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Safety of Uranium Fuel Fabrication Facilities

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Revision of Safety Guide SSG-6

DRAFT SPECIFIC SAFETY GUIDE

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1. INTRODUCTION

BACKGROUND

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

1.2. This Safety Guide provides specific recommendations on the safety of uranium fuel fabrication facilities.

1.3. Uranium and the waste generated in uranium fuel fabrication facilities are handled, processed, treated and stored at the facility. Uranium fuel fabrication facilities may process or use large amounts of hazardous chemicals, which can be toxic, corrosive, combustible and/or explosive.

1.4. The fuel fabrication processes can rely to a large extent on operator intervention and administrative controls to ensure safety, in addition to passive and active engineered safety measures. The potential for a release of energy in the event of an accident at a uranium fuel fabrication facility is associated with nuclear criticality or chemical reactions. The potential for release of energy is small in comparison with that of a nuclear power plant, with generally limited environmental consequences.

1.5. This Safety Guide supersedes IAEA Safety Standards Series No. SSG-6, Safety of Uranium Fuel Fabrication Facilities¹.

OBJECTIVE

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

1.7. The recommendations in this Safety Guide are aimed primarily at operating organizations of uranium fuel fabrication facilities, regulatory bodies, designers and other relevant organizations.

SCOPE

1.8. The safety requirements applicable to fuel cycle facilities (i.e. facilities for uranium refining, conversion, enrichment, reconversion², 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 uranium fuel fabrication facilities.

1.9. This Safety Guide deals specifically with the handling, processing, material transfer and storage of natural uranium and low enriched uranium (LEU) that has a ²³⁵U enrichment of no more than 6%, which could be derived from natural, high enriched or reprocessed uranium which might contain also traces of plutonium; it covers fabrication of uranium oxide fuels but it does not cover facilities that handle uranium metal fuels. This Safety Guide deals also with the generation and management of radioactive wastes and liquid, airborne and gaseous radioactive effluents arising from the handling and processing of these materials. Recommendations are also provided for auxiliary activities such as sampling, homogenization,

¹ INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Uranium Fuel Fabrication Facilities, IAEA Safety Standards Series No. SSG-6, IAEA, Vienna (2010).

² Often called also 'deconversion'

blending and analytical laboratory services. Completed fuel assemblies are usually stored at the fuel fabrication facility before being transported to the nuclear power plant. Such a storage facility is considered to be part of the fuel fabrication facility. This Safety Guide is limited to the safety of uranium fuel fabrication facilities; it does not deal with any impact that the manufactured fuel assemblies might have on safety for the reactors in which they are going to be used.

1.10. This Safety Guide includes specific recommendation on ensuring criticality safety in uranium fuel fabrication facilities. These recommendations supplement more detailed recommendations provided in IAEA Safety Standards Series No. SSG-27, Criticality Safety in the Handling of Fissile Material [2].

1.11. The implementation of safety requirements on the legal and governmental framework and regulatory supervision (e.g. requirements for the authorization process, regulatory inspection and regulatory enforcement) as established in IAEA Safety Standards Series No. GSR Part 1 (Rev.1), Governmental, Legal and Regulatory Framework for Safety [3] is not addressed in this Safety Guide.

1.12. This Safety Guide does not include recommendations on nuclear security. Recommendations on nuclear security for a uranium fuel fabrication facility are provided in IAEA Nuclear Security Series No. 13, Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5) [4] and guidance is provided in IAEA Nuclear Security Series No. 27-G, Physical Protection of Nuclear Material and Nuclear Facilities (Implementation of INFCIRC/225/Revision 5) [5]. However, this Safety Guide includes recommendations on managing interfaces between safety, nuclear security and the State system for nuclear material accounting and control.

STRUCTURE

1.13. Section 2 provides general safety recommendations for a uranium fuel fabrication facility. Section 3 provides recommendations on the development of a management system for such a facility 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 the safety analysis for operational states and accident conditions and presents the safety aspects of radioactive waste management in the uranium fuel fabrication facility and other design considerations. Section 6 addresses safety aspects in the construction stage. Section 7 addresses safety considerations in commissioning. Section 8 deals with safety in the stage of operation of the facility: 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 uranium fuel fabrication facility. Annex I shows the typical process routes for a uranium fuel fabrication facility. Annex II provides examples of structures, systems and components important to safety in uranium fuel fabrication facilities, grouped in accordance with process areas. Annex III provides examples of parameters for defining the operational limits and conditions for a uranium fuel fabrication facility.

2. HAZARDS IN URANIUM FUEL FABRICATION FACILITIES

2.1. In uranium fuel fabrication facilities, significant amounts of uranium compounds (in gaseous, liquid or solid state) are present and some of these compounds can be in a dispersible form, particularly in the early stages of the fuel fabrication process. In addition, the uranium compounds encountered exist in diverse chemical and physical forms and are used in conjunction with flammable or chemically reactive substances as part of the process. Thus, in these facilities, the main hazards are potential nuclear criticality

events and potential release of uranium hexafluoride (UF₆) and uranium dioxide (UO₂).

2.2. The chemical toxic hazards of LEU in a soluble form such as UF₆ are more significant than their radiotoxicity hazards. Along with UF₆, significant quantities of hazardous chemicals such as hydrogen fluoride (HF) are also present. In addition, when UF₆ is released it reacts with the moisture in the air to produce HF and soluble uranyl fluoride (UO₂F₂), which present additional safety hazards. Therefore, comprehensive safety analyses for uranium fuel fabrication facilities should also address the potential hazards resulting from these chemicals.

2.3. The radiotoxicity of LEU is low, and thus any potential off-site radiological consequences following an accident would be expected to be limited. However, the radiological consequences of an accidental release of enriched uranium resulting from reprocessing would likely be greater, and therefore should be considered in the safety assessment if the licence held by the facility permits the processing of such uranium.

2.4. Uranium fuel fabrication 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 ¹³¹I from a nuclear power plant 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.

2.5. For the application of the requirement that the concept of defence in depth be applied at the facility (see Section 2 of SSR-4 [1]), the first two levels of defence in depth if applied correctly to uranium fuel fabrication facilities should be able to reduce the risk to appropriately low levels by means of design and appropriate operating procedures (see Sections 5 and 8). All levels of defence in depth should be applied in accordance with a graded approach.

3. MANAGEMENT SYSTEM AND VERIFICATION SYSTEM FOR URANIUM FUEL FABRICATION FACILITIES

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

3.2. Requirements for the management system are established in GSR Part 2 [6]. Associated recommendations are provided in IAEA Safety Standards Series Nos GS-G-3.1, Application of the Management System for Facilities and Activities [7], GS-G-3.5, The Management System for Nuclear Installations [8], GSG-16, Leadership, Management and Culture for Safety in Radioactive Waste Management [9], and TS-G-1.4, The Management System for the Safe Transport of Radioactive Material [10].

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

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

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

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

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

MANAGEMENT RESPONSIBILITY

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

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

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

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

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

The management system should include arrangements for empowering relevant personnel to stop unsafe operations at the uranium fuel fabrication safety.

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

3.11. In accordance with para. 4.2(d) of SSR-4 [1], the operating organization is required to audit all safety related matters on a regular basis. This should include the examination of arrangements for

emergency preparedness and response, for example, emergency communications, evacuation routes and signage. Checks should be performed by the nuclear criticality safety staff who performed the safety assessments to confirm that the data used and the implementation of criticality safety measures are correct. Audits should be performed by personnel who are independent of those that performed the safety assessments or conducted the activities important for safety. The data from audits should be documented and submitted for management review and for action, if necessary.

RESOURCE MANAGEMENT

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

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

- (a) Determine the necessary competence of personnel and provide training, as necessary;
- (b) Prepare and issue specifications and procedures on safety related activities and operations;
- (c) Support the conduct of and perform safety assessments including modifications;
- (d) Have frequent personal contact with personnel, including observing work in progress;
- (e) Make provisions for staffing³, succession planning and retention of corporate knowledge.

3.14. Requirement 58 of SSR-4 [1] states that:

“The operating organization shall ensure that all activities that may affect safety are performed by suitably qualified and competent persons”.

In accordance with Requirement 58 and paras 9.38–9.47, the operating organization is required to ensure that these personnel receive training and refresher training at suitable intervals, appropriate to their level of responsibility. In particular, personnel involved in activities with fissile material, radioactive material, including waste, and chemicals should understand the nature of the hazard posed by these materials and how the risks are controlled by the established safety measures, operational limits and conditions, and operating procedures.

3.15. Requirement 11 of GSR Part 2 states that:

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

In accordance with paras 4.33–4.36 of GSR Part 2 [6], the management system for a uranium fuel fabrication facility is required to include arrangements for procurement.

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

PROCESS IMPLEMENTATION

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

“Operating procedures shall be developed that apply comprehensively for normal operation,

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

anticipated operational occurrences and accident conditions, in accordance with the policy of the operating organization and the requirements of the regulatory body.”

Paragraph 9.66 of SSR-4 states that:

“Operating procedures shall be developed for all safety related operations that may be conducted over the entire lifetime of the facility.”

The operating procedures should specify all parameters which are intended to be controlled and the criteria that should be fulfilled.

3.18. The management system for a uranium fuel fabrication facility should include management for criticality safety. Further recommendations on the management system for criticality safety are provided in SSG-27 [2].

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

3.20. Requirement 75 of SSR-4 [1] states:

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

The activities for ensuring safety throughout the lifetime of the facility or duration of the activity involve different groups and interface with other areas such as those related to nuclear security and to the system for nuclear material accounting and control. The activities with such interfaces should be identified in the management system, and should be coordinated, planned and conducted to ensure effective communication and clear assignment of responsibilities. Communications regarding safety and security should ensure that confidentiality of information is maintained. This includes the system of nuclear material accounting and control of, for which information security should be coordinated in a manner ensuring that subcriticality is not compromised.

