if all the containment barriers are impaired. Barriers may comprise the process equipment itself, or the room or building structure. The number of physical barriers for containment should be adapted to the safety significance of the hazard. The minimum number of barriers is two, in accordance with the principle of redundancy (see requirement 23 of SSR-4[1]). The preferred number of barriers is often three.

5.36. 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 enrichment facilities, reduces the normal environmental discharges of radioactive or chemical (mainly HF) material to very low levels. In such cases, the ventilation system may also be regarded as a containment barrier.

5.37. 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 containment barriers and the impact to the environment and the public complies with authorized limits.

5.38. The efficiency of filters and their resistance to chemicals (HF and NH_3), high temperatures of the exhaust gases and fire conditions should be taken into consideration.

Protection against external exposure

5.39. External exposure (Requirement 36 of SSR-4 [1]) 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 an enrichment facility will normally be sufficient to control adequately occupational exposure. 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.

5.40. Additional shielding or automation may also be required for the handling of reprocessed uranium.

5.41. When reprocessed uranium is processed, shielding should be strengthened for protection of the personnel, because of the higher gamma dose rates from ^{232}U daughters and fission products.

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

PROVISIONS FOR HEAT REMOVAL

5.43. Where the potential for exothermic reactions with large heat releases exists (as for example the fluorination process in conversion facilities) facility design should consider appropriate cooling system to remove heat from the chemical reactions and to ensure safe operation for all facility states. Continuous monitoring of cooling system should be ensured to prevent uncontrolled release of radioactive material.

5.44. Cooling water systems design should have provisions for periodic inspections and maintenance to address corrosion and ageing management.

POSTULATED INITIATING EVENTS

Internal hazards

Fire and explosion

5.45. Conversion facilities and enrichment facilities, like all industrial facilities, have to be designed to control fire hazards in order to protect personnel, the public and the environment. Fire in conversion facilities and enrichment facilities can lead to the dispersion of radioactive material and/or toxic material by breaching the containment barriers or may cause a criticality accident by affecting the system of the parameters used for the control of criticality (e.g. the moderation control system or the dimensions of processing equipment).

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

Fire hazard analysis

5.47. As an important aspect of fire hazard analysis, areas of the facility that require special consideration should be identified. Special fire hazard analyses should be carried out as follows:

(1) For conversion facilities:
- (a) Processes involving H_2, 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. NH_3, H_2, HNO_3, dodecane);
- (d) Areas with high fire loads, such as waste storage areas;
- (e) Waste treatment areas, especially those where incineration is carried out;
- (f) Rooms housing safety related equipment, e.g. items, such as air filtering systems, whose degradation may lead to radiological consequences that are considered to be unacceptable;
- (g) Transformers and rooms housing battery chargers;
- (h) Control rooms.

(2) For 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 prior to its conditioning;

(f) Control rooms.

5.48. Fire hazard analysis (Requirement 22 of SSR-4 [1]) involves identification of the causes of fires, assessment of the potential consequences of a fire and, where appropriate, estimation of the frequency or probability of occurrence of fires. It is 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. Fire hazard analyses of the facility should give particular consideration for the areas where:

(a) high-risk fire sources such as diffusers or centrifuges are located;

(b) combustible materials (including low voltage cables);

(c) safety equipment which should be protected are installed.

5.49. 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 or curtail the fire spreading.

5.50. 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

5.51. 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.

5.52. 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:

- Separation of the areas where non-radioactive hazardous material is stored from the process areas;
- Minimization of the fire load of individual rooms;
- 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;

— 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 capability of a fire to spread beyond the fire zone in which it breaks out. The higher the fire risk, the greater the number of fire zones a building should have;
— Suppression or limitation of the number of possible ignition sources such as open flames or electrical sparks.

5.53. Fire extinguishing devices, automatic or manually operated, with adequate extinguishing agent, should be installed in the areas where the outbreak of a fire is possible. In particular, 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 risk of HF generation and criticality events for enriched uranium. Consideration should be given to minimizing the environmental impact of the water used to extinguish fires.

5.54. The design of ventilation systems should be given particular consideration with regard to fire prevention. Dynamic containment comprises ventilation ducts and filter units, which may 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.

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

Explosions

5.56. 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.

5.57. In conversion facilities and enrichment facilities, the possible sources of explosions include:

(a) Gases (in conversion facilities: e.g. H_2 or NH_3 used in the reduction process; in enrichment facilities: chemical oxidants such as F_2, ClF_3 or UF_6). Design provisions should be implemented to prevent an explosive mixture of the above chemical oxidants and of hydrocarbons or halo-hydrocarbons. 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);
(c) Monitoring of possible deposits should be implemented to prevent any accumulation of

ammonium nitrate.

Flooding

5.58. Flooding in a conversion facility or an enrichment facility may lead to the dispersion of radioactive material if the radioactive material were 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.

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

5.60. In facilities where vessels and/or pipes containing water are present, 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.

5.61. Walls (and floors if necessary) of rooms where flooding could occur should be capable of withstanding the water load to avoid any 'domino effect' due to their failure.

Leaks and spills

5.62. 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. HF, F_2, NH_3, ClF_3) and to the unnecessary generation of waste. Leaks of hydrogenous fluids (water, oil, etc.) can adversely affect criticality safety. Leaks of flammable gases (e.g. H_2) or liquids can lead to explosions and/or fires. Leak detection systems should be deployed where leaks could occur.

5.63. For conversion and uranium recovery locations of enrichment facilities, vessels containing significant amounts of nuclear material in solution form should be equipped with level detectors and alarms to prevent overfilling and with secondary containment features such as bunds or drip trays of appropriate capacity and configuration to ensure criticality safety.

5.64. 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

5.65. To fulfil the requirement established in para. 6.89 of SSR-4 [1], an emergency power supply should be provided at least for:

- Monitoring systems for radiation protection and environmental protection;
- Detection and alarm systems for leaks of hazardous materials;
- Fire detection and alarm systems;

- Criticality accident detection and alarm systems;
- Ventilation systems, if necessary, for the confinement of hazardous material;
- Some process control components (e.g. heating elements and valves);
- Fire pumps, if fire water is dependent on off-site electrical power.

5.66. For enrichment facilities, a loss of electrical power may result in major operational consequences. In addition, there may be some safety implications from a loss of electrical power, such as the formation of solid uranium deposits.

- For the centrifuge process, 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.
- For the diffusion process, the inherent heat is sufficient to keep the UF_6 in its gaseous form for several days in the process equipment. However, solidification of the UF_6 may start beyond this period. A first potential safety issue involves the heating of solidified UF_6 for sublimation within the process equipment and piping, which may lead to local liquefaction of the UF_6 and a subsequent loss of confinement. A second potential safety issue is that a large quantity of solid enriched uranium could accumulate in an unsafe geometry such that a loss of moderation control could cause a criticality event.

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

5.68. 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 may have also some consequences for safety. For example:

- Loss of gas supply to gas-controlled safety valves and dampers: In accordance with the safety analysis, valves should be used that are ‘design to fail’ to a safe position;
- Loss of cooling or heating water: Adequate backup capacity or a redundant supply should be provided for in the design.

Processing errors

5.69. 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:

- Incomplete chemical reactions in conversion facilities may lead to a release of hazardous chemicals.
- Overpressure in the equipment may cause an increase of the levels of airborne radioactive material and/or concentration of hazardous material in the working areas of the facility.
- Excess of F_2 in the fluorination process in conversion facilities may result in its release.

