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IAEA Safety Standards

for protecting people and the environment

Safety of Conversion Facilities and Uranium Enrichment Facilities

Specific Safety Guide

No. SSG-5

IAEA

International Atomic Energy Agency

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SAFETY OF
CONVERSION FACILITIES AND
URANIUM ENRICHMENT FACILITIES

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

IAEA SAFETY STANDARDS SERIES No. SSG-5

SAFETY OF CONVERSION FACILITIES AND URANIUM ENRICHMENT FACILITIES

SPECIFIC SAFETY GUIDE

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FOREWORD

The IAEA's Statute authorizes the Agency to establish safety standards to protect health and minimize danger to life and property — standards which the IAEA must use in its own operations, and which a State can apply by means of its regulatory provisions for nuclear and radiation safety. A comprehensive body of safety standards under regular review, together with the IAEA's assistance in their application, has become a key element in a global safety regime.

In the mid-1990s, a major overhaul of the IAEA's safety standards programme was initiated, with a revised oversight committee structure and a systematic approach to updating the entire corpus of standards. The new standards that have resulted are of a high calibre and reflect best practices in Member States. With the assistance of the Commission on Safety Standards, the IAEA is working to promote the global acceptance and use of its safety standards.

Safety standards are only effective, however, if they are properly applied in practice. The IAEA's safety services — which range in scope from engineering safety, operational safety, and radiation, transport and waste safety to regulatory matters and safety culture in organizations — assist Member States in applying the standards and appraise their effectiveness. These safety services enable valuable insights to be shared and I continue to urge all Member States to make use of them.

Regulating nuclear and radiation safety is a national responsibility, and many Member States have decided to adopt the IAEA's safety standards for use in their national regulations. For the contracting parties to the various international safety conventions, IAEA standards provide a consistent, reliable means of ensuring the effective fulfilment of obligations under the conventions. The standards are also applied by designers, manufacturers and operators around the world to enhance nuclear and radiation safety in power generation, medicine, industry, agriculture, research and education.

The IAEA takes seriously the enduring challenge for users and regulators everywhere: that of ensuring a high level of safety in the use of nuclear materials and radiation sources around the world. Their continuing utilization for the benefit of humankind must be managed in a safe manner, and the IAEA safety standards are designed to facilitate the achievement of that goal.

THE IAEA SAFETY STANDARDS

BACKGROUND

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

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

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

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

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

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

THE IAEA SAFETY STANDARDS

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

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

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

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

Safety Fundamentals

Safety Fundamentals present the fundamental safety objective and principles of protection and safety, and provide the basis for the safety requirements.

Safety Requirements

An integrated and consistent set of Safety Requirements establishes the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements are governed by the objective and principles of the Safety Fundamentals. If the requirements are not met, measures must be taken to reach or restore the required level of safety. The format and style of the requirements facilitate their use for the establishment, in a harmonized manner, of a national regulatory framework. The safety requirements use ‘shall’ statements together with statements of

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

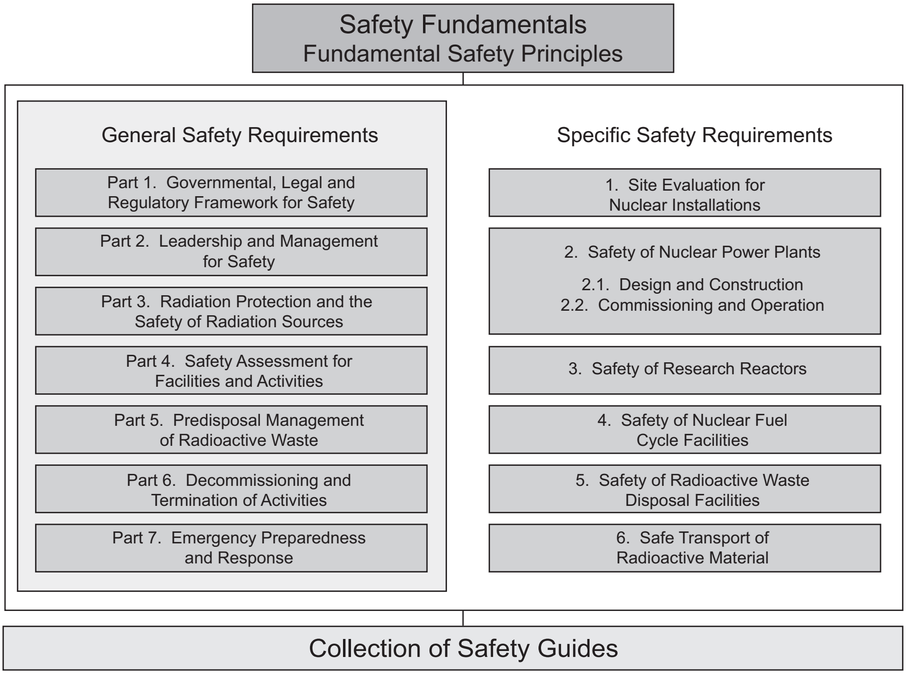


FIG. 1. The long term structure of the IAEA Safety Standards Series.

associated conditions to be met. Many requirements are not addressed to a specific party, the implication being that the appropriate parties are responsible for fulfilling them.