MEASUREMENT, ASSESSMENT, EVALUATION AND IMPROVEMENT

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

3.22. Deviation from operational limits or conditions, and deviations from procedures and unforeseen changes in process conditions that could affect nuclear criticality safety are required to be reported and promptly investigated by the operating organization and the operating organization is required to inform the regulatory body: see paras 9.34, 9.35 and 9.38 of SSR-4 [1]. The depth and extent of the investigation should be proportionate to the safety significance of the event, in accordance with a graded approach. The investigation should cover the following:

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

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

VERIFICATION OF SAFETY

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

3.25. Requirement 6 of SSR-4 [1] states that: “[a]n independent safety committee (or an advisory group) shall be established to advise the management of the operating organization on all safety aspects of the nuclear fuel cycle facility.”

3.26. The safety committee of a uranium fuel fabrication facility should have access to experts in areas of criticality safety and radiation protection. Such experts should be available to the facility at all times during operation.

4. SITE EVALUATION FOR URANIUM FUEL FABRICATION FACILITIES

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

4.2. The scope of the site evaluation for a uranium fuel fabrication facility is established in Requirement 3 of SSR-1 [10], Requirement 11 and paras. 5.1–5.14 of SSR-4 [1] and should reflect the specific hazards listed in Section 2 of this Safety Guide.

4.3. The population density and population distribution in the vicinity of a uranium fuel fabrication facility are required to be considered in the site evaluation process to minimize any possible health consequences for people in the event of a release of radioactive material and hazardous chemicals (see Requirements 4 and 12 of SSR-1 [13]). Also, in accordance with Requirement 25 and paras 6.1–6.2 of SSR-1 [13], the dispersion in air and water of radioactive material released from the conversion facility or uranium enrichment facility are required to be assessed taking into account the orography, land cover and meteorological features of the region. The environmental impact from the facility under all facility

states is required to be evaluated (see para. 5.3 of SSR-4 [1]) and should meet the applicable criteria.

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

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

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

5. DESIGN OF URANIUM FUEL FABRICATION FACILITIES

SAFETY FUNCTIONS

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

“The design shall be such that the following main safety functions are met for all facility states of the nuclear fuel cycle facilities:

- (a) Confinement and cooling of radioactive material and associated harmful materials;**
- (b) Protection against radiation exposure;**
- (c) Maintaining subcriticality of fissile material.”**

These are applicable to uranium fuel fabrication facilities except for cooling of radioactive material.

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

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

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

5.5. The requirements on maintaining subcriticality are established in Requirement 38 and paras 6.138–6.156 of SSR-4 [1]. Further recommendations on maintaining subcriticality of uranium fuel fabrication facilities are provided in Section 3 of SSG-27 [2].

Design basis and safety analysis

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

5.7. The safety requirements relating to design basis for items important to safety and for the design

basis analysis for a nuclear fuel cycle facility are established in Requirements 14 and 20 of SSR-4 [1], respectively.

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

- (a) Release of uranium such as from an explosion in a reaction vessel;
- (b) Release of UF₆ such as due to the rupture of a hot cylinder;
- (c) Release of hydrogen fluoride such as due to the rupture of a storage tank;
- (d) Internal and external hazards, including internal and external explosions (in particular hydrogen explosions), internal and external fires, dropped loads and handling errors, extreme meteorological phenomena (in particular earthquakes, flooding and tornadoes), accidental aircraft crashes.

5.9. These hazards are of major safety significance as they might result in chemical and radiological consequences for the site personnel. In addition, they could also result in some adverse off-site consequences for the public or the environment.

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

Structures, systems and components important to safety

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

“The design of the nuclear fuel cycle facility: [...]

(e) shall provide for structures, systems and components and procedures to control the course of and, as far as practicable, to limit the consequences of failures and deviations from normal operation that exceed the capability of safety systems.”

Annex II of this Safety Guide presents examples of structures, systems and components important to safety and representative events that might challenge the associated safety functions in uranium fuel fabrication facilities.

Confinement of radioactive material and toxic chemical material

5.12. To meet Requirements 34 and 42 of SSR-4 [1] on protection against internal radiation exposure and against toxic chemical hazards, the use of and the inventory of UF₆ in dispersible form in the facility should be kept to a minimum.

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

5.14. The use of an appropriate containment system should be the primary method for protection against the spreading of contamination from areas where significant amounts of either uranium powders or hazardous substances in dispersible form are handled (Requirement 35 of SSR-4 [1]). When practicable, and to improve the effectiveness of the static containment system (physical barriers), a dynamic containment system should be used to create pressure gradients to cause a flow of air towards parts of equipment or areas that are more contaminated. A cascade of reducing absolute pressures can thus be

established between the environment outside the building and the hazardous material inside.

5.15. In the design of the ventilation and containment systems for the uranium fuel fabrication facility, 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. face velocity at the opening of enclosures); (vi) the dose rate at the filters; (vii) the potential accumulation of nuclear fissile materials in ventilation elements (filters, ventilation ducts); and (viii) the humidity and potential for moisture within the ventilation system, (viii) predictive and preventative maintenance strategies. In addition, generation of smoke in case of fire should be considered which could pose different requirements to the ventilation system.

5.16. To prevent the propagation of a fire through ventilation ducts and to maintain the integrity of firewalls, ventilation systems should be equipped with fireproof dampers and should be constructed from non-flammable and non-corrosive materials.

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

Protection of workers

5.18. Requirements on the design of uranium fuel fabrications facilities to ensure radiation protection of workers are established in Requirement 8 of SSR-4 [1].

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

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

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

5.22. 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 concentrations of hazardous substances in gaseous form in ventilation systems should be installed as necessary. Means for monitoring areas within the ventilation system to detect unwanted accumulation of radioactive or fissile

material should be provided as necessary.

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

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

5.25. Paragraph 3.9 of GSR Part 3 [15] states that:

“Any person or organization applying for authorization: [...]

e) Shall, as required by the regulatory body, have an appropriate prospective assessment made for radiological environmental impacts, commensurate with the radiation risks associated with the facility or activity.

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

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

5.27. The uncontrolled dispersion of radioactive substances to the environment as a result of an accident can occur if all the confinement barriers are impaired. Barriers may comprise the process equipment, or the room or the building itself.

5.28. Ventilation of the containment systems, by the discharge of exhaust gases through a stack via gas cleaning equipment such as a filter, reduces the normal environmental discharges of radioactive material to very low levels. In such cases, the ventilation system may also be regarded as a confinement barrier. The number of physical barriers for confinement should be adapted to the safety significance of the hazard. The minimum number of barriers is two, in accordance with the principle of redundancy (see Requirement 23 of SSR-4 [1]). The preferred optimum number of barriers is often three.

Protection against external exposure

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

5.30. External exposure of workers should be controlled by means of an appropriate combination of requirements on distance, time and shielding. The installation of shielding or the setting of restrictions on

occupancy should be considered for areas used for storing cylinders, in particular for empty cylinders that have contained reprocessed uranium since some by-products of irradiation will have remained in the cylinder. Similar precautions should be taken in areas of the facility where uranium has a high specific density and significant amounts of uranium are present (e.g. in storage areas for pellets and fuel).

5.31. When uranium dioxide is of low density (as is the case in conversion or blending units for instance), the shielding provided by the vessels and pipework of the uranium fuel fabrication facility will normally be sufficient to control exposure.

5.32. When reprocessed uranium is processed, additional protective measures should be considered for protection of personnel because of the higher gamma dose rates from ^{232}U daughters and fission products (^{208}Tl and ^{212}Bi). Such measures may include administrative arrangements to limit the period of time for which uranium is stored on the site or the installation of shielding.

Prevention of nuclear criticality

5.33. Prevention of nuclear criticality is an important topic with various aspects to be considered during the design of a uranium fuel fabrication facility (see Requirement 38 of SSR-4 [1]). Paragraphs 5.34–5.40 provide recommendations on some of the main elements of criticality safety that are specific for uranium fuel fabrication facilities. More detailed recommendations on criticality safety are provided in SSG-27 [2].

5.34. If a fuel fabrication facility processes uranium with ^{235}U mass fraction lower than 1% ^{235}U , a full criticality safety assessment is not necessary (see para. 6.138 of SSR-4 [1]). In such cases it should be demonstrated that there is no credible fault sequence in which uranium with higher than 1% ^{235}U enrichment is fed to the process. For further recommendations see para 2.8 of SSG-27 [2].

5.35. Paragraphs 6.138–6.148 of SSR-4 [1] establish requirements for the prevention of criticality by means of design. For the prevention of criticality in a uranium fuel fabrication facility the following parameters should be subject to control:

- (a) Mass and enrichment level(s) of fissile material present in a process and in storage between processes (e.g. uranium powder in rooms and vessel scrubbers, pellets in storage).
- (b) Geometry and interaction of processing equipment. Control can be achieved by limitation of the dimensions or shape (e.g. by means of safe diameters for storage vessels, control of slabs, appropriate separation distances between containers in storage). The loss of confinement and/or geometry due to leaks or breaks should also be accounted for.
- (c) Concentration of fissile material in solutions (e.g. in the wet process for recycling uranium).
- (d) Presence of reflectors or appropriate neutron absorbers (e.g. in the construction of storage areas, drums for powder and fuel shipment containers).
- (e) Degree of moderation. For example, this can be achieved by means of control of moisture levels and of the amount of additives in powder.

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

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

For uranium fuel fabrication facilities, to the extent practicable, vessels which could contain fissile

material should be made geometrically favourable and should be designed for the maximum authorized enrichment level including a reasonable safety margin.

5.37. The criticality safety analysis should demonstrate that the design of equipment and the related safety measures are such that the values of controlled parameters are always maintained in the subcritical range, i.e. that the facility is in a subcritical state at all times. This should be achieved by determining the effective multiplication factor (k_{eff}), which depends on the mass, the geometry, the distribution and the nuclear properties of the fissionable material and all other material with which it is associated. The calculated value of k_{eff} (including all uncertainties and biases) should then be compared with the value specified by the design limit (which should be set in accordance with paras 2.4–2.7 of SSG-27 [2]).