— Releases of large amounts of nitrogen may result in a reduction of the oxygen concentration in breathing air in the work areas of the facility.
— Loss of steam or hot water supply may result in the solidification of UF_6 in the piping and equipment.
— Failure of the air supply may result in the failure of safety related air operated valves.

Facility and equipment failures

5.70. Particular consideration should be given to the confinement of highly corrosive and hazardous materials such as UF_6, F_2 and HF in vessels, pipes and pumps and to powder transfer lines where abrasive powder will cause erosion.

5.71. The design should minimize the potential for mechanical impacts to 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.

5.72. 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.

5.73. To prevent failure of equipment containing hazardous materials (as for example calciners or furnaces), effective programmes for maintenance, periodic testing and inspection should be defined at the design phase.

External hazards

General

5.74. A conversion facility or an 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 [10] and its associated Safety Guides. Examples of specific external hazards for a conversion facility or an enrichment facility are provided in the following paragraphs under appropriate headings.

Earthquakes

5.75. To ensure that the design of a conversion facility or an enrichment facility provides the required degree of robustness, a detailed seismic assessment (see SSR-1 [10] and IAEA Safety Standards Series No. SSG-9, Seismic Hazards in Site Evaluation for Nuclear Installations, [12]) should be made including the following seismically induced events:

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

(c) Loss of containment functions (static and dynamic);
(d) Loss of safety functions for ensuring the return of the facility to a safe state and maintaining the facility in a safe state after an earthquake, including structural functions and functions for the prevention of other hazards (e.g. fire, explosion, load drop and flooding);
(e) The effect on criticality safety functions such as geometry and/or moderation of the following:
    — Deformation (geometry control);
    — Displacement (geometry control, fixed neutron poisons);
    — Loss of material (geometry control, soluble neutron poisons).

External fires and explosions and external toxic hazards

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

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

Extreme weather conditions

5.78. A conversion facility or an enrichment facility should be protected against extreme weather conditions as identified in the site evaluation (see Section 4) by means of appropriate design provisions. These should generally include the following:

— The ability of structures important to safety to withstand extreme weather loads;
— The prevention of flooding of the facility including adequate means to evacuate water from the roof in cases of extreme rainfall;
— The guarantee of safe state for the facility in accordance with the operational limits and conditions.

Tornadoes

5.79. 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 be in compliance with specific national regulations relating to hazards from tornadoes.

5.80. High winds are capable of lifting and propelling objects as large as automobiles or telephone 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 secondary fragments arising from collisions with and spallation of concrete walls or from other types of transfer of momentum.

Extreme temperatures

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

5.82. 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. For structures without expansion joints, the additional loads to due thermal expansion on structural systems should be considered in the design.

Snowfall and ice storms

5.83. The occurrence of snowfall, ice storms and its effects should be taken into account in the design and 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

5.84. For flooding events, attention should be focused on potential leak paths (containment breaks) into structures, systems and components important to safety at risk of damage. In all cases, equipment containing fissile material should be designed to prevent any criticality accident. Electrical systems, instrumentation and control systems, emergency power systems (batteries and power generation systems) and control rooms should be protected by design.

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

Accidental aircraft crashes

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

5.87. For evaluating the consequences of impacts or the adequacy of the design to resist aircraft impacts, only realistic crash scenarios should be considered, which may require the knowledge of such factors as the possible angle of impact or the potential for fire and explosion due to the aviation fuel load. In general, fire cannot be ruled out following an aircraft crash and so the establishment of specific requirements for fire protection and for emergency preparedness and response will be necessary.

INSTRUMENTATION AND CONTROL (I&C)

5.88. Instrumentation should be provided to monitor the relevant variables and systems and general conditions of the facility over their respective ranges for: (1) normal operation; (2) anticipated operational occurrences; and (3)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.

5.89. Instrumentation should be provided for measuring all the main variables whose variation may affect the safety of processes (such as pressure, temperature and flowrate). In addition, instrumentation should be provided for monitoring general conditions at the facility (such as radioactivity levels, releases of effluents and ventilation conditions), and for obtaining any other information about the facility necessary for its reliable and safe operation (such as presence of personnel and environmental conditions).

5.90. Passive and active engineering controls are more reliable than administrative control and should be preferred for control in normal 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.

5.91. 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 impression of the status and performance of the facility. Devices should be installed that provide in an efficient manner visual and, as appropriate, audible indications of operational states that have deviated from normal conditions and that could affect safety.

Control rooms and panels

5.92. 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 in the location of control rooms in the facility. 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 paid to identifying those events, both internal and external to the control rooms, that may pose a direct threat to the operation of control rooms. Human Ergonomic factors should be taken into account in the design of control rooms and the design of control room displays and systems.

Safety related I&C systems

5.93. Safety related I&C systems of a conversion facility or an enrichment facility should include systems for the following:

(1) I&C relating to criticality detection and alarm:
- Radiation detectors (gamma and/or neutron detectors) – see para. 6.173 of SSR-4 [1];
- For enrichment facilities, in-line devices for enrichment measurement should be used to monitor the enrichment levels of products.

(2) Fire detection:
- All rooms with fire loads or significant amounts of fissile and/or toxic chemical material should be equipped with fire alarms.
- Gas detectors should be used in areas where a leakage of gases (e.g. H_2) could conceivably produce an explosive atmosphere.

(3) Process control:
- Temperatures, pressures, flow rates, concentrations of chemicals and/or radioactive material, tank levels, cylinder weights.
- 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).
- 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.

(4) Control of ventilation:
- Mainly devices for measuring differential pressures across high efficiency particulate air (HEPA) filters and airflows.

(5) Control of gaseous and liquid effluents:
- Real time measurements should be provided if there is a risk of exceeding regulatory limits; otherwise, retrospective measurements on continuously sampled filters and/or probes will generally be sufficient.

(6) Control of explosive mixtures:
- Real time measurements, controls and alarms are necessary if there is a risk of exceeding regulatory and safety limits, e.g. devices for measuring the concentration of O_2 in the reduction kiln in conversion facilities.

(7) Control of occupational radiation exposure:

- For monitoring external exposure sensitive films and/or dosimeters with real time displays and/or alarms should be used, especially in areas with inspection equipment such as X-ray generators and active sources.
- 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.

(8) Control of asphyxiants:

- Presence and concentration of asphyxiants (such as N_2, NO_x, NH_3 etc) in working areas where it might impact operational safety should be measured.

(9) Control of chemical releases:

- Real time detection and alarm systems should be used in the process areas and/or laboratories where HF,UF_6 and ClF_3 above atmospheric pressure is present.

HUMAN FACTOR CONSIDERATIONS

5.94. The requirements relating to human factor considerations are established in Requirement 27 of SSR-4 [1].

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

- Possible effects on safety of unauthorized human actions (with account taken of ease of intervention by the operator and tolerance of human error);
- The potential for occupational exposure.

5.96. 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:

(a) Design of working conditions to ergonomic principles.

- The operator–process interface, e.g. electronic control panels displaying all the necessary information and no more;
- The working environment, e.g. good accessibility of and adequate space around equipment and suitable finishes to surfaces for ease of cleaning.

(b) Choice of location and clear labelling of equipment so as 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 for 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) Operational experience feedback relevant to human factors.