Safety Guides

Safety Guides provide recommendations and guidance on how to comply with the safety requirements, indicating an international consensus that it is necessary to take the measures recommended (or equivalent alternative measures). The Safety Guides present international good practices, and increasingly they reflect best practices, to help users striving to achieve high levels of safety. The recommendations provided in Safety Guides are expressed as 'should' statements.

APPLICATION OF THE IAEA SAFETY STANDARDS

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

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

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

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

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

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

DEVELOPMENT PROCESS FOR THE IAEA SAFETY STANDARDS

The preparation and review of the safety standards involves the IAEA Secretariat and four safety standards committees, for nuclear safety (NUSSC), radiation safety (RASSC), the safety of radioactive waste (WASSC) and the safe transport of radioactive material (TRANSSC), and a Commission on Safety Standards (CSS) which oversees the IAEA safety standards programme (see Fig. 2).

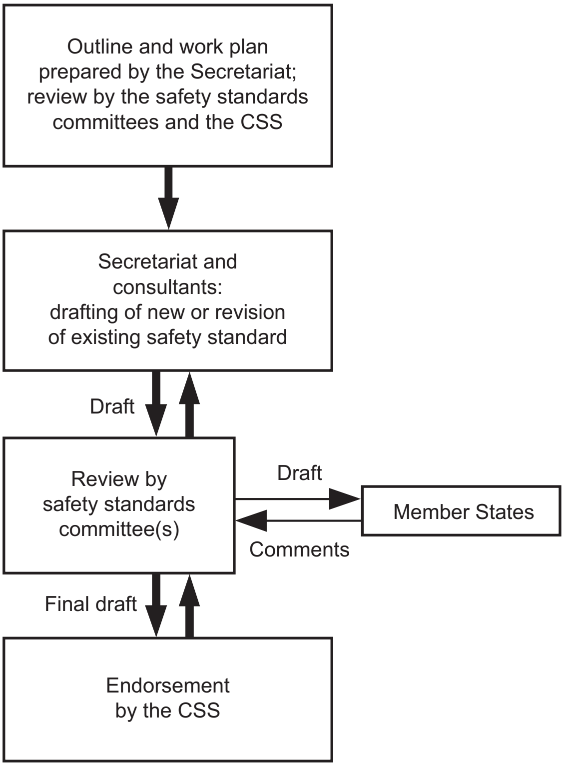


FIG. 2. The process for developing a new safety standard or revising an existing standard.

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

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

INTERACTION WITH OTHER INTERNATIONAL ORGANIZATIONS

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

INTERPRETATION OF THE TEXT

Safety related terms are to be understood as defined in the IAEA Safety Glossary (see http://www-ns.iaea.org/standards/safety-glossary.htm). Otherwise, words are used with the spellings and meanings assigned to them in the latest edition of The Concise Oxford Dictionary. For Safety Guides, the English version of the text is the authoritative version.

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

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

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

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. This Safety Guide on the Safety of Conversion Facilities and Uranium Enrichment Facilities makes recommendations on how to meet the requirements established in the Safety Requirements publication on the Safety of Nuclear Fuel Cycle Facilities [1], and supplements and elaborates on those requirements.

1.2. The safety of conversion facilities and uranium enrichment facilities is ensured by means of their proper siting, design, construction, commissioning, operation including management, and decommissioning. This Safety Guide addresses all these stages in the lifetime of a conversion facility or an enrichment facility, with emphasis placed on design and operation.

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

OBJECTIVE

1.4. The objective of this Safety Guide is to provide recommendations that, in the light of experience in States and the present state of technology, should be followed to ensure safety for all stages in the lifetime of a conversion facility or a uranium enrichment facility. These recommendations specify actions, conditions or procedures necessary for meeting the requirements established in Ref. [1]. This Safety Guide is intended to be of use to designers, operating organizations and regulators for ensuring the safety of conversion facilities and enrichment facilities.

SCOPE

1.5. The safety requirements applicable to fuel cycle facilities (i.e. facilities for uranium ore processing and refining, conversion, enrichment, fabrication of fuel including mixed oxide fuel, storage and reprocessing of spent fuel, associated conditioning and storage of waste, and facilities for the related research and development) are established in Ref. [1]. The requirements applicable specifically to conversion facilities and enrichment facilities are established in Appendix III of Ref. [1]. This Safety Guide provides recommendations on meeting the requirements established in Sections 5–10 and in Appendix III of Ref. [1].

1.6. This Safety Guide deals specifically with the handling, processing and storage of depleted, natural and low enriched uranium (LEU) that has a ^{235}U concentration of no more than 6%, which could be derived from natural, high enriched, depleted or reprocessed uranium. In conversion facilities for the conversion of uranium concentrate to UF_6, several different conversion processes are currently used throughout the world on a large industrial scale. At present enrichment facilities use either the gaseous diffusion process or the gas centrifuge process.

1.7. The implementation of other safety requirements, such as those on the legal and governmental framework and regulatory supervision (e.g. requirements for the authorization process, regulatory inspection and regulatory enforcement) as established in Ref. [2] and those on the management system and the verification of safety (e.g. requirements for the management system and for safety culture) as established in Ref. [3], is not addressed in this Safety Guide. Recommendations on meeting the requirements for the management system and for the verification of safety are provided in Ref. [4].

1.8. Sections 3–8 of this publication provide recommendations on radiation protection measures for meeting the safety requirements established in the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (Ref. [5]). The recommendations in the present Safety Guide supplement the recommendations on occupational radiation protection provided in Ref. [6].