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

5.39. The criticality safety analysis should include the following:

- (a) The use of a conservative approach taking into account:
 - (i) Uncertainties in physical parameters and of the physical possibility of worst-case moderation conditions and the potential of non-homogeneous distributions of moderators;
 - (ii) Optimal geometry configuration of a system with fissile material;
 - (iii) Plausible operational occurrences and their combinations if they cannot be shown to be independent;
 - (iv) Operational states that might result from external hazards.
- (b) The use of appropriate verified and validated computer codes that are validated together with the appropriate data libraries of nuclear reaction cross-sections, for the normal and credible abnormal conditions being analysed, while taking into account any bias and its uncertainties (see paras 4.20–4.25 of SSG-27 [2]).

5.40. The following parameters should be included in the scope of a subcriticality analysis for a uranium fuel fabrication facility (see para. 6.144 of SSR-4 [1]):

- (a) *Enrichment*. The potential for errors in the calculation of the uranium enrichment of a fissile material should be considered if the maximum authorized enrichment level is not used in the criticality safety analysis (see para. 5.38)
- (b) *Mass*. The mass margin should be sufficient to compensate for possible over-batching of uranium in normal operation (see also para. 3.17 of SSG-27 [2]).
- (c) *Geometry of processing equipment*. The potential for changes in dimensions during operation is required to be considered (e.g. bulging of slab tanks or slab hoppers) in accordance with para. 6.144 of SSR-4 [1].
- (d) *Concentration and density*. The analysis should cover: (i) a range of uranium concentrations for solutions; and (ii) a range of powder and pellet densities plus moderators for solids, to determine the most reactive conditions that could occur.
- (e) *Moderation*. The analysis should cover the presence of moderators that are commonly present in uranium fuel fabrication facilities, such as water, oil and other hydrogenous substances (e.g. additives for uranium dioxide powder), or that might be present in accident conditions (e.g. water from firefighting). Special consideration should be given to cases of inhomogeneous moderation, for example when additives are included in the uranium dioxide powder.
- (f) *Reflection*. The most conservative margin should be retained of those margins resulting from different assumptions such as:

- (i) A hypothetical thickness of water around the processing unit.
 - (ii) Consideration of the neutron reflection effect due to the presence of materials around the processing unit (e.g. human bodies, organic materials, wood, concrete, steel of the container). Consideration should be given to those materials that could lead to a greater increase of the neutron multiplication factor than with a water reflection (e.g. concrete floor, walls): see para. 3.22 of SSG-27 [2].
- (g) *Neutron interaction.* Consideration should be given to neutron interaction between all facility parts. This includes the minimum distance of mobile units containing uranium (e.g. drums) and the engineered means for ensuring the minimal distance between equipment containing uranium.
 - (h) *Neutron absorbers.* The neutron absorbers that may be used in uranium fuel fabrication facilities include cadmium, boron, gadolinium and polyvinyl chloride (PVC) used in ‘spiders’ inside powder drums, plates in the storage areas for pellets or fuel assemblies and borosilicate glass rings (‘Raschig’ rings) in tanks for liquids. The effects of the inadvertent removal of the neutron absorbers should be considered in the analysis. Presence and effectiveness of absorbers should be verified on a periodic basis and before batching of containers or vessels relying on those absorbers. Absorber parameters include thickness, density and nuclide composition of both the absorber material and the hydrogenated material used to increase its absorption efficiency, if applicable.

POSTULATED INITIATING EVENTS

5.41. Paragraph 6.60 of SSR-4[1] states that “The list of internal and external hazards, including human induced hazards (see Requirements 15 and 16), shall be used to select initiating events for detailed further analysis.” Paragraphs 5.42–5.88 provide recommendations on foreseeable internal and external hazards for uranium fuel fabrication facilities.

Internal hazards

Fire and explosion

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

5.43. Fire in uranium fuel fabrication facilities might lead to the dispersion of radioactive material and/or toxic material by breaching the confinement barriers, or might cause a criticality accident by affecting the system or the parameters used for the control of criticality (e.g. the moderation control system or the dimensions of the processing equipment). Special consideration should be given to the firefighting media deployed, and their potential moderation effect. Fire extinguishing media and the safety of their use is required to be addressed with regard to criticality safety.

5.44. The fire hazards that are specifically encountered in a uranium fuel fabrication facility, such as hazards due to solvents and hydrocarbon diluents, hydrogen peroxide, anhydrous ammonia (which is explosive and flammable), sulphuric acid or nitric acid (which pose a danger of ignition by reaction with organic materials), zirconium (a combustible metal, especially in powder or chip forms) and hydrogen, should be given due consideration at the design stage for the facility. Specialized equipment to detect hydrogen fires, should be considered and the design of hydrogen piping should avoid joints prone for failures. For the purpose of suppressing metallic fires appropriate firefighting equipment should be considered.

Fire hazard analysis

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

- (a) Processes involving hydrogen, such as conversion, sintering and reduction of uranium oxide;
- (b) Processes involving zirconium in powder form or the mechanical treatment of zirconium metal;
- (c) Workshops such as the recycling shop and laboratories where flammable liquids and/or combustible liquids are used in processes such as solvent extraction;
- (d) The storage of reactive chemicals (e.g. ammonia, sulphuric acid, nitric acid, hydrogen peroxide, pore formers, lubricants);
- (e) Areas with high fire loads, such as waste storage areas;
- (f) Waste treatment areas;
- (g) Rooms housing safety related equipment, e.g. items such as air filtering systems, whose damage might lead to radiological consequences that are considered to be unacceptable;
- (h) Control rooms;
- (i) Impact of a fire on a solid UF₆ cylinder;
- (j) Vehicles such as UF₆ cylinder transporters and forklifts that use hydrocarbon fuel.

5.46. Fire hazard analysis for uranium fuel fabrication facilities should involve 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 should be used to assess the inventory of fuels and initiation sources, and to determine the appropriateness and adequacy of measures for fire protection. Computer modelling of fires may sometimes be used in support of the fire hazard analysis.

5.47. 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 may seem low, a fire might have significant consequences for safety and, as such, certain protective measures should be undertaken, such as delineating small fire areas, to prevent or curtail the fire from spreading.

5.48. 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

5.49. 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. Measures for mitigation should be put in place to minimize the consequences of a fire in the event that a fire breaks out despite preventive measures.

5.50. To accomplish the two-fold aim of fire prevention and mitigation, a number of general and specific measures should be taken, including the following:

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

(e) Suppression or limitation of the number of possible ignition sources such as open flames or electrical sparks.

5.51. Paragraph 6.79 of SSR-4 [1] establishes requirements for the analysis with regard to fire extinguishing systems. Fire extinguishing devices, automatic or manually operated, with adequate extinguishing agent, should be installed in zones where the outbreak of a fire is possible. In particular, the installation of automatic firefighting devices with water sprays should be carefully assessed for areas where uranium may be present, with account taken of the potential for criticality. Consideration should be given to the collection and treatment of the water used to extinguish fires.

5.52. A detection and/or suppression system should be installed that is commensurate with the risks from internal fires and explosions and is in compliance with national requirements.

5.53. The design of ventilation systems should be given particular consideration with regard to fire prevention. Dynamic containment systems comprise ventilation ducts and filter units which might constitute weak points in the fire protection system unless they are of suitable design. Fire dampers should be mounted in the ventilation system unless the likelihood of widespread fires is acceptably low. 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.

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

Explosions

5.55. An explosion can be induced by a 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.

5.56. In uranium fuel fabrication facilities, the possible sources of explosions include the following:

- (a) Gases (e.g. hydrogen used in the conversion process and sintering furnaces, heating gas, cracked ammonia gas containing a mixture of hydrogen and nitrogen);
- (b) Chemical compounds such as ammonium nitrate used in recycling workshops;
- (c) By-products such as red oil, which might be produced in the solvent extraction process.

5.57. For mitigating the risk of explosions, consideration should be given to the use of an inert gas atmosphere or dilution systems and to the ability of the components of the system to withstand explosions (e.g. explosions in sintering furnaces). Recycling systems should be regularly monitored to prevent the deposition of ammonium nitrate. In areas with potentially explosive atmospheres, the electrical network and equipment should be protected in accordance with national requirements.

Flooding

5.58. Flooding in a uranium fuel fabrication facility might lead to the dispersion of radioactive material and to changes in the conditions for neutron moderation. Flooding can potentially result in buoyancy induced failure of vessels, pipes and equipment causing a loss of confinement.

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

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

Leaks and spills

5.61. In addition to the loss of raw materials and its environmental impact, leaks from equipment and components such as pumps, valves and pipes can lead to the dispersion of radioactive material (e.g. UO_2 , triuranium octoxide (U_3O_8) powder, UF_6) and toxic chemicals (e.g. hydrogen fluoride), and to the unnecessary generation of waste. Leaks of hydrogenous fluids (e.g. water, oil) can alter the neutron moderation and/or reflection and thereby reduce criticality safety. Leaks of flammable gases (e.g. hydrogen, natural gas, propane) or liquids can lead to explosions and/or fires. Leak detection systems should be deployed where leaks could occur.

5.62. Vessels containing significant amounts of nuclear material, or hazardous chemicals, in liquid form should be equipped with level detectors and alarms to prevent overfilling and with secondary confinement features such as bunds or drip trays of appropriate capacity. For fissile material the configuration is required to ensure criticality safety: see para. 6.143 of SSR-4 [1].

5.63. Where it is possible for uranium powder to spill in quantities that could be significant from the standpoint of criticality safety, consideration should be given to installing design features to prevent water or moderator intrusion. Installation of humidity detectors and drainage systems should also be considered.

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 meet the requirements established in para. 6.89 of SSR-4 [1], an emergency back-up power supply should be provided at least for the following systems and components:

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

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

- (a) Loss of gas supply to gas controlled safety valves and dampers: In accordance with the safety analysis, valves should be used that are designed to fail to a safe position.
- (b) Loss of cooling or heating water: Adequate backup capacity or a redundant supply should be provided in the design.
- (c) Loss of breathing air: Backup capacity or a redundant supply should be provided to allow work in areas with airborne radioactive material to continue to be performed.