SAFETY ANALYSIS

5.97. The safety assessment of the conversion facilities and enrichment facilities should include the safety analysis of the variety of hazards for the whole facility and all activities. The IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), Safety Assessment for Facilities and Activities [13] requires that all credible postulated initiating events shall be assessed.

5.98. The list of postulated initiating events identified should take into account all the internal and external hazards and the resulting event scenarios and should be carried out considering all the structures, systems and components important to safety that might be affected.

Safety analysis for operational states

5.99. A facility specific, realistic, enveloping and robust (i.e. conservative) assessment of internal and external occupational exposure and exposure of the public should be performed on the basis of the following assumptions:

(1) Calculations of the source term should use: (i) the material with the highest specific activity for an 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 approach plus uncertainties may also be used.

(2) 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.

(3) Calculations of the estimated doses to the public (i.e. a ‘critical group’ of people living in the vicinity of the facility) 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

5.100. The acceptance criteria associated with the accident analysis should be defined in accordance with GSR Part 4 (Rev. 1), Requirement 16 [13], and with respect to any national regulations and relevant criteria.

5.101. For a conversion facility or an enrichment facility, consequences of design basis accidents 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 individuals exposed or affected and the source of the release, pathways for the transport of material to the individuals and the exposure times.

5.102. 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 worst case consequences should be determined.

5.103. The following two approaches, or an equivalent approach, should be considered in the safety assessment of conversion and enrichment facilities:

(1) One approach involves the identification of structures, systems and components important to safety and administrative measures which either reduce the consequences and/or the likelihoods of potential accidents below established criteria.

(2) Another approach involves the identification of structures, systems and components important to safety which by design, along with administrative measures, ensure that the consequences of enveloping accident cases with predetermined initiating events are within established criteria. Unlike the first approach, for this approach, only accident consequences and not likelihoods are considered for demonstrating safety. For example, for this approach, the facility designers would ensure that by design the criticality dose contour from an assumed reference criticality excursion (to be defined and justified by the operator) would not impact the public. However, if this is not possible, then a justification should be provided by the operator as to why this cannot be achieved.

Analysis of Design Extension Conditions

5.104. The safety analysis should also identify design extension conditions followed by an analysis of their progression and consequences in accordance with Requirement 21 of SSR-4 [1]. The objective is to analyse additional accident scenarios to be addressed in the design of a conversion or uranium enrichment facility to ensure that the design is 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. Moreover, the possibility of conditions arising that could lead to early releases of radioactive material or to large releases of radioactive material is practically eliminated. Design extension conditions include events more severe than design basis accidents that originate from extreme events or combinations of events 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 Appendix of SSR-4 [1] should be used including combinations of initiating events as well as events with additional failures. Accidents that have more severe consequences as well as progression of events that could potentially lead to a criticality event, 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.

5.105. 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.

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

5.107. Examples of design extension conditions that are applicable to conversion and uranium enrichment facilities can be found in the IAEA Safety Report Series No. 90, Safety Reassessment for Nuclear Fuel Cycle Facilities in Light of the Accident at the Fukushima Daiichi Nuclear Power Plant [14].

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

Assessment of possible radiological or associated chemical consequences

5.109. The main steps in the safety analysis should include the following:

(a) Analysis of actual 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 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 (material, mass, release rate, temperature, etc.).
(h) Identification and analysis of pathways by which material that is released could be dispersed in the

environment.

5.110. Considerations for interface between safety and security. The analysis of the site conditions involves a review of the meteorological, geological and hydrological conditions at the site that may influence facility operations or may play a part in transporting material or transferring energy that might be released from the facility.

5.111. Environmental transport 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.

5.112. The identification of personnel and members of the public (the critical groups) who may potentially be affected by an accident involves a review of descriptions of the facility and of demographic information.

MANAGEMENT OF RADIOACTIVE WASTE AND EFFLUENTS

5.113. The general requirements for optimization of protection and safety for waste and effluent management and the formulation of a waste strategy are established in the IAEA Safety Standards Series No. GSR Part 5, Predisposal Management of Radioactive Waste [15] with additional guidance provided in the IAEA Safety Standards Series No. GSG-3, The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste [16], IAEA Safety Standards Series No. GSG-1, Classification of Radioactive Waste [17], IAEA Safety Standards Series No. SSG-41, Predisposal Management of Radioactive Waste from Nuclear Fuel Cycle Facilities [18] and IAEA Safety Standards Series No. GS-G-3.3, The Management System for the Processing, Handling and Storage of Radioactive Waste [19]. Recommendations are provided in the following paragraphs on aspects that are particularly relevant or specific to conversion facilities and uranium enrichment facilities.

5.114. Conversion facilities and enrichment facilities should be designed to minimize the generation of radioactive waste. For economic and environmental reasons, the recovery of uranium and the reuse of chemicals are common practices in conversion facilities and enrichment facilities. These practices help to minimize the generation of waste in both solid and liquid forms.

5.115. In the design phase, 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.

5.116. In the case of conversion facilities and enrichment facilities, the nuclear material to be recovered is uranium both from scraps and as secondary outputs from ventilation filters or from cleaning of the facility. The process of recovering uranium from scraps may include dissolution and solvent extraction, which generate liquid effluents. An appropriate balance should thus be achieved between the loss of uranium through unrecovered waste and the generation of liquid effluents in the recovery process.

MANAGEMENT OF GASEOUS AND LIQUID RELEASES

5.117. Liquid effluents to be discharged to the environment should be monitored and treated as necessary to reduce the discharges of radioactive material and hazardous chemicals.

5.118. Monitoring equipment should be installed as necessary, such as differential pressure gauges for detecting filter failures and devices for measuring activity or gas concentration and for measuring the discharge flow measuring devices by continuous sampling.

5.119. Radionuclides in effluents discharged to the environment should be in soluble form to allow effective dispersal in the aquatic system without coagulation, deposition, and buildup of the radionuclides resulting in the need for environmental clean-up activities.

OTHER DESIGN CONSIDERATIONS

5.120. In meeting requirement 7 of SSR-4 [1], the design of the facility and equipment, including the selection of materials, should be such as to limit the accumulation of uranium and the ease of cleaning and/or surface decontamination should be taken into account at an early stage. Considering inadvertent accumulation of uranium in process lines, ventilation systems and containers special consideration should be given also to operational experience feedback (see Ref. [20]).

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

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

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

5.123. Requirements for control over the transfer of radioactive and hazardous materials are listed in Requirement 28 and para. 6.111 – 6.112 in SSR-4 [1].

5.124. For incoming containers, containing radioactive or hazardous material, sufficient technical provisions for checking the integrity should be considered during the design phase.

5.125. All containers used for transportation of radioactive and hazardous material on site should be considered in the safety analysis.

5.126. For cases where misidentification of containers could impose hazard, provisions for easy identification of the content should be used, if possible (for example unique colors, shapes, valves).

5.127. Technical provisions for inspection and maintenance of containers as items important to safety should be available. All containers should be controlled by a computer based system (actual status, position, technical conditions).

5.128. The analyses of handlings should cover

— Transportation routes and intersections;
— Technical limits of the transportation vehicles;
— Handling failures during transportation.

5.129. The design of the facility and the production processes should take into account the number of onsite transfers of radioactive and hazardous materials across different safety related zones (such as contamination and criticality control zones).