1.9. The typical process routes of conversion facilities and enrichment facilities are shown in schematic diagrams in Annexes I and II (see also Ref. [7]).

STRUCTURE

1.10. This Safety Guide consists of eight sections and four annexes. Section 2 provides the general safety recommendations for a conversion facility or an enrichment facility. Section 3 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 4 deals with safety in the design stage; it provides recommendations on safety analysis for operational states and accident conditions and discusses the safety aspects of radioactive waste management in the conversion facility or enrichment facility and other design considerations. Section 5 addresses the safety aspects in the construction stage. Section 6 discusses safety considerations in commissioning. Section 7 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 planning and preparedness. Section 8 provides recommendations on meeting the safety requirements for the decommissioning of a conversion facility or an enrichment facility. Annexes I and II show the typical process routes for a conversion facility and an enrichment facility. Annexes III and IV provide examples of structures, systems and components important to safety and operational limits and conditions grouped in accordance with process areas, for conversion facilities and enrichment facilities, respectively.

2. GENERAL SAFETY RECOMMENDATIONS

2.1. In conversion facilities and enrichment facilities, large amounts of uranium compounds are present in a dispersible form:

- In conversion facilities, uranium exists in diverse chemical and physical forms and is used in conjunction with flammable or chemically reactive substances as part of the process.
- In enrichment facilities, most of the uranium is in the chemical form UF_6. The physical form of UF_6 could be the gaseous, liquid or solid state.

2.2. In conversion facilities and enrichment facilities, the main hazards are HF and UF_6. In addition, where uranium is processed that has a ^{235}U concentration of more than 1%, criticality may be a significant hazard. Workers, the public and the environment must be protected from these hazards during commissioning, operation and decommissioning.

2.3. Generally, in a conversion facility or an enrichment facility, only natural uranium or LEU that has a ^{235}U concentration of no more than 6% is processed. The radiotoxicity of this uranium is low, and any potential off-site radiological consequences following an accident would be expected to be limited. However, the radiological consequences of an accidental release of reprocessed uranium would be likely to be greater, and this should be taken into account in the safety assessment if the licence held by the facility permits the processing of reprocessed uranium.

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

2.5. Conversion facilities and enrichment facilities do not pose a potential radiation hazard with the capacity to cause an accident with a significant off-site release of radioactive material (in amounts equivalent to a release to the atmosphere of ^{131}I with an activity of the order of thousands of terabecquerels). However, deviations in processes may develop rapidly into dangerous situations involving hazardous chemicals.

2.6. For the application of the requirement that the concept of defence in depth be applied at the facility (see Section 2 of Ref. [1]), the first two levels of defence in depth are the most important, as risks can be reduced to insignificant levels by means of design and appropriate operating procedures (see Sections 4 and 7).

3. SITE EVALUATION

3.1. The site evaluation process for a conversion facility or an enrichment facility will depend on a large number of criteria, some of which are more important than others. At the earliest stage of planning a facility, a list of these criteria should be prepared and considered in accordance with their safety significance. In most cases, it is unlikely that all the desirable criteria can be met, and the risks posed by possible safety significant external initiating events (e.g. earthquakes, aircraft crashes, fires and extreme weather conditions) will probably dominate in the site evaluation process. These risks should be compensated for by means of adequate design provisions and constraints on processes and operations as well as possible economic arrangements.

3.2. The density of population in the vicinity of a conversion facility or an enrichment facility and the direction of the prevailing wind at the site should be considered in the site evaluation process to minimize any possible health consequences for people in the event of a release of hazardous chemicals.

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

4. DESIGN

GENERAL

Safety functions for conversion facilities and enrichment facilities

4.1. Safety functions (see Ref. [1], Appendix III, para. III.1), i.e. the functions the loss of which may lead to releases of radioactive material or chemical releases having possible radiological consequences for workers, the public or the environment, are those designed for:

(1) Prevention of criticality;
(2) Confinement for the prevention of releases that might lead to internal exposure and for the prevention of chemical releases;
(3) Protection against external exposure.

4.2. For conversion facilities:

— The main hazard is the potential release of chemicals, especially HF and UF_6. Controls to address this hazard will adequately protect also against internal radiation exposure.
— A criticality hazard exists only if the conversion facility processes uranium with a ^{235}U concentration greater than 1%.
— External exposure is a concern for the handling of residues containing thorium and its daughter products produced in fluorination reactors. External exposure is also a concern in the handling of recently emptied cylinders, especially those used as containers for reprocessed uranium, where there is a buildup of ^{232}U.

4.3. For enrichment facilities:

— The main hazard is a potential release of UF_6;
— A criticality hazard exists since the concentration of ^{235}U present in enrichment facilities is greater than 1%;
— External exposure is a concern in the handling of recently emptied cylinders, especially those used as containers for reprocessed uranium, with buildup of ^{232}U.

Specific engineering design requirements

4.4. The following requirements apply:

(1) The requirements on prevention of criticality are established in paras 6.43–6.51 and III.3–III.7 of Appendix III of Ref. [1];
(2) The requirements on confinement for the prevention of releases that might lead to internal exposure and chemical hazards are established in paras 6.37–6.39, 6.54–6.55 and paras III.8 and III.9 of Appendix III of Ref. [1];
(3) The requirements on protection against external exposure are established in paras 6.40–6.42 of Ref. [1]. Shielding should be considered for processes or areas that could involve sources of high levels of external gamma radiation, such as reprocessed uranium or newly emptied cylinders (e.g. exposure to daughter products of ^{232}U and ^{238}U).