Processing errors

5.67. The loss of process media such as hydrogen, nitrogen or steam or any excess of these media might have consequences for safety. Examples of such events are:

- (a) Incomplete chemical reactions, potentially leading to a release of UF₆ into the off-gas treatment system;
- (b) Loss of leaktightness of equipment used for transporting uranium powder if a nitrogen flow is used for sealing;
- (c) Reduction of criticality safety due to loss of favourable geometry or loss of moderation control by excess of process gases;
- (d) Increase of levels of airborne contamination and/or concentration of hazardous material in the work areas of the facility because of overpressure in the equipment;
- (e) Reduction of oxygen concentration in breathing air in the work areas of the facility due to a release of large amounts of nitrogen.

5.68. The flow and pressure of process gases should be controlled continuously. In case of deviations in the flow or pressure, shutdown and/or lock up sequences should start automatically.

Facility failures and equipment failures

5.69. To meet Requirement 40 of SSR-4 [1], particular consideration should be given to the confinement of the highly corrosive HF (in vessels, pipes and pumps) and to powder transfer lines where abrasive powder will cause erosion.

5.70. The design should minimize the potential for mechanical impacts to containers of hazardous material caused by moving devices such as vehicles and cranes. Mechanical failures during the processing of nuclear material could result in damage to equipment (e.g. by crushing, bending or breakage) which might result in a degradation of criticality control, confinement or shielding. 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

5.71. 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.

5.72. To prevent failure of equipment containing hazardous materials (for example furnaces), effective programmes for maintenance, periodic testing and inspection should be established at the design stage (see also paras 5.137–5.139).

External hazards

General

5.73. A uranium fuel fabrication facility should be designed in accordance with the nature and severity of the external hazards, either natural or human induced, identified and evaluated in accordance with the provisions of SSR-1 [13] and Requirement 16 of SSR-4 [1]. Detailed recommendations on external hazards are provided in Safety Standards Series Nos SSG-9 (Rev. 1), Seismic Hazards in Site Evaluation for Nuclear Installations [17], SSG-18, Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations [18], SSG-21, Volcanic Hazards in Site Evaluation of Nuclear Installations [19], SSG-68, Design of Nuclear Installations Against External Events Excluding Earthquakes [20]. Recommendations for specific external hazards for a fuel fabrication facility are provided in paras 5.74–5.88.

Earthquakes

5.74. To ensure that the design of a uranium fuel fabrication facility provides the required degree of robustness, a detailed seismic assessment (see SSR-1 [13] and SSG-9 (Rev. 1) [17]) should be made

including the following seismically induced events:

- (a) Loss of support services, including utilities.
- (b) Loss of confinement functions (static and dynamic).
- (c) Loss of safety functions for ensuring the return of the facility to a safe state and maintaining the facility in a safe state after an earthquake, including structural functions and functions for the prevention of other hazards (e.g. fire, explosion, load drop, flooding).

The effect on criticality safety controls such as geometry, moderation, poisoning and reflection of the following:

- (i) Deformation (geometry control);
- (ii) Displacement (geometry control, fixed neutron absorbers, neutron interaction);
- (iii) Loss of material (geometry control, soluble neutron absorbers);
- (iv) Ingress of moderating material (moderation control).

5.75. Depending on the site characteristics and location of the uranium fuel fabrication facility, as evaluated in the site assessment (see Section 4), the effect of a tsunami induced by an earthquake and other extreme flooding events should be addressed in the facility design.

External fires and explosions and external toxic hazards

5.76. Hazards from external fires and explosions could arise from various sources in the vicinity of uranium fuel fabrication 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 conduct a survey of potentially hazardous installations and transport operations for hazardous material in the vicinity of the facility. In the case of explosions, risks should be assessed for compliance with overpressure criteria.

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

Extreme meteorological phenomena

5.79. A uranium fuel fabrication facility should be protected against extreme meteorological conditions as identified in the site evaluation (see Section 4) by means of appropriate design provisions. These should generally include the following:

- (a) The ability of structures important to safety to withstand extreme weather loads;
- (b) The prevention of flooding of the facility including adequate means to evacuate water from the roof in cases of extreme rainfall;
- (c) The safe shutdown of the facility in accordance with the operational limits and conditions.

Tornadoes

5.80. Measures for the protection of the facility against tornadoes will depend on the meteorological

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

5.81. 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 possible secondary fragments arising from collisions with and spallation from concrete walls or from other types of transfer of momentum.

Extreme temperatures

5.82. The potential duration of extreme low or high temperatures should be taken into account in the design of support system equipment to prevent unacceptable effects such as the freezing of cooling circuits or adverse effects on venting and cooling systems.

5.83. If safety limits for humidity and/or temperature are specified in a building or a compartment, the air conditioning system should be designed to perform efficiently also under extreme hot or wet weather conditions.

Snowfall and ice storms

5.84. The occurrence of snowfall and ice storms and their effects should be taken into account in the design of the facility and the safety analysis. Snow and ice are generally taken into account as an additional load on the roofs of buildings. The neutron reflecting effect or the interspersed moderation effect of the snow, if relevant, should be considered.

Flooding

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

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

Accidental aircraft crashes

5.87. In accordance with the risks identified in the site evaluation (see Section 4), uranium fuel fabrication facilities should be designed to withstand the design basis impact.

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

established.

INSTRUMENTATION AND CONTROL

5.89. Instrumentation should be provided to monitor the relevant parameters 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 operating procedures.

5.90. Instrumentation should be provided for measuring all the main parameters whose variation might 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 criticality safety related parameters, radiation 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).

5.91. Passive and active engineering controls are more reliable than administrative controls 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, which for a uranium fuel fabrication facility is generally the shutdown state.

5.92. Appropriate information should be made available to the operator for monitoring the effects of automatic actions. The layout of instrumentation and the manner of presentation of information should provide the operating personnel with an adequate picture of the status and performance of the facility. 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. Provision should be made for the automatic measurement and recording of values of parameters that are important to safety and where applicable, manual periodic testing should be used to complement automated continuous testing of conditions.

Control rooms and panels

5.93. Control rooms and human-machine interface panels should be provided to centralize the availability of information and monitoring of actions. The need for and the location of control rooms and panels in different areas should be evaluated taking into account occupational exposure, safety of personnel and emergency response. 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 might pose a direct threat to the operators and to the operation of control rooms. Ergonomic factors should be taken into account in the design of control rooms and the design of control room displays and systems.

Safety related instrumentation and control systems

5.94. Safety related instrumentation and control systems of a uranium fuel fabrication facility should include systems for the following:

(a) Criticality control and criticality detection and alarm:

- (i) Depending on the method of criticality control, the control parameters usually include mass, density, moisture content, isotopic composition, fissile content, moderation, poisoning,

- reflection of additives and spacing between items.
- (ii) Radiation detectors (gamma and/or neutron detectors) with audible and, where necessary, visible alarms for initiating immediate evacuation from the affected area, should cover all the areas where a significant quantity of fissile material is present: see para. 6.173 of SSR-4 [1].
- (b) Fire detection:
- (i) All rooms with fire loads or significant amounts of fissile and/or toxic chemical material should be equipped with fire alarms.
 - (ii) Gas detectors should be used in areas where a leakage of gases (e.g. hydrogen) could produce an explosive atmosphere.
- (c) Process control:
- (i) Parameters such as temperatures, pressures, flow rates, concentrations of chemicals and/or radioactive material, tank levels, cylinder weights should be monitored.
 - (ii) Before heating a UF₆ cylinder, the weight of UF₆ should be measured and should be confirmed to be below the fill limit (e.g. by using a second independent weighing scale).
 - (iii) If the system has the capability of reaching a temperature where hydraulic rupture can occur, the temperature during heating should be limited by means of two independent systems.
- (d) Monitoring and control of ventilation: Differential pressures across high efficiency particulate air (HEPA) filters, prefilters, enclosure exhausts and air flows into hot cells, gloveboxes and hoods should be measured and controlled.
- (e) Control of occupational radiation exposure.
- (i) Dosimeters with real time displays and/or alarms, especially in areas with inspection equipment such as X ray generators and radioactive sources (for monitoring external exposure) should be installed.
 - (ii) Continuous sampling of filters for retrospective measurement and/or real time measurement with alarms for the detection of releases of radioactive material (for monitoring internal exposure)) should be installed in areas where radioactive releases have the potential to occur.
- (f) Control of gaseous and liquid effluents.
- (i) Real time measurements should be provided if there is a risk of foreseeable potential for authorized limits being exceeded; otherwise retrospective measurements on continuously sampled filters or probes should be sufficient.
 - (ii) The installation and functionality of detection and alarm system for abnormal releases should be ensured.
- (g) Control of chemical releases. Real time detection and alarm systems should be used in the process areas and laboratories where UF₆ is present.

HUMAN FACTOR CONSIDERATIONS

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

5.96. Human factors in operation, inspection, periodic testing and maintenance should be considered at the design stage. Human factors to be considered for a uranium fuel fabrication facility should include the following:

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

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

- (a) Design of working conditions to ergonomic principles:
 - (i) The operator–process interface, for example, electronic control panels displaying all necessary information and no superfluous information.
 - (ii) The working environment, for example, good access to and adequate space around equipment and suitable finishes to surfaces for ease of cleaning.
- (b) Choice of location and clear labelling of equipment 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) Operating experience feedback relevant to human factors

SAFETY ANALYSIS

5.98. : Requirement 14 of GSR Part 4 (Rev. 1) [11] states that: **“The performance of a facility or activity in all operational states and, as necessary, in the post-operational phase be assessed in the safety analysis”**. The safety analysis for uranium fuel fabrication facilities should include the safety analysis of the variety of hazards for the whole facility and all activities.