Design of the storage area for UF_6 cylinders

5.130. Provision should be made for avoiding any deep corrosion of cylinders that could result in a loss of confinement of depleted UF_6.

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

5.132. Flammable material should not be stored close to the storage area for UF_6 cylinders.

5.133. A large aircraft crash on the storage area for UF_6 cylinders is generally not considered as 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.

5.134. 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

5.135. In line with Requirement 32 of SSR-4 [1], the design of facility should 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.

5.136. 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.

5.137. An ageing management programme should be implemented at the design stage to allow timely maintenance or anticipating equipment replacements.

5.138. Effectiveness of the ageing management programme should be reviewed and assessed periodically.

6. CONSTRUCTION

6.1. Requirements for construction of conversion facilities and enrichment facilities are listed in Requirement 53 and para. 7.1–7.7 of SSR-4 [1]. General guidance on the construction and construction management of nuclear installations is provided in the IAEA Safety Standards Series No. SSG-38, Construction for Nuclear Installations [21].

6.2. For conversion facilities and 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. 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.

6.4. 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' shops before its installation at the enrichment facility. This will also aid commissioning, maintenance and decommissioning of the facility. Components and cables in an enrichment facility should be clearly labelled, owing to the complexity of the control systems.

6.5. Preferably, construction work should be completed prior to commissioning of the facility or its parts. In cases when the construction and commissioning or operational phases overlap, the appropriate precautions should be considered to minimize potential adverse impact of construction activities on safety. Consideration should be also given to the protection of equipment which has been already installed.

6.6. All structures and components after their installation should be properly cleaned and painted with suitable primer followed by appropriate surface treatment. Effect of nearby activities handling corrosive substances should also be considered.

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

7. COMMISSIONING

7.1. The requirements for commissioning are established in Requirement 54 of SSR-4 [1] and subsequent paragraphs. The operating organization should make the best use of the commissioning stage to become completely familiar with the facility. It should also be an opportunity to promote and further enhance safety culture, including positive behaviours and attitudes, throughout the entire organization.

7.2. For a conversion facility or an enrichment facility, the commissioning should be divided into two main phases:

(1) Inactive or ‘cold’ commissioning (i.e. commissioning prior to the introduction of uranium into the facility). In this phase, the facility’s systems are systematically tested, from both individual items of equipment and the systems in their entirety. As much verification and testing as possible should be carried out because of the relative ease of taking corrective actions in this phase. However, given the low radiation levels in a conversion facility or an enrichment facility, it would also be acceptable to carry out some of these activities in the subsequent phase.
   The operating organization should also take the opportunity to finalize the set of operational documents.
(2) Active or ‘hot’ commissioning (i.e. commissioning with the use of uranium). In this phase, the safety systems and measures for confinement and for radiation and chemical protection should be tested.
   Testing in this phase should consist of: (i) checks for airborne radioactive material and checks of levels of exposure at the workplace; (ii) smear checks on surfaces; (iii) checks for gaseous discharges and releases of liquids; and (iv) checks for the unexpected accumulation of material.
   Testing in this second step should be carried out 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.

7.3. 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 processes for the removal of uranium.

7.4. During inactive 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 air flows within the plant are as estimated by the calculations during the design phase.

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. Where possible, lessons from the commissioning and operation of similar conversion facility or an enrichment facility should be sought out and applied.

8. OPERATION

8.1. Organization of operation of conversion facilities and uranium enrichment facilitiesThe distinctive features of a conversion facility or an enrichment facility described in para 2.1 should be taken into account in meeting the safety requirements established in SSR-4 [1] for operation. In this section, specific recommendations on operational practices and additional considerations in meeting the safety requirements for a conversion facility or an enrichment facility are presented.

8.2. The safety committee in a conversion facility or an enrichment facility, as defined in SSR-4 [1], para. 4.29, should be created from the safety committee established for commissioning. Its function should be specified in the management system, it should be adequately staffed, and it should include diverse expertise and have appropriate independence from the direct line management of the operating organization.

QUALIFICATION AND TRAINING OF PERSONNEL

8.3. The safety requirements relating to the qualification and training of facility personnel are established in requirements 56 and 58 of SSR-4 [1]. Further recommendations are provided in paras 4.6–4.25 of GS-G-3.1 [6].

8.4. 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: (1) an H_2 explosion in a reduction furnace in a conversion facility; and (2) a lubrication oil fire in a gaseous diffusion enrichment facility. In addition, personnel should be provided periodically with basic training in radiation safety.

8.5. Complementary training of safety and security personnel and their mutual participation in exercises of both types should be part of the training programme to effectively manage the interface between safety and security. In particular, personnel with responsibilities and expertise in safety analysis and safety assessment 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 most effectively.

OPERATIONAL DOCUMENTATION

8.6. Requirement 57 of SSR-4 [1] and subsequent paragraphs require that operational limits and conditions are developed for a uranium conversion and 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 operator.

8.7. Operating documents should be prepared that list 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.

8.8. Examples of limits on operating parameters (SSR-4 [1], para. 9.31) for a uranium conversion and enrichment facility are:

— The maximum enrichment of uranium allowed at the facility;
— The feed specification limits;
— The maximum allowed inventories for processes and for the facility.

8.9. Consideration should be given to ensuring that uranium is present only in areas designed for the storage or handling of uranium. Programmes should be put in place for routine monitoring for surface contamination and airborne radioactive material, and more generally for ensuring an adequate level of housekeeping.

8.10. Operating procedures to directly control process operations should be developed. 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 required to ensure criticality safety, fire protection, emergency planning and environmental protection.

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

MAINTENANCE, CALIBRATION AND PERIODIC TESTING AND INSPECTION

8.12. When carrying out maintenance in a conversion facility or an 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 hydrogen fluoride, fluorine, hydrogen and nitric acid.

8.13. Maintenance should follow good practices with particular consideration given to:

— Work control, e.g. handover and handing back of documents, means of communication and visits to job sites, changes to the planned scope of work, suspension of work and ensuring safe access.
— Equipment isolation, e.g. disconnection of electrical cabling and heat and pressure piping and venting and purging of equipment.
— Testing and monitoring, e.g. checks before commencing work, monitoring during maintenance and checks for recommissioning.
— Safety precautions for work, e.g. specification of safety precautions, ensuring the availability of personal protective equipment and ensuring its use and emergency plans.
— Reinstallation of equipment, e.g. reassembly, reconnection of pipes and cables, testing,

cleaning the job site and monitoring after recommissioning.

8.14. Attention should also be paid to the handling of radioactive sources and X ray equipment used in a conversion facility or an enrichment facility for specific purposes, e.g. those used for the inspection of welds or flow gauges.

8.15. Equipment configurations during maintenance can be changed to abnormal settings and hence unexpected operational modes with no prior safety analysis or operational limits and conditions could be reached. When maintenance is performed on installation that may contain enriched uranium or near a storage location of enriched uranium, criticality safety staff should be consulted before the work commences.

8.16. All temporary changes to the facility configuration during maintenance activities should be coordinated between safety and security specialists to avoid potential conflicts (e.g. cut 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 which could affect the systems or structures required for neutron isolation of adjacent fissile units. When the changes affect temporarily these systems or structures, it should be ensured that these systems or structures continue to deliver their required safety function when reinstated.

8.17. Compliance of the operational performance of the ventilation system with the fire protection requirements (see para 5.56) should be verified on a regular basis.