Design basis accidents and safety analysis

4.5. The definition of a design basis accident in the context of fuel cycle facilities can be found in para. III-10 of Annex III of Ref. [1]. The safety requirements relating to design basis accidents are established in paras 6.4–6.9 of Ref. [1].

Conversion facilities

4.6. The specification of a design basis accident (or equivalent) will depend on the facility design and national criteria. However, particular consideration should be given to the following hazards in the specification of design basis accidents for conversion facilities:

(a) A release of HF or ammonia (NH_3) due to the rupture of a storage tank;
(b) A release of UF_6 due to the rupture of a storage tank, piping or a hot cylinder;
(c) A large fire originating from H_2 or solvents;
(d) An explosion of a reduction furnace (release of H_2);
(e) Natural phenomena such as earthquakes, flooding or tornadoes[1];
(f) An aircraft crash;
(g) Nuclear criticality accidents, e.g. in a wet process area with a ^{235}U content of more than 1% (reprocessed uranium or unirradiated LEU).

4.7. The first four types of events ((a)–(d)) are of major safety significance as they might result in chemical and radiological consequences for on-site workers and may also result in some adverse off-site consequences for people or the environment. The last type of accident on the list would generally be expected to result in few or no off-site consequences unless the facility is very close to occupied areas.

4.8. The hazards listed in para. 4.6 may occur as a consequence of a postulated initiating event (PIE). Selected PIEs are listed in Annex I of Ref. [1].

4.9. The potential occurrence of a criticality accident should be considered for facilities that process uranium with a ^{235}U concentration of more than 1%. Particular consideration should be given to the potential occurrence of a

[1] For some facilities of older design, natural phenomena were not given consideration. These phenomena should be taken into account for the design of new conversion and enrichment facilities.

criticality accident for facilities treating various feed products including reprocessed uranium.

Enrichment facilities

4.10. The specification of a design basis accident (or equivalent) will depend on the facility design and national criteria. However, particular consideration should be given to the following hazards in the specification of design basis accidents for enrichment facilities:

(a) The rupture of an overfilled cylinder during heating (input area);
(b) The rupture of a cylinder containing liquid UF_6 or the rupture of piping containing liquid UF_6 (depending on the facility design for product take-off);
(c) A large fire, especially for diffusion facilities;
(d) Natural phenomena such as earthquakes, flooding or tornadoes (see footnote 1);
(e) An aircraft crash;
(f) A nuclear criticality accident.

4.11. These hazards would result primarily in radiological consequences for on-site workers, but might also result in some adverse off-site consequences for people or the environment. The last type of hazard on the list would generally be expected to result in few or no off-site consequences unless the facility is very close to populated areas.

4.12. The hazards listed in para. 4.10 may occur as a consequence of a PIE. Selected PIEs are listed in Annex I of Ref. [1].

Structures, systems and components important to safety

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

SAFETY FUNCTIONS

Prevention of criticality

4.14. “For the prevention of criticality by means of design, the double contingency principle shall be the preferred approach” (Ref. [1], para 6.45). Paragraph III.5 of Appendix III of Ref. [1] establishes requirements for the control of system parameters for the prevention of criticality in conversion facilities and enrichment facilities. Some examples of the parameters subject to control are listed in the following:

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

4.15. Paragraph III.4 of Appendix III of Ref. [1] requires that preference be given to achieving criticality safety by design rather than by means of administrative measures. As an example, to the extent practicable, vessels which could contain fissile material should be made geometrically safe.

4.16. Several methods can be used to perform the criticality 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. Calculations should be suitably verified and validated and performed under a quality management system.

4.17. The aim of the criticality analysis is to demonstrate that the design of equipment is such that the values of controlled parameters are always maintained in the subcritical range. This is generally achieved by determining the effective multiplication factor (k_{eff}), which depends on the mass, the distribution and the nuclear properties of uranium and all other materials with which it is associated.

The calculated value of k_{eff} is then compared with the value specified by the design limit.

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

— The use of a conservative approach (with account taken of uncertainties in physical parameters and of the physical possibility of worst case moderation conditions);
— The use of appropriate and qualified computer codes that are validated within their applicable range and of appropriate data libraries of nuclear reaction cross-sections.

4.19. The following are recommendations for conducting a criticality analysis for a conversion facility or an enrichment facility to meet the safety requirements established in para. III.6 of Appendix III of Ref. [1]:

— *Mass.* The mass margin should be 100% of the maximum value attained in normal operation (to compensate for possible ‘double batching’, i.e. the transfer of two batches of fissile material instead of one batch in a fuel fabrication process) or equal to the maximum physical mass that could be present in the equipment.
— *Geometry of processing equipment.* “The potential for changes in dimensions during operation shall be considered” (e.g. bulging of slab tanks or slab hoppers).
— *Neutron interaction.* Preference should be given to engineered spacing over spacing achieved by administrative means.
— *Moderation*. Hydrogenous substances (e.g. water and oil) are common moderators that are present in conversion facilities and enrichment facilities or that may be present in accident conditions (e.g. water from firefighting); the subcriticality of a UF_6 cylinder should rely only on moderation control.
— *Reflection.* Full water reflection should be assumed in the criticality analysis unless it is demonstrated that the worst case conditions relating to neutron reflection (e.g. by human beings, organic materials, wood, concrete, steel of the container) result in a lower degree of reflection. The degree of reflection in interacting arrays should be carefully considered since the assumption of full water reflection may provide a degree of neutronic isolation from interacting items. Moderation control should ensure criticality safety for an individual UF_6 cylinder or an array of UF_6 cylinders for any conditions of reflection.