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

Safety analysis for operational states

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

- (1) Calculations of the source term should use: (i) the material with the highest specific activity for a given isotopic composition; (ii) the licensed inventory of the facility; (iii) the maximum material throughput that can be processed by the facility. The poorest performances of barriers in normal operation should be used in the calculations. A best estimate methodology with the use of adequate margins may also be used.
- (2) Calculations of the estimated doses due to occupational exposure should be made on the basis of the conditions at the most exposed workplaces, should use maximum annual working times and should account for maintenance activities. 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. to the representative person) should be made on the basis of maximum estimated releases of radioactive material to the air and to water, maximum depositions to the ground, and direct exposure. Conservative models and parameters should be used to calculate the estimated doses to the public.

Safety analysis for accident conditions

Methods and assumptions for safety analysis for accident conditions

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

5.102. The consequences of design basis accidents for a uranium fuel fabrication facility could cause 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 or 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.

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

5.104. To demonstrate the protection of workers, public and the environment from accidents the following two approaches or an equivalent approach should be considered in the safety assessment of a uranium fuel fabrication facility:

- (1) The first approach involves the identification of structures, systems and components important to safety. It also involves demonstrating that these structures, systems and components can reduce the consequences and/or the likelihoods of potential accidents below the pre-established criteria.
- (2) The second approach starts with the selection of the limiting accident conditions, referred to as bounding or enveloping scenarios. It should be then demonstrated in a conservative way, with no account taken of any (active) structures, systems and components important to safety or administrative measures, that the consequences of these limiting accident conditions are within established facility independent acceptance criteria (see also Requirement 16 of GSR Part 4 [11]). This assessment is followed by an assessment of the possible accident sequences to identify provisions of design features and administrative measures, taking into account a graded approach in accordance with Requirement 11 of SSR-4 [1], to further reduce the consequences and/or the likelihoods of potential accidents and to provide information for the development of the emergency plans.

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

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

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

The potential occurrence of a criticality accident should be considered for uranium fuel fabrication facilities that process uranium with a ^{235}U enrichment of more than 1% as part of the safety analysis for accident conditions. Particular consideration should be given to the potential occurrence of a criticality accident for facilities handling and processing various feed products including reprocessed uranium.

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

Analysis of design extension conditions

5.108. The safety analysis should also identify design extension conditions and their progression and consequences should be analysed in accordance with Requirement 21 of SSR-4 [1]. The objective is to identify and analyse additional accident scenarios to be addressed in the design of a uranium fuel fabrication 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 are sufficient for the protection of the public, and sufficient time would be available to take such actions, and moreover, that the possibility of conditions arising that could lead to early releases of radioactive material or to large releases of radioactive material is practically eliminated (see para. 6.74 of SSR-4 [1]). Design extension conditions include events more severe than design basis accidents that could 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 the Appendix of SSR-4 [1] are required to be used including combinations of initiating events as well as events with additional failures. Accidents that have more severe consequences as well as 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.

5.109. 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.

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

5.111. Examples of design extension conditions that are applicable to uranium fuel fabrication facilities can be found in Ref. [21].

5.112. Analysis of design extension conditions should also demonstrate that the uranium fuel fabrication facility can be brought into the state where the confinement function and subcriticality can be maintained in the long-term.

Assessment of possible radiological or chemical consequences

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

(a) Analysis of the actual site conditions (e.g. meteorological, geological, hydrogeological site

conditions) and conditions expected in the future including internal and external initiating events with the potential for adverse effects.

- (b) Specification of facility design information and facility configurations, with the corresponding operating procedures and administrative controls for operations.
- (c) Identification of individuals and population groups (for facility personnel and members of the public) who could possibly be affected by radiation risks and/or associated chemical risks arising from the operation of the facility.
- (d) Identification and analysis of conditions at the facility, including internal and external initiating events that could lead to a release of material or energy with the potential for adverse effects, the time frame for emissions and the exposure time, in accordance with reasonable scenarios.
- (e) Quantification of the consequences for the individuals and population groups identified in the safety assessment.
- (f) Identification and specification of the structures, systems and components important to safety that may be credited to reduce the likelihood and/or 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 the accident conditions.
- (g) Characterization of the source term (e.g. material, mass, release rate, temperature).
- (h) Identification and analysis of pathways by which material that is released could be dispersed in the environment.
- (i) Considerations for the interfaces between safety and nuclear security.

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

5.115. 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.

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

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

EMERGENCY PREPAREDNESS AND RESPONSE

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

5.119. The operating organization of a facility is required to establish emergency arrangements that take into account the potential hazards at the facility (Requirement 47 and 72 of SSR-4 [1]). The emergency plan and the necessary equipment and provisions should be determined on the basis of selected scenarios for design extension conditions and beyond design basis accidents (or the equivalent). The conditions

under which an off-site emergency is required to be declared for a facility should include criticality accidents, widespread fires in the uranium powder area, and earthquakes.

MANAGEMENT OF RADIOACTIVE WASTE

5.120. The general requirements for optimization of protection and safety for waste and effluent management and the formulation of a waste strategy are established in IAEA Safety Standards Series No. GSR Part 5, Predisposal Management of Radioactive Waste [25] and recommendations are provided in IAEA Safety Standards Series Nos GSG-3, The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste [26], GSG-1, Classification of Radioactive Waste [27], SSG-41, Predisposal Management of Radioactive Waste from Nuclear Fuel Cycle Facilities [28]. Recommendations on aspects that are particularly relevant or specific to uranium fuel fabrication facilities are provided in paras 5.121–5.124.

5.121. In accordance with Requirement 24 of SSR-4 [1]) the generation of radioactive waste is required to be kept to the minimum practicable in terms of both activity and volume, by means of appropriate design measures. Recovery of nuclear material and reuse of chemicals should be applied to the extent practicable in uranium fuel fabrication facilities to minimize the generation of waste in both solid and liquid forms.

5.122. It is a good practice to reduce the volume and to minimize the reactivity of the radioactive waste in a waste treatment centre on the site. Some important elements of a waste treatment centre are the following:

- A dedicated workshop for waste treatment;
- Equipment for decontamination;
- The means for conditioning waste;
- Devices for measuring activity;
- A system for ensuring the identification and traceability of and record keeping for waste products;
- Sufficient capacity for storage of waste.

5.123. In the case of uranium fuel fabrication facilities, the nuclear material to be recovered is uranium both from scraps (i.e. products that are out of specification and that are not directly recycled in the fuel fabrication process) 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 be sought between the benefits of recovering useful material, the solid and liquid waste generated and the environmental impact.

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

MANAGEMENT OF GASEOUS AND LIQUID EFFLUENTS

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

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

5.127. Where necessary, equipment should be installed to reveal potential failure of treatment systems, such as differential pressure gauges to identify failed filters. If required by the safety analysis or the

relevant authorization, discharge monitoring should be provided via continuous sampling of the activity in the liquid or gas, coupled with continuous measurement of the discharge flow rate.

OTHER DESIGN CONSIDERATIONS

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

5.129. For specific process areas such as conversion areas and sintering furnaces, consideration should be given to the means by which the facility can be shut down safely in an emergency.

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

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

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

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

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

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

5.135. For cases where misidentification of containers could pose a hazard, provisions for easy identification of the content should be used, if possible (for example, use of unique colours, shapes, valves).

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

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

- (a) Transport routes and intersections within the facility;
- (b) Technical limits of the transport vehicles;
- (c) Handling failures during transport.

AGEING MANAGEMENT CONSIDERATIONS

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

5.139. 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.

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

6. CONSTRUCTION OF URANIUM FUEL FABRICATION FACILITIES

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

6.2. For uranium fuel fabrication 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 by the regulatory body to the construction site should be used to provide feedback of information to the construction contractor to prevent future operational problems.

6.4. Current good practices should be used for building construction and for the fabrication and installation of facility equipment.

6.5. Preferably, construction work should be completed before commissioning of the facility or its parts. In cases when the construction and commissioning stages or operational stages overlap, 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.

6.7. The effects of nearby activities handling corrosive substances should also be considered.

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

7. COMMISSIONING OF URANIUM FUEL FABRICATION FACILITIES

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

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

- 7.3. For a uranium fuel fabrication facility, the commissioning should be divided into two main stages:
- (1) Inactive or ‘cold’ commissioning (i.e. commissioning before the introduction of uranium into the facility). In this stage, the facility’s systems are systematically tested, both individual items of equipment and the systems in their entirety. As much verification and testing as possible should be performed because of the relative ease of taking corrective actions in this stage. However, given the low radiation levels in a uranium fuel fabrication facility, it would also be acceptable to conduct some of these activities in the subsequent phase. The operating organization should take the opportunity to finalize the set of operational documents and to train the personnel in the safety requirements, operating procedures (including those for maintenance) and emergency procedures. At the end of this stage, the operating organization should provide evidence of conformity of the facility to design requirements and safety requirements and operational readiness for active commissioning to the regulatory body
 - (2) Active or ‘hot’ commissioning (i.e. commissioning with the use of uranium). In this stage, the safety systems and measures for confinement and for radiation 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 sampling of surfaces; (iii) checks for aerial and liquid discharges; and (iv) checks for the unexpected accumulation of material. Testing in this second step should be performed with the use of natural or depleted uranium to prevent risks of criticality, to minimize occupational exposure and to reduce the possible need for decontamination.
- 7.4. During 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 stage.
- 7.5. During commissioning and later during operation of the facility, the estimated doses to personnel that were calculated should be compared with the actual doses or dose rates. If, in operation, the actual doses are higher than the calculated doses, corrective actions should be taken, including making any necessary changes to the licensing documentation (i.e. the safety analysis report) or adding or changing safety features or work practices.
- 7.6. To minimize the contamination of equipment during commissioning, process testing with uranium should be used where necessary to evaluate the performance of instruments for the detection of radiation or to evaluate the processes for the removal of uranium.
- 7.7. Sufficient operating personnel, suitably qualified and with the necessary training should be available at each stage of the commissioning.
- 7.8. Where possible, lessons identified from the commissioning and operation of similar uranium fuel fabrication facilities should be sought out and applied.