8.18. A programme of periodic inspections of the facility should be established, whose purpose is to verify that the facility is operating in accordance with the operational limits and conditions. Suitably qualified and experienced persons should carry out inspections.

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

8.20. 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

8.21. The operating organization should take into account following issues in implementing a systematic ageing management programme in line with requirement 60 of SSR-4 [1]:

(a) Support for the ageing management programme by the management of the operating organization;
(b) Early implementation of an ageing management programme;
(c) A proactive approach based on an adequate understanding of structures, systems and components

ageing, rather than a reactive approach responding to structures, systems and components failures;

(d) Optimal operation of structures, systems and components to slow down the rate of ageing degradation;
(e) 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) Minimization of human performance factors that may lead to premature degradation, through enhancement of personnel motivation, sense of ownership and awareness, and understanding of the basic concepts of ageing management;
(g) Availability and use of correct operating procedures, tools and materials, and of a sufficient number of qualified personnel for a given task;
(h) Feedback of operating experience to learn from relevant ageing related events.

8.22. The aging management programme should consider the technical as well as the non-technical aspects of ageing and its effectiveness should be regularly assessed and reviewed (see also para. 5.144).

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

— Monitoring of deterioration (Measurement of metallic impurities in fluoric acid);
— Regular visual inspections of uranium powder pipes;
— Monitoring of operating conditions (taking heat images of electrical cabinets; check of temperatures of ventilator bearings).

CONTROL OF MODIFICATIONS

8.24. The management system for a conversion facility or an enrichment facility should include a standard process for all modifications (see para. 3.15). This process should use a modification control form or an equivalent management tool. The modification control form should contain a description of the modification and why it is being made. The main purpose of the modification control form is to ensure that a safety assessment is conducted for the modification. The modification control form should be used to identify all the aspects of safety that may be affected by the modification, and to demonstrate that adequate and sufficient safety provisions are in place to control the potential hazards.

8.25. 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.

8.26. Modification control forms should be scrutinized by and be subject to approval by qualified and experienced persons to verify that the arguments used to demonstrate safety are suitably robust. This should be considered particularly important if the modification could have an effect on 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.

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

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

8.29. Modifications performed on design, layout or procedures of the facility might negatively affect security equipment and vice versa. For example, malfunction of safety equipment may damage nearby security equipment. Therefore, before approval and implementation, any proposed changes to the facility or management arrangements should be reviewed, assessed and endorsed from the safety objective view. In addition, its interface with security should be evaluated to verify that they do not compromise each other.

8.30. 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) periodic safety review or an equivalent process.

8.31. The modification control documentation should be retained at the facility in accordance with national requirements.

RADIATION PROTECTION

8.32. The requirements for radiation protection in operation are established in SSR-4 [1], para. 9.90-9.101 and in the IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [22]; recommendations are provided in the IAEA Safety Standards Series No. GSG-7, Occupational Radiation Protection [23]. The operating organization should have a policy to optimize protection and safety and is required to ensure doses are below national dose limits and within any dose constraints set by the operating organization (SSR-4 [1], para. 9.91). 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.

8.33. In a conversion facility or an enrichment facility, the main radiological hazard 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 the uranium oxides UO_2

and U_3O_8 pose a particular hazard because of their long biological half-lives (and therefore effective half-lives)[1]. Thus, close attention should be paid to the confinement of uranium powders and the control of contamination in the workplace. In enrichment facilities most uranium compounds have a short biological half-life. The chemical hazards for the uranium compounds found in conversion and enrichment facilities dominate the radiological hazards.

8.34. In conversion facilities and 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. In meeting provisions 9.94 and 9.120 of SSR-4 [1] for uranium conversion facilities (if applicable) or for uranium enrichment facilities emergency arrangements for criticality incidents should be put in place, which are the only events in which a high external dose rate would be encountered.

8.35. Interventions for maintenance and/or modifications are major activities that require justification and optimization of protective actions, as specified in GSR Part 3 [22]. The procedures for intervention should include:

(a) Estimation of the external exposure prior to 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:
   — Identifying specifically the risks associated with the intervention;
   — Specifying in the work permit the protective measures for the intervention (such as for the individual and collective means of protection, e.g. use of masks, clothing and gloves, and time limitation);
(c) Measurement of the occupational exposure during the intervention;
(d) Implementation of feedback of information for identifying possible improvements.

8.36. 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 its being discharged to the atmosphere.

8.37. The monitoring results from the radiation protection programme should be compared with the operational limits and conditions and corrective actions should be taken if necessary. Furthermore, these monitoring results should be used to verify the dose calculations made in the initial environmental impact assessment.

8.38. 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

[1] The biological half-life is the time taken for the amount of a material in a specified tissue, organ or region of the body 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.

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 carried out at ventilation hoods and entrances to containment areas. Pressure drops across air filter banks should be checked and recorded regularly.

(c) A high standard of housekeeping should be maintained at the facility. Cleaning techniques should be used that do not give rise to airborne radioactive material, e.g. the use of vacuum cleaners with HEPA filters.

(d) Regular contamination surveys of areas of the facility and equipment should be carried out to confirm the adequacy of cleaning programmes.

(e) Contamination zones should be delineated and clearly indicated.

(f) Continuous air monitoring should be carried out to alert facility operators if levels of airborne radioactive material exceed predetermined action levels.

(g) Mobile air samplers should be used at possible sources of contamination as necessary.

(h) An investigation should be carried out promptly in response to readings of high levels of airborne radioactive material.

(i) Personnel and equipment should be checked for contamination and should undergo decontamination if necessary, prior to their 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 risk of 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 the cleaning of process equipment).

(l) Personal protective equipment should be maintained in good condition, cleaned as necessary, and should be inspected.

(m) Any personnel having wounds should protect them with an impervious covering for work in contamination zones.

8.39. 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 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.

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

8.41. The method for assessing doses due to internal exposure may be based upon the collection of data from air sampling in the workplace, in combination with worker occupancy data. This method should be assessed, and should be reviewed as appropriate by the regulatory body.

8.42. On the completion of maintenance work, the area concerned should be decontaminated if necessary, and air sampling and smear checks should be carried out to confirm that the area can be returned to normal use.

8.43. 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 carried out inside the vessel to determine whether any restrictions on the allowed time period for working are required.

8.44. 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 and dose models in conjunction with reliable data on effluents.

8.45. There are only limited operations in a conversion facility or an 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.

8.46. Moreover, it should be noted that much more extensive controls for limiting external exposure will be required in the processing of reprocessed uranium than in the processing of natural uranium.

8.47. Radioactive sources are also used in a conversion facility or an enrichment facility for specific purposes, e.g. radioactive sources are used for checking uranium enrichment.

8.48. 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.

8.49. 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 carried out before the first introduction of uranium from other than natural sources.

CRITICALITY CONTROL

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

8.51. In addition, operational aspects of the control of criticality hazards in conversion facilities and enrichment facilities should include:

(a) Anticipation of unexpected changes in conditions that could increase the risk 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) The control of the enrichment level should be such that deviations that could lead to enrichment above the maximum enrichment used in criticality safety analysis, should be detected before a significant amount of material above this limit has accumulated;
(c) In the management of moderating materials; for example, before an empty cylinder is used in the facility to receive material enriched by ^{235}U above 1%, checks should be undertaken to ensure that no hydrogenous material is present in the cylinder (e.g. water, oil, water or plastics);
(d) Management of mass in transfer of uranium (procedures, mass measurement, systems and records) for which safe mass control is used;
(e) Reliable methods for detecting the onset of any of the foregoing conditions;
(f) Periodic calibration or testing of systems for the control of criticality hazards;
(g) Evacuation drills to prepare for the occurrence of a criticality and/or the actuation of an alarm.