— *Neutron absorbers.* "When taken into account in the safety analysis, and if there is a risk of degradation, the presence and the integrity of neutron absorbers shall be verifiable during periodic testing. Uncertainties in absorber parameters shall be considered in the criticality calculations." The neutron absorbers that may be used in conversion facilities and enrichment facilities include cadmium, gadolinium or boron in annular storage vessels or transfer vessels for liquids. Absorber parameters include thickness, density and isotopic concentration.

Confinement to protect against internal exposure and chemical hazards

4.20. As far as possible, the following parameters should be minimized:

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

4.21. Conversion facilities and enrichment facilities should be designed to minimize, to the extent practicable, contamination of the facility and releases of radioactive material to the environment, and to facilitate decontamination and eventual decommissioning. Especially in the working areas where liquid UF_6 is processed, two static barriers should be installed. Particular consideration should also be given to minimizing the use of flexible hoses and to ensuring their maintenance and periodic checking.

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

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

Protection of workers

4.24. 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. Conversion facilities and enrichment facilities should be designed with appropriately sized ventilation and containment systems in areas of the facility identified as having potential for giving rise to significant concentrations of airborne radioactive material and other hazardous material. Wherever possible, the layout of ventilation equipment should be such that the flow of air is from the operation gallery towards the equipment.

4.25. The need for the use of protective respiratory equipment should be minimized through careful design of the containment and ventilation systems. For example, a glovebox, hood or special device should be used to ensure the continuity of the first containment barrier when changing a valve to remove the need for respiratory protection.

4.26. In areas that may contain airborne uranium in particulate form, primary filters should be located as close to the source of contamination as practicable unless it can be shown that the design of the ventilation ducts and the air velocity are sufficient to prevent unwanted deposition of uranium powder in the ducts. Multiple filters in series should be used to avoid reliance on a single filter. In addition, duty and standby filters and/or fans should be provided to ensure the continuous functioning of ventilation systems. If this is not the case, it should be ensured that failure of the duty fan or filter will result in the safe shutdown of equipment in the affected area.

4.27. Monitoring equipment such as differential pressure gauges (on filters, between rooms or between a glovebox and the room in which it is located) and devices for measuring uranium or gas concentrations in ventilation systems should be installed as necessary. Alarm systems should be installed to alert operators to fan failure or high or low differential pressures. At the design stage, provision should also be made for the installation of equipment for monitoring airborne radioactive material and/or gas monitoring equipment. Monitoring points should be chosen that would correspond most accurately to the exposure of workers and would minimize the time for detection of any leakage (see para. 6.39 of Ref. [1]).

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

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

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

Protection of the environment

4.31. The uncontrolled dispersion of radioactive or chemical substances to the environment as a result of an accident can occur if all the containment barriers are impaired. Barriers may comprise the process equipment itself, or the room or building structure. The number of physical barriers for containment should be adapted to the safety significance of the hazard. The minimum number of barriers is two, in accordance with the principle of redundancy (see para. II-1 of Annex II of Ref. [1]). The optimum number of barriers is often three. In addition, ventilation of the containment systems, by the discharge of exhaust gases through a stack via gas cleaning mechanisms such as wet scrubbers in conversion facilities, or cold traps and dry chemical absorbers in enrichment facilities, reduces the normal environmental discharges of radioactive or chemical (mainly HF) material to very low levels. In such cases, the ventilation system may also be regarded as a containment barrier. The design should also provide for the monitoring of the environment around the facility and the identification of breaches to the containment barriers.

Protection against external exposure

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

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

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

POSTULATED INITIATING EVENTS

Internal initiating events

Fire and explosion

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

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

4.37. For gaseous diffusion enrichment facilities, fire prevention and mitigation should be given due consideration for the use and storage of lubricating oils or oxidants like ClF_3.

Fire hazard analysis

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

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

(2) For gaseous diffusion enrichment facilities:
   - (a) Areas with high fire loads, such as areas containing lubricating oil tanks and vessels containing degreasing or decontamination solvents;
   - (b) The storage areas for reactive chemicals (e.g. ClF_3, F_2);
   - (c) Diesel storage tanks;
   - (d) Transformers and rooms housing battery chargers;
   - (e) Areas storing combustible waste prior to its conditioning;
   - (f) Control rooms.

(3) For gas centrifuge enrichment facilities:
   - (a) Diesel storage tanks;
   - (b) Transformers and rooms housing battery chargers;
   - (c) The storage of solvents (e.g. methylene chloride CH_2Cl_2);
   - (d) Areas storing combustible waste prior to its conditioning;
   - (e) Control rooms.