8. OPERATION OF URANIUM FUEL FABRICATION FACILITIES

ORGANIZATION OF OPERATION OF URANIUM FUEL FABRICATION FACILITIES

- 8.1. The distinctive features of a uranium fuel fabrication facility described in Section 2 should be taken into account in meeting the safety requirements for operation established in Section 9 of SSR-4 [1].
- 8.2. In a uranium fuel fabrication facility, many individual processes are performed with full automation, which helps to reduce human interaction with radioactive material. Because of this, more emphasis is placed on administrative measures, monitoring and preventive maintenance to ensure safe

operation.

8.3. The internal safety committee in a uranium fuel fabrication facility, in accordance with para. 4.29 of SSR-4 [1], should be created from the safety committee established for commissioning (see also paras 3.26).

STAFFING OF A URANIUM FUEL FABRICATION FACILITY

8.4. Requirement 56 of SSR-4 [1] states that: “[t]he operating organization shall ensure that the nuclear fuel cycle facility is staffed with competent managers and sufficient qualified personnel for the safe operation of the facility.”

8.5. Para. 9.16 of SSR-4 [1] states that: “[a] detailed programme for the operation and utilization of the nuclear fuel cycle facility shall be prepared in advance and shall be subject to the approval of senior management.”

The programme for the operation and utilization of a uranium fuel fabrication facility should be reviewed and updated periodically to ensure that it is consistent with and supports long term objectives.

8.6. The staffing should address the development of professional and managerial skills and experience, and take into account losses of personnel and their knowledge due to retirement and other reasons. The long term staffing plan should allow sufficient time for the transfer of responsibilities to new personnel, and thereby facilitate continuity in the conduct of duties.

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

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

- (a) Retaining a minimum number of qualified personnel on the site to ensure safe operation of the facility;
- (b) Ensuring that a minimum number of qualified back-up personnel remain available off the site;
- (c) Establishing additional measures to prevent the spread of an infection on the site, in accordance with national and international guidance (e.g. enabling remote working for non-essential personnel).

QUALIFICATION AND TRAINING OF PERSONNEL

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

8.10. The operating personnel of a uranium fuel fabrication facility should receive specific training in criticality safety and radiation safety and emphasis should be made on protection from radiation exposure and chemical hazards and the arrangements for emergency preparedness and response: see paras 9.41 and 9.125 of SSR-4 [1].

8.11. 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 as well as in operational safety including radiation protection personnel and nuclear criticality safety staff should be provided with a working knowledge of the security requirements of the facility and security experts should be provided with a working knowledge of the safety considerations of the facility, so that potential conflicts between safety and security can be resolved effectively.

OPERATIONAL DOCUMENTATION

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

8.13. Operating documents should be prepared that list all the operational limits and conditions under which the facility is operated. Annex III gives examples of parameters that can be used for defining the operational limits and conditions in the various processing areas of the facility.

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

- The maximum enrichment of uranium allowed at the facility;
- The specifications for UF₆ cylinders and the maximum inventory of UF₆ cylinders allowed in the storage area;
- The maximum allowed throughputs and inventories for the facility;
- Minimum staffing requirements and availability of specific expertise (nuclear criticality expert).

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

8.16. Operating procedures should be developed to control process operations directly. The procedures should include directions for attaining a safe state of the facility for all anticipated operational occurrences and accident conditions. In a uranium fuel fabrication facility, the safe operational state attained after any anticipated operational occurrence is often the shutdown state. Nevertheless, specific operating procedures should be used for the shutdown of certain equipment such as UF₆ vaporizers, rotary kilns for uranium dioxide and sintering furnaces. Procedures of this type should include the actions needed to ensure criticality safety, fire protection, emergency planning and environmental protection.

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

8.18. Procedures should be developed for planned outages of production needed for activities such as inventory checking, maintenance and other operational needs. These procedures should specify systems for ensuring fissile materials are returned to their safe locations. The duration of scheduled activities and relevant compensatory measures should be specified in the procedures.

MAINTENANCE, CALIBRATION AND PERIODIC TESTING AND INSPECTION

8.19. The safety requirements relating to maintenance, calibration, periodic testing and inspection of

conversion facilities and uranium enrichment facilities are established in Requirement 65 and paras 9.74–9.82 of SSR-4 [1].

8.20. Maintenance activities in a uranium fuel fabrication facility should be pre-authorized on the basis of a safety assessment.

8.21. Before maintenance is performed in areas where fissile material is located (or near such areas), criticality safety staff should be consulted (see also para. 5.46 of SSG-27 [2]).

8.22. Maintenance activities using radioactive sources or X-ray generators should be coordinated with radiation protection personnel especially when performed by sub-contractors.

8.23. When performing maintenance in a uranium fuel fabrication 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, ammonia, hydrogen and nitric acid.

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

- (a) 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, ensuring safe access);
- (b) Equipment isolation (e.g. disconnection of equipment from power supply, heat and pressure piping, venting and purging of equipment);
- (c) Testing and monitoring (e.g. checks before commencing work, monitoring during maintenance, checks for recommissioning);
- (d) Safety precautions for work (e.g. specification of safety precautions, ensuring the availability of fully functional personal protective equipment and ensuring its use, emergency response procedures);
- (e) Reinstallation of equipment (e.g. reassembly, reconnection of pipes and cables, testing, cleaning the job site, monitoring after recommissioning);
- (f) Verifying that after maintenance is performed the work area and equipment have been placed back within normal safe condition.

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

8.26. All temporary changes to the facility configuration during maintenance activities should be coordinated between safety and security specialists to avoid potential conflicts (e.g. loss of electrical power supply on some safety systems, opening of barriers and doors). Compensatory measures should be implemented as necessary.

8.27. The operating organization should have a system in place which ensures that the information and experience gained through maintenance activities are collected, recorded, analysed and utilized in the operating experience feedback programme.

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

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

calibrations and these inspections.

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

AGEING MANAGEMENT

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

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

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

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

- (a) Monitoring of deterioration;
- (b) Regular visual inspections of uranium powder pipes;
- (c) Monitoring of operating conditions (e.g. taking heat images of electrical cabinets, check of temperatures of ventilator bearings).

CONTROL OF MODIFICATIONS

8.34. Requirement 61 of SSR-4 [1] states that “[t]he operating organization shall establish and implement a programme for the control of modifications to the facility.” The management system for a uranium fuel fabrication facility should include a standard process for all modifications (see para. 3.19). The work control system, quality assurance procedures and appropriate testing procedures of the facility should be used for the implementation of modifications.

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

8.36. The operating organization should prepare procedural guidelines and provide training to ensure

that the responsible personnel have the necessary training and authority to ensure that modification projects are carefully considered: see paras 9.57(e) and 9.58 of SSR-4 [1]. The safety of modifications should be assessed for potential hazards during installation, commissioning and operation. Decision making relating to modifications should be conservative.

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

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

8.39. The modification 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, operating procedures). Procedures for the control of documentation should be put in place to ensure that documents are changed within a reasonable time period following the modification. Personnel should be informed and trained accordingly before operation commences.

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

8.41. Modifications performed on design, layout or procedures of the facility might adversely affect security equipment and vice versa. For example, malfunction of safety equipment might damage nearby security equipment. Therefore, in addition to the safety review, the interface of the proposed modifications with security should be evaluated before approval and implementation to verify that they do not compromise each other: see Requirement 75 of SSR-4 [1].

8.42. 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 unforeseen effects on the overall safety of the facility. This should be part of (or additional to) the periodic safety review or an equivalent review process.

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

CONTROL OF NUCLEAR CRITICALITY HAZARDS

8.44. The requirements for criticality safety in uranium fuel fabrication facilities are established in paras 9.83–9.86 of SSR-4 [1], and general recommendations are provided in SSG-27 [2]. In a uranium fuel fabrication facility, it is particularly important that the procedures for controlling criticality hazards are strictly applied.

8.45. Operational aspects of the control of criticality hazards in uranium fuel fabrication facilities should be taken into consideration, including the following:

- (a) Prevention of unexpected changes in conditions that could increase the probability of a criticality accident; for example, unplanned accumulation of uranium powder (e.g. in ventilation ducting),

inadvertent precipitation of material containing uranium in storage vessels or loss of neutron absorbers.

- (b) Management of moderating materials, particularly water; for example, decontamination of gloveboxes and ventilation hoods, or in laboratories, and leakages of oils from gear boxes or use of a water or CO₂ based firefighting system (e.g. automatic sprinklers).
- (c) Management of mass in transfer of uranium (procedures, mass measurement, systems and records) for which safe mass control is used.
- (d) Auxiliary activities such as sampling, homogenization and blending.
- (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.

8.46. The tools used for the purposes of nuclear material accounting and control, such as the instruments used to conduct measurements of mass, volume or isotopic composition and software used for these purposes, may also have application in the area of criticality safety. However, if there is any uncertainty about the characteristics of material containing uranium, conservative values should be used for parameters such as the level of enrichment and the density.

8.47. Criticality hazards might be encountered when performing maintenance work. The collection of waste and residues arising from decontamination activities should be considered in the criticality safety analysis.

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

RADIATION PROTECTION

8.49. The requirements for radiation protection in operation are established in paras 9.90-9.101 of SSR-4 [1] and in IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [15]; recommendations are provided in IAEA Safety Standards Series No. GSG-7, Occupational Radiation Protection [31]. The operating organization should have a policy to optimize protection and safety and is required to ensure doses are below national dose limits and within any dose constraints set by the operating organization (see para. 9.91 of SSR-4 [1]).

8.50. In a uranium fuel fabrication facility, the main radiological hazard for both the personnel and the public is from the inhalation of airborne material containing uranium compounds. In uranium fuel fabrication facilities, insoluble compounds of uranium such as uranium dioxide and triuranium octoxide pose a particular hazard because of their long biological half-lives (and therefore effective half-lives)⁴ and their typically relatively small particle size (typically a few micrometres in diameter) when encountered in uranium fuel fabrication facilities.