8.52. 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]).

INDUSTRIAL AND CHEMICAL SAFETY

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

8.54. The chemical hazards found in conversion facilities and enrichment facilities may be summarized as follows:

— Chemical hazards due to the presence of HF (e.g from UF_6), F_2, HNO_3, NH_3 and uranium compounds;

— Explosion hazards due to hydrogen (H_2), ammonia (NH_3), ammonium nitrate, methanol, solvents and oxidants present in diffusion cascades;
— Asphyxiation hazards due to the presence of nitrogen or carbon dioxide.

8.55. Presence of HF in conversion facilities represents the main hazard for the protection of personnel, public and environment. Special consideration should be therefore given to storage, handling and processing of HF on site (as for example transfer of large volumes of HF from storage tanks to the process). Industry specific national requirements should be applied as appropriate.

8.56. The threshold of HF that a human can detect by smelling is lower than the occupational exposure level. As a consequence, specific routine occupational measurements for HF need not be implemented. In addition, releases of UF_6 generate a visible white cloud of UO_2F_2 particulates and HF that can easily be seen. For release of UF_6 and other chemical releases that result in visible clouds, periodic training should be given to all site personnel to follow the procedure "see, evacuate or shelter, and report".

8.57. A health surveillance programme should be set up, in accordance with national regulations, for routinely monitoring the health of personnel who may be exposed to uranium and associated chemicals, e.g. HF, F_2 and HNO_3. Both the radiotoxicity and the chemical toxicity effects of uranium should be considered, as necessary, as part of the health surveillance programme.

8.58. Fire hazard analyses should be conducted periodically to incorporate changes that may adversely affect the potential for and spread of fires (see para.5.51).

RISK OF OVERFILLING OF CYLINDERS

8.59. 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 .

8.60. In a conversion facility or an enrichment facility, the weight of a cylinder being filled should be monitored to reduce the risk of overfilling, generally by means of weighing scales.

8.61. 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).

8.62. 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

8.63. Movement of cylinders containing liquid UF_6 should be minimized. Cylinders containing liquid UF_6 should be moved only using 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 and restrictions on load movement above hot cylinders.

ON-SITE HANDLING OF SOLID UF_6

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

8.65. Cylinders containing solid UF_6 should be moved only using appropriately qualified apparatus.

8.66. 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, then its cooling should be considered to reduce a risk of rupture in accordance with facility procedures.

STORAGE OF TAILS

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

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

8.69. Periodic inspections of the tails 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

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

8.71. Gaseous radioactive and chemical discharges should be treated, where appropriate, by means of HEPA filters and chemical scrubbing systems. Performance standards should be set that specify performance levels at which filters or scrubber media are to be changed. After filter changes, tests should be carried out to ensure that new filters are correctly seated.

8.72. Liquid discharges should be treated effectively. Chemicals should be recovered and reused where possible. This is particularly important for HF produced in the deconversion process. Care should be taken to ensure that HF is suitable for reuse externally.

8.73. One easy way to minimize the generation of solid radioactive waste is to remove as much outer packing as possible before material is transferred to contamination areas. Processes such as incineration, metal melting and compaction can be used to reduce the volume of wastes. As far as reasonably practicable and in accordance with national regulations, waste material should be treated to allow its further use. Cleaning methods should be adopted at the facility that minimize the generation of waste.

8.74. In conversion facilities, unburnt 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

8.75. The requirements for emergency preparedness and response are established in Requirement 72 and paras. 9.120 – 9.132 of SSR-4 [1], in IAEA Safety Standards Series No. GSR Part 7, Preparedness and Response for a Nuclear or Radiological Emergency [24], and recommendations are provided in GS-G-2.1 [25] and in IAEA Safety Standards Series No. GSG-2, Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency [26]. The conditions for declaration of an emergency at a conversion facility or an enrichment facility may include large releases of UF_6, HF, F_2 and NH_3 and also, depending on national requirements and facility specific considerations, criticality accidents, large fires (e.g. in the solvent extraction units of a conversion facility) or explosions.

8.76. The emergency preparedness should include how and when an interface with local and national emergency response organizations should be established. This arrangement should be tested periodically to ensure effective operation during an emergency. Clear communication and authorization protocols should be established with local authorities to ensure proper functioning of the emergency response organization.

8.77. The operator should ensure availability of personnel with specific expertise on the type of hazards present in facility as well as specific environmental sampling equipment for local authorities to support appropriate decision-making.

8.78. Emergency plans and contingency plans should be developed in a coordinated manner, considering all of the responsibilities of the facility personnel and security forces, to ensure that in the event of a simultaneous response of both groups to an event, all critical functions can be performed in a timely manner. Emergency response plans should consider nuclear security events as possible emergency initiators and their implications on emergency situations and be coordinated with the security response. Strategies for rapidly determining the origin of events and deploying appropriate first responders (safety personnel, security forces or a combination of both) should be developed including the roles and actions of security forces and emergency response personnel. These situations should be jointly exercised and evaluated. From this, lessons should be identified and recommendations should be made to improve the overall response.

8.79. For establishing access control procedures during emergencies, when there is a necessity for rapid access and egress of personnel, safety and security specialists should cooperate closely. Both safety and security objectives should be sought for during emergencies as much as possible, in accordance with regulatory requirements. When it is not possible, the best solution taking into account both objectives should be pursued.

FEEDBACK OF OPERATING EXPERIENCE

8.80. Requirements on feedback of operating experience are listed in SSR-4 [1], paras. 9.133 – 9.137. Further guidance on operational experience program is provided in SSG-50 [9].

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

9. PREPARATION FOR DECOMMISSIONING

9.1. Requirements for the preparation of safe decommissioning of a conversion facility or an enrichment facility are established in SSR-4 [1], paras 10.1 – 10.13, and in the IAEA Safety Standards Series No. GSR Part 6, Decommissioning of Facilities [27], Sections 2 to 7.

9.2. Special measures should be implemented during the preparatory works for decommissioning to ensure that criticality control is maintained when handling equipment containing nuclear material which criticality safety is controlled by geometry.

9.3. In addition to the general preparations for decommissioning described in the IAEA Safety Standards Series No. SSG-47, Decommissioning of Nuclear Power Plants, Research Reactors and Other Nuclear Fuel Cycle Facilities [28] the following preparatory steps specific to conversion facilities and uranium enrichment facilities should be performed:

(a) A post-operational cleanout should be performed to remove all the gaseous UF_6 and the bulk amounts of uranium compounds and other hazardous materials from the process equipment.

(b) In conversion facilities, the first step is to carry out dry mechanical cleaning, to minimize the generation of liquid waste. The uranium resulting from the dry mechanical cleaning process should be recovered.

— In centrifuge enrichment facilities, gaseous UF_6 is pumped out and recovered in cold traps. In addition, flushing with an inert gas (e.g. N_2) should be used to remove the residual UF_6 and HF.