4.39. Fire hazard analysis involves identification of the causes of fires, assessment of the potential consequences of a fire and, where appropriate, estimation of the frequency or probability of occurrence of fires. It is used to assess the inventory of fuels and initiation sources, and to determine the appropriateness and adequacy of measures for fire protection. Computer modelling of fires may sometimes be used in support of the fire hazard analysis.

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

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

Fire prevention, detection and mitigation

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

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

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

4.44. Fire extinguishing devices, automatic or manually operated, with adequate extinguishing agent, should be installed in the areas where the outbreak of a fire is possible (see Ref. [1], Appendix III, para. III.10). In particular, “the installation of automatic firefighting devices with water sprays shall be assessed with care for areas where UF_6 is present, with account taken of the potential risk of HF generation and criticality events for enriched material” (Ref. [1], Appendix III, para. III.11). Consideration should be given to minimizing the environmental impact of the water used to extinguish fires.

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

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

Explosions

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

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

(a) Gases (in conversion facilities: e.g. H_2 or NH_3 used in the reduction process; in enrichment facilities: chemical oxidants such as F_2, ClF_3 or UF_6). Design provisions should be implemented to prevent an explosive mixture of the above chemical oxidants and of hydrocarbons or halo-hydrocarbons. Where the prevention of such an explosive mixture cannot be ensured, consideration should be given to the use of an inert gas atmosphere or dilution systems.

(b) Solid chemical compounds (in conversion facilities only: ammonium nitrate when in a high temperature environment);
(c) Monitoring of possible deposits should be implemented to prevent any accumulation of ammonium nitrate.

Flooding

4.49. Flooding in a conversion facility or an enrichment facility may lead to the dispersion of radioactive material if the radioactive material were not kept in a confined state (e.g. yellow cake, ammonium diuranate (ADU) in conversion). For UF_6, which is always kept in a confined state, flooding would only result in a release of hazardous materials if there were a simultaneous loss of confinement.

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

4.51. 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.

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

Leaks and spills

4.53. Leaks from containment systems such as vessels, cylinders, pumps, valves and pipes can lead to the dispersion of radioactive material (e.g. uranium solutions and powders, gaseous or liquid UF_6) and toxic chemicals (e.g. HF, F_2, NH_3, ClF_3) and to the unnecessary generation of waste. Leaks of hydrogenous fluids (water, oil, etc.) can adversely affect criticality safety. Leaks of flammable gases (e.g. H_2) or liquids can lead to explosions and/or fires. Leak detection systems should be deployed where leaks could occur.

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

4.55. 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 support systems

4.56. To fulfil the requirement established in para. 6.28 of Ref. [1], an emergency power supply should be provided for:

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

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

— For the centrifuge process, a backup electrical power system should be provided for the removal of the UF_6 from the cascade and its transfer to UF_6 cylinders or chemical absorber traps.
— For the diffusion process, the inherent heat is sufficient to keep the UF_6 in its gaseous form for several days in the process equipment. However, solidification of the UF_6 may start beyond this period. A first potential safety issue involves the heating of solidified UF_6 for sublimation within the process equipment and piping, which may lead to local liquefaction of the UF_6 and a subsequent loss of confinement. A second potential safety issue is that a large quantity of solid enriched uranium could accumulate in an unsafe geometry such that a loss of moderation control could cause a criticality event.

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

4.59. The loss of general supplies such as gas for instrumentation and control, cooling water for process equipment and ventilation systems, heating water, breathing air and compressed air may have also some consequences for safety. For example:

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

Loss or excess of process media

4.60. The following list gives examples of hazards to be considered during the safety assessment as defined in para. 6.29 of Ref. [1]:

— Incomplete chemical reactions in conversion facilities may lead to a release of hazardous chemicals.
— Overpressure in the equipment may cause an increase of the levels of airborne radioactive material and/or concentration of hazardous material in the working areas of the facility.
— Excess of F_2 in the fluorination process in conversion facilities may result in its release.
— Releases of large amounts of nitrogen may result in a reduction of the oxygen concentration in breathing air in the work areas of the facility.
— Loss of steam or hot water supply may result in the solidification of UF_6 in the piping and equipment in a diffusion facility.
— Failure of the air supply may result in the failure of safety related air operated valves.

Mechanical failure

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

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

4.63. 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.

External initiating events

Earthquakes

4.64. A conversion facility or enrichment facility should be designed for the design basis earthquake to ensure that the ground motion during an earthquake at the site would not induce a loss of confinement capability (especially for confinement of UF_6 and HF) or a criticality accident (i.e. a seismically induced loss of criticality safety functions, such as geometry and moderation) with possible significant consequences for site personnel or members of the public.

4.65. To define the design basis earthquake for the facility, the main characteristics of the disturbance (intensity, magnitude and focal distance) and the distinctive geological features of the local ground should be determined. The approach should ideally evaluate the seismological factors on the basis of historical data for the site. Where historical data are inadequate or yield large uncertainties, an attempt should be made to gather palaeoseismic data to enable the determination of the most intense earthquake affecting the site to have occurred over the period of historical record. The different approaches can be combined since the regulatory body generally takes into account the results of scenarios based on historical data and those based on palaeoseismic data in the approval of the design.

4.66. One means of specifying the design basis earthquake is to consider the historically most intense earthquake, but increased in intensity and magnitude, for the purpose of obtaining the design response spectrum (the relationship between frequencies and ground accelerations) used in designing the facility. Another way of specifying the design basis earthquake is to perform a geological review, to determine the existence of capable faults and to estimate the ground motion that such faults might cause at the location of the facility.