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

- (a) Estimation of the external exposure before the intervention.
- (b) Preparatory activities to minimize the doses due to occupational exposure, including:
 - (i) Identifying specifically the risks associated with the intervention;

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

- (ii) Specifying protective measures in the work permit for the intervention such as for the individual and collective means of protection (e.g. use of masks, clothing and gloves, time limitation).
- (c) Measurement of the occupational exposure during the intervention.
- (d) Implementation of feedback of information for identifying possible improvements.

8.52. 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 being discharged to the atmosphere.

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

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

- (a) Performance targets should be set for all parameters relating to internal exposure, e.g. levels of contamination.
- (b) Enclosures and ventilation systems should be routinely inspected, tested and maintained to ensure that they continue to fulfil their design requirements. Regular flow checks should be performed at ventilation hoods and entrances to confinement areas. Pressure drops across air filter banks should be checked and recorded regularly. Surveillance of the ventilation system should be conducted to detect any unwanted accumulation of fissile and radioactive material.
- (c) A high standard of housekeeping should be maintained at the facility. Cleaning techniques 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 performed to confirm the adequacy of cleaning programmes.
- (e) Contamination zones should be delineated and clearly indicated.
- (f) Continuous air monitoring should be performed to alert facility operators if levels of airborne radioactive material exceed predetermined action levels.
- (g) Mobile air samplers should be used where there are possible sources of contamination, as necessary.
- (h) An investigation should be conducted promptly in response to readings of high levels of airborne radioactive material.
- (i) Personnel and equipment should be checked for contamination and should undergo decontamination if necessary, before leaving contamination zones. Entry to and exit from the work area should be controlled to prevent the spread of contamination. In particular, changing rooms and decontamination facilities should be provided.
- (j) Temporary means of ventilation and means of confinement should be used when intrusive work increases the potential for causing contamination by airborne radioactive material (e.g. during periodic testing, inspection or maintenance).
- (k) Personal protective equipment (e.g. respirators, gloves, clothes) should be made available for dealing with releases of chemicals or radioactive material from the normal means of confinement in specific operational circumstances (e.g. during maintenance or the cleaning of process equipment before changing enrichment levels).
- (l) Personal protective equipment should be maintained in good condition, should be cleaned as necessary, and should be periodically inspected.
- (m) Any personnel having wounds should protect them with an impervious covering for work in contamination zones.

8.55. In vivo monitoring and biological sampling should be made available as necessary for monitoring doses due to occupational exposure.

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

8.57. For exposures which are expected to be low, 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 personnel occupancy data. This method should be assessed and should be reviewed as appropriate by the regulatory body.

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

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

8.60. The radiation doses due to internal exposure received by members of the public who live in the vicinity of the site should be regularly estimated by means of monitoring data on effluents.

8.61. There are limited areas in a uranium fuel fabrication facility where specific measures for controlling external exposure are required. Typically, these will be areas where uranium is stored in bulk. However, it should be noted that the processing of recycled uranium will necessitate much more extensive measures for controlling external exposure.

8.62. Radioactive sources and radiation generators are also used in a uranium fuel fabrication facility for specific purposes, for example:

- (a) Radioactive sources are used for checking uranium enrichment (e.g. ^{252}Cf for rod scanning);
- (b) Gamma rays are generated in the checking of uranium enrichment;
- (c) X-ray generators are used for inspecting fuel rods.

8.63. External exposure should be controlled by:

- (a) Ensuring that locations containing significant amounts of uranium are remote from areas of high occupancy;
- (b) Removing uranium from vessels adjacent to work areas in use for extended maintenance work;
- (c) Ensuring that radioactive sources are changed by suitably qualified and experienced persons;
- (d) Performing routine surveys of radiation dose rates.

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

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

INDUSTRIAL AND CHEMICAL SAFETY

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

8.67. The industrial and chemical hazards present in uranium fuel fabrication facilities may be summarized as follows:

- (a) Chemical hazards due to the presence of hydrogen fluoride (e.g. from uranium hexafluoride), ammonia, nitric acid, sulphuric acid, potassium hydroxide, sodium hydroxide and uranium compounds.
- (b) Chemical hazards due to the presence of UF₆, hydrogen fluoride (including produced through hydrolysis of UF₆ in contact with air moisture), fluorine, nitric acid, ammonia and uranium compounds;
- (c) Explosion hazards due to hydrogen, ammonium nitrate, ammonia, methanol and solvents and liquefied petroleum gas (LPG);
- (d) Asphyxiation hazards due to the presence of nitrogen or carbon dioxide.

8.68. The exposure of workers to chemical hazards should be assessed using a method similar to that for the assessment of radiation doses and should be based upon the collection of data from air sampling in the workplace, in combination with personnel occupancy data. This method should be assessed and reviewed as appropriate by the regulatory body. The acceptable levels of occupational exposure for various chemical hazards in a fuel fabrication facility can be found in Ref. [22].

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

8.70. Fire hazard analyses should be conducted periodically to incorporate changes that might adversely affect the potential for and spread of fires (see para. 5.46). Specific fire protection equipment to handle metal fires should be present.

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

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

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

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

MANAGEMENT OF RADIOACTIVE WASTE AND EFFLUENTS

8.75. 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].

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

8.77. Chemicals should be recovered and reused where possible. This is particularly important for hydrofluoric acid. Care should be taken to ensure that hydrofluoric acid is suitable for reuse.

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

EMERGENCY PREPAREDNESS AND RESPONSE

8.79. The requirements for emergency preparedness and response are established in Requirement 72 and paras. 9.120–9.132 of SSR-4 [1] and in GSR Part 7 [23], and recommendations are provided in GS-G-2.1 [22] and in IAEA Safety Standards Series No. GSG-2, Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency [32]. The conditions for declaration of an off-site emergency at a uranium fuel fabrication facility may include large releases of UF₆, and also depending on national requirements and facility specific considerations, criticality accidents, large fires or explosions.

8.80. For a uranium fuel fabrication facility, special consideration should be given to the use of water sprays for dealing with the release of hazardous chemicals such as ammonia or hydrofluoric acid.

8.81. The emergency preparedness arrangements should address how and when an interface with local and national emergency response organizations should be established. These arrangements should be tested periodically to ensure effective operation during an emergency. Clear communication and authorization protocols should be established with local authorities to ensure that the emergency response organization can respond effectively to an emergency at the facility.

8.82. The operating organization should ensure availability of personnel with specific expertise on the type of hazard present in facility as well as availability of specific environmental sampling equipment to support local authorities in appropriate decision making relating to an emergency at the facility.

8.83. Emergency plans and contingency plans should be developed in a coordinated manner, considering all responsibilities of the facility personnel and security forces, to ensure that in the case of an event when simultaneous response of both groups is needed, all crucial functions can be performed in a timely manner. Emergency response plans should consider nuclear security events as possible initiators of an emergency and their implications on emergency situations and should 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. These strategies should also include the roles and actions of security forces and emergency response personnel. The response to such events should be jointly exercised and evaluated by security forces and emergency response personnel. From these exercises or evaluations, lessons should be identified, and recommendations should be made to improve the overall response to a potential event.

8.84. For establishing access control procedures for an emergency, when there is a necessity for rapid

access and egress of personnel, safety specialists and security specialists should cooperate closely. Both safety objectives and security objectives should be met in an emergency, in accordance with regulatory requirements. When this is not possible, the best solution that takes into account both objectives should be pursued.

FEEDBACK OF OPERATING EXPERIENCE

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

8.86. The programme for the feedback of operating experience at uranium fuel fabrication facilities should cover experience and lessons identified from events and accidents at the facility as well as from other nuclear fuel cycle facilities worldwide and other relevant non-nuclear accidents. It should also include evaluation of trends in operational disturbances, trends in malfunctions, near misses and other incidents that have occurred at uranium fuel fabrication facilities and, as far as applicable, at other nuclear installations. The programme should include consideration of technical, organizational and human factors. Useful information on the causes and consequences of many of the most important anomalies and accidents that have been observed in uranium fuel fabrication facilities and other nuclear fuel cycle facilities is provided in Ref. [29].

9. PREPARATION FOR DECOMMISSIONING OF URANIUM FUEL FABRICATION FACILITIES

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

9.2. The decommissioning of uranium fuel fabrication facilities is less difficult than that for other fuel cycle facilities because of the low specific activity of the LEU that is processed in the operational lifetime of such facilities. Consequently, the vast majority of the solid radioactive waste arising from the facility will be low and intermediate level waste or exempt waste.

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

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

- (a) A post-operational cleanout should be performed to remove all bulk amounts of uranium and other hazardous materials.
- (b) 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.
- (c) Risk assessments and method statements for the licensing of the decommissioning process should be prepared.

9.5. The decommissioning plan for uranium fuel fabrication facilities should be developed following

the recommendations provided in SSG-47 [34]. Specific consideration should be given to the following elements:

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

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

- (a) The (updated) decommissioning plan is realistic and can be implemented 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) storage capacities and disposal considering its transport and processing.