(c) Any grounds (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;

— 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 guidance provided in SSG-47 [28]. Specific consideration should be given to the following elements:

(a) The description of 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 facility's commissioning and operation stages (see GSR - Part 6 [27], Requirements 8 and 10) to take account of new information and emerging technologies to ensure that:

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

REFERENCES

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

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Criticality Safety in the Handling of Fissile Material, Safety Standards Series No. SSG-27, IAEA, Vienna (2009).

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

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

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

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Application of the Management System for Facilities and Activities, Safety Standards Series No. GS-G-3.1, IAEA, Vienna (2006).

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

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

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

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

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

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Seismic Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSG-9, IAEA, Vienna (2010).

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

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

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

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, The Safety Case and Safety Assessment

for the Predisposal Management of Radioactive Waste, IAEA Safety Standards Series No. GSG-3, IAEA, Vienna (2013).

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

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

[19] INTERNATIONAL ATOMIC ENERGY AGENCY, The Management System for the Processing, Handling and Storage of Radioactive Waste, IAEA Safety Standards Series No. GS-G-3.3, IAEA, Vienna (2008).

[20] INTERNATIONAL ATOMIC ENERGY AGENCY, NUCLEAR ENERGY AGENCY, IAEA/NEA Fuel Incident Notification and Analysis System (FINAS).

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

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

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

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

[25] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR OFFICE, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS OFFICE FOR THE

COORDINATION OF HUMANITARIAN AFFAIRS, WORLD HEALTH ORGANIZATION, Arrangements for Preparedness for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GS-G-2.1, IAEA, Vienna (2007).

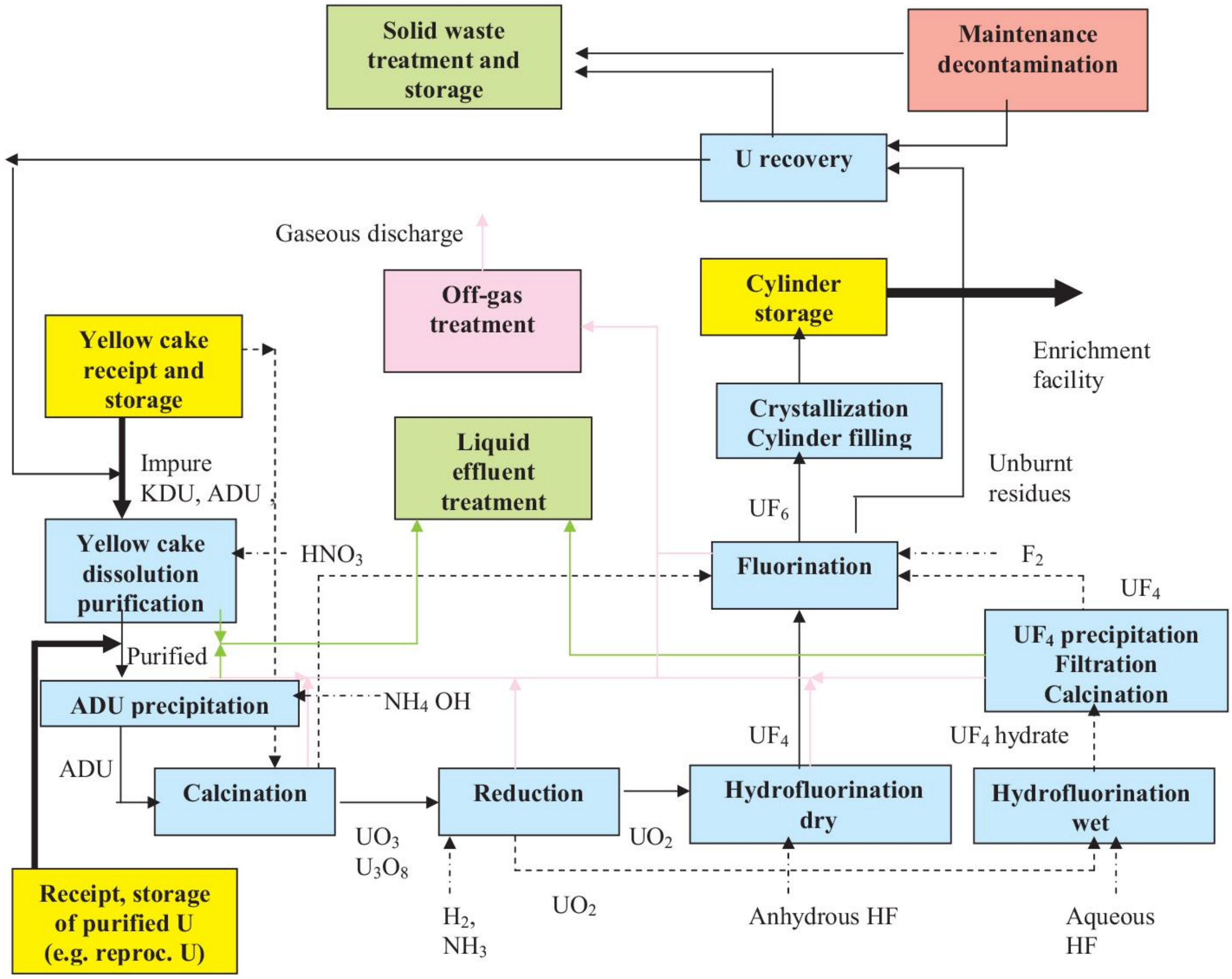
[26] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR OFFICE, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency, IAEA Safety Standards Series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

[27] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Facilities, IAEA Safety Standards Series No. GSR Part 6, IAEA, Vienna (2014).

[28] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Nuclear Power Plants, Research Reactors and Other Nuclear Fuel Cycle Facilities, IAEA Safety Standards Series No. SSG-47, IAEA, Vienna (2018).