4.67. An adequately conservative spectrum should be used for calculating the structural response to guarantee the stability of buildings and to ensure the integrity of the ultimate means of confinement in the event of an earthquake.

Certain structures, systems and components important to safety will require seismic qualification. This will apply mainly to equipment used for storage and vessels that will contain significant amounts of fissile or toxic chemical materials. Design calculations for the buildings and equipment should be made to verify that, in the event of an earthquake, no unacceptable release of fissile or toxic material to the environment would occur and the risk of a criticality accident would be very low.

External fires and explosions

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

4.69. To demonstrate that the risks associated with such external hazards are below acceptable levels, the operating organization should first identify all potential sources of hazards and then estimate the associated event sequences affecting the facility. The radiological or associated chemical consequences of any damage should be evaluated and it should be verified that they are within acceptance criteria. Toxic hazards should be assessed to verify that specific gas concentrations meet the acceptance criteria. It should be ensured that external toxic hazards would not adversely affect the control of the facility. The operating organization should carry out a survey of potentially hazardous installations and transport operations for hazardous material in the vicinity of the facility. In the case of explosions, risks should be assessed for compliance with overpressure criteria. To evaluate the possible effects of flammable liquids falling objects (such as chimneys) and missiles resulting from explosions, their distance from the facility and hence their potential to cause physical damage should be assessed.

Extreme weather conditions

4.70. Typically, extreme weather conditions assumed in the design and in the evaluation of the response of a conversion facility or an enrichment facility are wind loading, tornadoes, tsunamis, extreme rainfall, extreme snowfall, extreme temperatures and flooding.

4.71. The general approach is to use a deterministic design basis value for the extreme weather condition and to assess the effects of such an event on the safety of the facility. The rules for obtaining the design basis values for use in the assessment may be specified by local regulations.

4.72. The design provisions will vary according to the type of hazard and its effects on the safety of the facility. For example extreme wind loading is associated with rapid structural loading and thus design provisions for an event involving extreme wind loading should be the same as those for other events with potentially rapid structural loading such as earthquakes. However, effects of extreme precipitation or extreme temperatures would take time to develop and hence there would be time for operational actions to be taken to limit the consequences of such events.

4.73. A conversion facility or an enrichment facility should be protected against extreme weather conditions by means of appropriate design provisions. These should generally include:

- — The ability of structures important to safety to withstand extreme weather loads;
- — The prevention of flooding of the facility;
- — The guarantee of safe state for the facility in accordance with the operational limits and conditions.

Tornadoes

4.74. Measures for the protection of the facility against tornadoes will depend on the meteorological conditions for the area in which the facility is located. The design of buildings and ventilation systems should be in compliance with specific regulations relating to hazards from tornadoes.

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

Extreme temperatures

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

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

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

Snowfall

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

Floods

4.79. Flooding should be taken into account in the design of a facility. Two approaches to dealing with flooding hazards have been put forward:

— In some States the highest flood levels recorded over the period of historical record are taken into account and nuclear facilities are sited at specific locations or at a sufficient elevation to avoid major damage.
— In other States, in which the use of dams is widespread and where a dam has been built upstream of a potential or existing site for a nuclear facility, the hazard posed by a breach of the dam is taken into account. The buildings of the facility are designed to withstand the water wave released from the breach. In such cases the equipment — especially that used for the storage of fissile material — should be designed to prevent any criticality accident.

Accidental aircraft crash hazards

4.80. The likelihood and possible consequences of impacts onto a facility should be calculated by assessing the number of aircraft that come close to the facility and their flight paths, and by evaluating the areas vulnerable to impact, i.e. areas where hazardous material is processed or stored. If the risk is acceptably low, no further evaluations are necessary. See also para. 5.5 (item (h)) of Ref. [1].

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

INSTRUMENTATION AND CONTROL (I&C)

Instrumentation

4.82. Instrumentation should be provided to monitor the variables and systems of the facility over their respective ranges for: (1) normal operation; (2) anticipated operational occurrences; and (3) design basis accidents, to ensure that adequate information can be obtained on the status of the facility and proper actions can be undertaken in accordance with the operating procedures or in support of automatic systems.

4.83. Instrumentation should be provided for measuring all the main variables whose variation may affect the processes, for monitoring for safety purposes general conditions at the facility (such as radiation doses due to internal and external exposure, releases of effluents and ventilation conditions), and for obtaining any other information about the facility necessary for its reliable and safe operation. Provision should be made for the automatic measurement and recording of values of parameters that are important to safety.

Control systems

4.84. Passive and active engineering controls are more reliable than administrative control and should be preferred for control in normal operational states and in accident conditions. Automatic systems should be designed to maintain process parameters within the operational limits and conditions or to bring the process to a safe state.

4.85. Appropriate information should be made available to the operator for monitoring the effects of automatic actions. The layout of instrumentation and the manner of presentation of information should provide the operating personnel with an adequate impression of the status and performance of the facility. Devices should be installed that provide in an efficient manner visual and, as appropriate, audible indications of operational states that have deviated from normal conditions and that could affect safety.