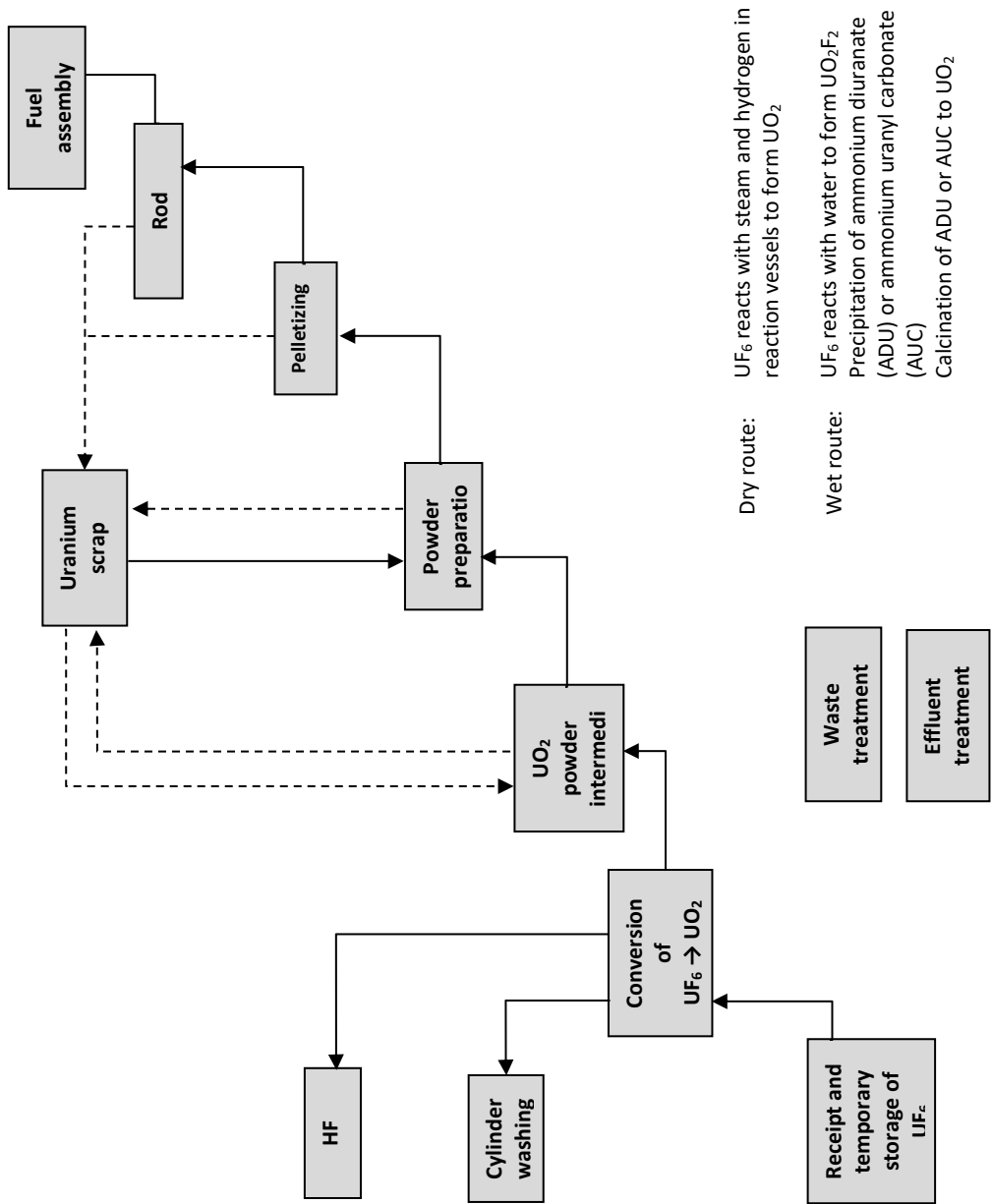
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ANNEX I TYPICAL PROCESS ROUTES IN A URANIUM FUEL FABRICATION FACILITY



ANNEX II
EXAMPLES OF STRUCTURES, SYSTEMS AND COMPONENTS IMPORTANT TO
SAFETY AND POSSIBLE CHALLENGES TO SAFETY FUNCTIONS FOR
URANIUM FUEL FABRICATION FACILITIES

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
Receipt and temporary storage of UF ₆ cylinders	Means of transport	Rupture of cylinder	(2)
	Device for measuring enrichment of ²³⁵ U	Processing of uranium beyond safety limits	(1)
	Cylinder weighing scale	Rupture of cylinder	(1), (2)
	Shielding	Increase in dose rate	(3)
Conversion area	Vaporization furnace	Rupture of cylinder	(1), (2)
	Cylinder leak detection device	Release of uranium or HF	(1), (2)
	Heating device Cylinder high temperature detection device	Rupture of cylinder	(1), (2)
	Reaction vessel and rotary kiln	Release of uranium, HF and process gases; Degradation of criticality margin (moderation, geometry)	(1), (2)
	Kiln low temperature detection device	Water condensation in the kiln	(1)
	H ₂ pipe work H ₂ detection device	Explosion	(2)
	Measurement device to determine the humidity of the powder	Degradation of criticality safety margin (moderation)	(1)
	Tanks for HF	Release of HF	(2)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged
	Facilities for treatment of off-gases	Release of HF to the environment	(2)
Intermediate storage of uranium oxide powder	Powder containers	Release of uranium Degradation of criticality safety margin (neutron absorber)	(1), (2), (3)
	Scales	Degradation of criticality safety margin (mass)	(1)
	Shelves	Release of uranium Degradation of criticality safety margin (geometry)	(1), (2)
	Shielding	Increase in dose rate	(3)
Powder preparation	Storage areas, blenders, granulators, pipes	Release of uranium Bulging of vessel	(2), (3) (1)
	Device to control the amount of additives	Degradation of criticality safety margin (moisture)	(1)
	High moisture detection device in uranium powder hoppers	Degradation of criticality safety margin (moisture)	(1)
Pelleting shop	Presses	Release of uranium	(2), (3)
	Sintering furnaces	Explosion	(2)
	H ₂ pipe work	Explosion	(2)
	H ₂ detection device		
	Grinding machines	Release of uranium	(2), (3)
	Sludge recovery from wet grinding	Degradation of criticality safety margin (geometry, moderation, mass)	(1)
	Pellet storage	Release of uranium	(2), (3)
		Degradation of criticality safety margin (geometry, neutron absorber)	(1)
Laboratory	Press, sintering furnace, grinding machine	See other process areas above	(1), (2)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged
	Storage shielding	Increase in dose rate	(3)
Fuel rod manufacturing	Rod loader	Release of uranium	(2)
	Welding machines	Release of uranium Fire due to zirconium particles	(2)
	Rod scanner	External exposure	(3)
	Fuel rod storage	Degradation of criticality safety margin (geometry, neutron absorber, moderation, moisture)	(1)
	Storage shielding	Increase in dose rate	(3)
Fuel assembly manufacturing	Assembling lines	Degradation of criticality safety margin (geometry, neutron absorber) Fire due to zirconium particles	(1) (2)
	Cranes	Dropped assembly	(1), (2)
	Washing facilities	Degradation of criticality safety margin (geometry, neutron absorber)	(1)
	Fuel assembly storage	Degradation of criticality safety margin (geometry, moisture)	(1), (3)
	Storage shielding	Increase in dose rate	(3)
Uranium scrap recovery	Furnaces, vessels, pipes	Release of uranium Degradation of criticality safety margin (geometry, mass) Explosion (H ₂ , chemicals) Fire	(1), (2)
Radioactive waste treatment	Treatment facilities	Release of uranium Release of chemicals Fire	(1), (2)

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged
	Devices for measuring uranium content	Degradation of criticality safety margin (mass)	(1)
	Radioactive waste storage	Fire	(1), (2)
Building	Areas for nuclear and chemical activities	Loss of confinement	(2)
Ventilation system	Fan and filters for input air	Fire	(2)
	Ventilation control system	Uncontrolled release of uranium	(2)
	Filters inside the process areas	Fire Degradation of criticality safety margin (mass)	(1), (2)
	Ducts for air and process gas	Degradation of criticality safety margin (mass)	(1)
	Final filter stage for exhaust air	Fire	(2)
	Fan for exhaust air, stack	Uncontrolled release of uranium	(2)
	Measurement devices for radioactivity in exhaust air	Uncontrolled release of uranium	(2), (3)
Treatment and release of water	Tank	Uncontrolled release of uranium	(1), (2)
	Treatment facilities	Uncontrolled release of uranium	(2)
	Measurement devices for radioactivity in water	Uncontrolled release of uranium	(1), (2)
Cylinder washing	Shielding	Increase in dose rate	(3)
Power supply system	Emergency power supply system	Release of uranium under loss of ventilation due to loss of electric power	(2)

ANNEX III
EXAMPLES OF PARAMETERS FOR DEFINING OPERATIONAL LIMITS AND
CONDITIONS FOR URANIUM FUEL FABRICATION FACILITIES

Process area (including storage areas)	Parameters for defining operational limits and conditions
Area for receipt and temporary storage of UF ₆ cylinders	Level of moderation Enrichment Mass UF ₆ composition Surface contamination
Building	Leaktightness
Conversion area	Level of moderation Pressure in process equipment Temperature in process equipment Composition of the process gas HF content in the process off-gas Uranium content in by-products Surface contamination of process equipment
Intermediate storage of uranium oxide powder	Level of moderation Mass in buckets Mass of absorber in drums Geometry of shelves Surface contamination of process equipment
Powder preparation	Relative humidity in the process area Geometry of slab hopper Integrity of powder lines and powder containers Amount of the additives (moderator) Level of moderation Mass in buckets Mass of absorber in drums Humidity of powder
Pelleting shop	Humidity of powder Mass in buckets Mass of absorber in drums Geometry of shelves Height of green pellets in sintering boats Temperature of sintering furnace Composition of atmosphere in sintering furnace Height of pellet tray stacks Geometry of shelves Surface contamination of radioactive sources and process equipment

Process area (including storage areas)	Parameters for defining operational limits and conditions
Laboratory	Mass of uranium Uranium content in waste Levels of surface contamination of radioactive sources and process equipment
Manufacturing and storage area for fuel rods	Height of pellet tray stacks Geometry of shelves Contamination of rods Geometry of rod transfer Geometry of rod cases Levels of surface contamination of radioactive sources
Manufacturing and storage area for fuel assemblies	Position of neutron absorbers Geometry of storage
Uranium scrap recovery	Geometry of vessels Mass of uranium Uranium content in waste
Treatment of radioactive waste	Mass of uranium Uranium content in waste
Ventilation system	Stages of pressure in the building Mass of uranium (e.g. in prefiltering filters) Vacuum in the sampling lines Uranium content in exhaust air
Treatment and release of water	Uranium concentration Uranium content in released water

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