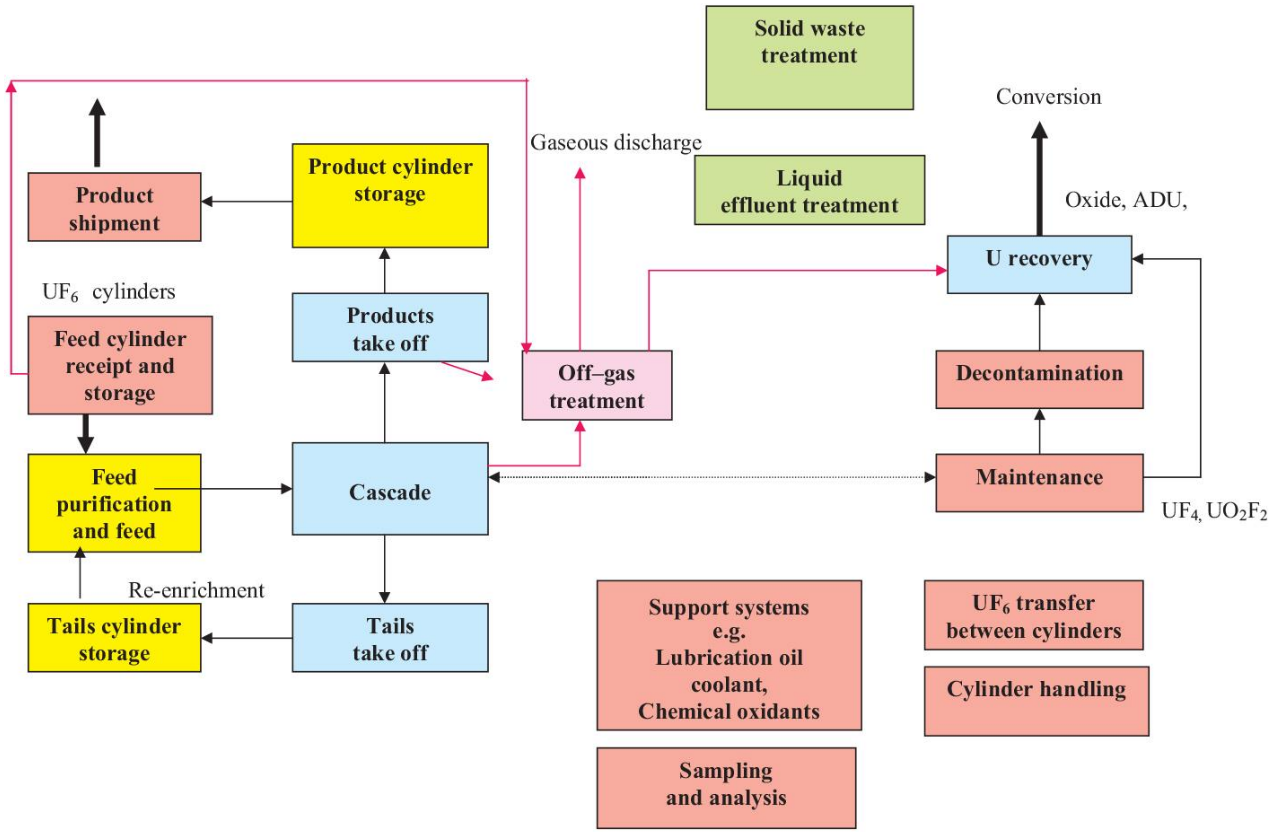
ANNEX I

TYPICAL PROCESS ROUTES IN A CONVERSION FACILITY



ANNEX II

TYPICAL PROCESS ROUTES IN AN ENRICHMENT FACILITY



ANNEX III

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

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

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Reagents				
Receipt and storage of anhydrous HF	— Flexible hoses and transfer devices; — Automatic shutoff 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 shutoff valves; — Storage vessels	Release of NH_3	(2)	
Receipt of H_2	— Flexible hose and transfer devices; — Automatic shutoff 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

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, purification and storage of yellow cake				
Dissolution	Dissolver and facilities for off-gas treatment	Release of uranium and nitrogen oxide (NOx)	(2)	Concentration of nitrogen oxide in gaseous effluent
Purification	— Fire detectors; — Flameproof apparatus	Fire	(2)	
Receipt and storage of purified uranium, e.g. reprocessed uranium				
Receipt of uranium nitrate (enriched uranium)	Checking device for ^{235}U content	Processing of uranium beyond safety limits	(1)	Enrichment, concentration

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
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
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 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

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
	Off-gas treatment units	Release of uranium powder	(2)	Uranium concentration
Dry hydro fluorination				
	— Hydro fluorination reactor; — Facilities for off-gas treatment	Release of HF	(2)	HF, uranium content in gases
	Shielding	Increase in dose rate	(3)	Thickness
Wet hydro fluorination				
	— Hydro fluorination 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

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				
	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
	Vessels, piping	Release of UF_6	(2)	Integrity of tank, valves and lines
	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

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
	Means of transportation, 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
Solvent extraction	Mixer settlers or extraction columns	Fire Releases	(2)	Temperature
Intermediate storage of unburnt residues	Shielding	Increase in dose rate	(3)	Thickness
Off-gas treatment				
	Aerosol and gas measuring devices	Release of HF, F_2 and uranium	(2)	Uranium content in released air
	Columns, piping	Release of uranium and HF	(2)	HF content in released air

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Treatment of liquid effluents				
	Tank, piping	Release of uranium and other impurities	(2)	Uranium concentration; Uranium content in released water
	Measuring devices for radioactive and chemical impurities	Release of uranium and other impurities	(2)	
	Exhaust pipe	Release of uranium and other impurities	(2)	
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

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

Note: Safety function includes: (1) Criticality prevention; (2) Confinement to protect against internal exposure and chemical hazards; (3) Protection against external exposure.

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

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
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 containment 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 enrichment facilities

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 in 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; Criticality; Criticality; Release of UF_6; Release of UF_6; 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

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
	— 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 Freon® leading to an explosion	(1), (2)	— Maintenance of the integrity of the tubes — Pressure and temperature limits
	In-line analysers to monitor for hydrocarbons or Freon® and for detecting ingress of oil or Freon®	Reaction of UF_6 with oil leading to criticality and/or explosion	(1), (2)	Limit on hydrocarbon concentrations
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 UF_6; Release of liquid UF_6	(1), (2)	Vapour pressure of HF Pressure Visual empty cylinder inspection Weight limit

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 containment barrier or atmosphere; External radiation dose from any accumulated uranium or uranium daughter isotopes	(1), (2), (3)	Temperature measuring device of cold traps
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

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Maintenance				
	Geometrically safe containers for the collection of residues.	Criticality Operator exposure	(1), (2)	Safe 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
Uranium recovery				
	Various criticality controls (e.g. on mass, geometry, concentration); Level controls on tanks; Storage of liquors and/or recovered uranium in safe geometry tanks or containers	Criticality; Process liquor spill; Operator exposure	(1), (2)	Limits on concentration and mass; Safe dimensions of the containers

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Off-gas treatment				
	Differential pressure; Activity measurements and alarms; HF concentration measurements; Safe geometry scrubbers	Blocked or torn filters: failure of ventilation or discharge to atmosphere	(1), (2)	High and low pressure alarms Safe dimension of apparatus
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 containment barrier	(1), (2), (3)	Pressure and temperature limits; Detection limits for UF_6 detectors; Visual inspection and pressure test of connectors
Cylinders 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

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Radioactive waste treatment				
	Treatment facilities	Release of uranium; Release of chemicals; Fire	(1), (2)	
	Measuring devices for uranium content	Degradation of criticality safety margin (mass)	(1)	
	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 control system	Release of uranium	(2)	Differential pressure on filters

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
	Filters inside the process areas		(1), (2)	Differential pressure on filters
	Ducts for air and process gas	Degradation of criticality safety margin (mass)	(1)	Mass of uranium (e.g. pre-filters)
	Final filter stage for waste air	Fire	(2)	Differential pressure on filters
	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
	Measurement devices for radioactivity in water	Release of uranium	(2), (1)	Sampling and analyses before release

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
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.	Nuclear Safety Commission, Canada
Baggett, G.	URENCO (Capenhurst), United Kingdom
Bogdanova, T.	Federal Environmental, Industrial and Nuclear Supervision Service of Russia, Russian Federation
Casoli, B.	Institute for Radiological Protection and Nuclear Safety, France
Costa, C.G.S.	Brazilian Nuclear Industry, Brazil
Faraz, Y.	Nuclear Regulatory Commission, United States of America
Groche, K.	Germany
Michaelson, T.	International Atomic Energy Agency
Morikami, Y.	Japan Nuclear Fuel Limited, Japan
Nocture, P.	International Atomic Energy Agency
Petit, J.	Cogema, France
Rossi, J.L.	EURODIF Production, France
Rovny, J.	International Atomic Energy Agency
Shokr, A.	International Atomic Energy Agency
Visser, T.	URENCO, Netherlands