Control rooms

4.86. Control rooms should be provided to centralize the main data displays, controls and alarms for general conditions at the facility. Occupational exposure should be minimized by locating the control rooms in parts of the facility where the levels of radiation are low. For specific processes, it may be useful to have dedicated control rooms to allow the remote monitoring of operations, thereby reducing exposures and risks to operators. Particular consideration should be paid to identifying those events, both internal and external to the control rooms, that may pose a direct threat to the operators and to the operation of control rooms. Ergonomic factors should be taken into account in the design of control rooms.

Safety related I&C systems for normal operation

4.87. Safety related I&C systems for normal operation of a conversion facility or an enrichment facility should include:

(1) Instrumentation and control relating to the process, e.g. indicating temperatures, pressures, flow rates, concentrations of chemicals and/or radioactive material, tank levels, cylinder weights.
    The corresponding requirements are established in paras III.13 and III.14 of Appendix III of Ref. [1]. In filling UF_6 cylinders, the weight should be monitored by appropriate and reliable devices to ensure that the fill limit is not exceeded.
(2) I&C relating to criticality safety.
    For enrichment facilities, in-line devices for enrichment measurement should be used to monitor the enrichment levels of products. For diffusion enrichment facilities, the ratio of hydrogen to uranium should be monitored by an in-line analyser (e.g. an HF infrared analyser).
(3) I&C relating to the chemical purity of UF_6 (for diffusion enrichment facilities).
    The corresponding requirement is established in para. III.15 of Appendix III of Ref. [1].
(4) I&C relating to ventilation, i.e. mainly devices for measuring differential pressures across high efficiency particulate air (HEPA) filters and airflows.

(5) I&C relating to gaseous and liquid effluents.
Real time measurements should be provided if there is a risk of exceeding regulatory limits; otherwise, retrospective measurements on continuously sampled filters and/or probes will generally be sufficient.
(6) I&C relating to the prevention of explosive mixtures.
Real time measurements, controls and alarms are necessary if there is a risk of exceeding regulatory and safety limits, e.g. devices for measuring the concentration of O_2 in the reduction kiln in conversion facilities.

Safety related I&C systems for anticipated operational occurrences

4.88. In addition to the listing provided in para. 4.87, I&C systems for use in anticipated operational occurrences should include the following provisions:

(1) All rooms with both fire loads *and* significant amounts of fissile and/or toxic chemical material should be equipped with fire alarms (except where the permanent presence of operators is sufficient).
(2) Gas detectors should be used in areas where a leakage of gases (e.g. H_2) could produce an explosive atmosphere.
(3) Real time detection and alarm systems should be used in the process areas and/or laboratories where HF and UF_6 above atmospheric pressure is present.
(4) The devices used for monitoring releases of gaseous and liquid effluents in operational states should also be capable of measuring releases during anticipated operational occurrences. If the amounts released are significant, the recommendation presented in item (3) of para. 4.89 should be followed.

Safety related I&C systems for design basis accident conditions

4.89. I&C systems relating to design basis accidents should, in addition to the previous listings, include provisions to address the following situations:

(1) Criticality.
The requirement on I&C systems relating to criticality control is established in para. III.16 of Appendix III of Ref. [1].
(2) Chemical release.
The requirement on I&C systems relating to monitoring for chemical releases is established in para. III.17 of Appendix III of Ref. [1].

(3) Release of effluents.
The devices used for measuring releases of gaseous and liquid effluents in operational states should also be capable of measuring such releases in the case of a design basis accident. If the measurement devices used in operational states become saturated in accident conditions, resulting in unmonitored releases of effluents, environment sampling should be used to estimate the releases of gaseous and liquid effluents.

HUMAN FACTOR CONSIDERATIONS

4.90. The requirements relating to human factor considerations are established in paras 6.15 and 6.16 of Ref. [1].

4.91. Human factors in operation, inspection, periodic testing, and maintenance should be considered at the design stage. Human factors to be considered include:

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

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

(a) Design of working conditions to ergonomic principles.
  — The operator–process interface, e.g. electronic control panels displaying all the necessary information and no more;
  — The working environment, e.g. good accessibility of and adequate space around equipment and suitable finishes to surfaces for ease of cleaning.
(b) Choice of location and clear labelling of equipment so as to facilitate maintenance, testing, cleaning and replacement;
(c) Provision of fail-safe equipment and automatic control systems for accident sequences for which reliable and rapid protection is required;
(d) Good task design and job organization, particularly during maintenance work, when automated control systems may be disabled;
(e) Minimization of the need to use additional means of personal radiation protection.

SAFETY ANALYSIS

4.93. Safety analysis for conversion facilities and enrichment facilities should be performed in two major steps:

— The assessment of occupational exposure and public exposure for operational states of the facility and comparison with authorized limits for operational states;
— Determination of the radiological and associated chemical consequences of design basis accidents (or the equivalent) for the public and verification that they are within the acceptable limits specified for accident conditions.

4.94. The results of these two steps should be reviewed for identification of the possible need for additional operational limits and conditions.

Safety analysis for operational states

Occupational exposure and exposure of the public

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

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

Releases of hazardous chemical material

4.96. Facility specific, realistic, robust (i.e. conservative) estimations of chemical hazards to workers and releases of hazardous chemicals to the environment should be performed in accordance with the standards applied in the chemical industry.

Safety analysis for accident conditions

Methods and assumptions for safety analysis for accident conditions

4.97. For conversion facilities and enrichment facilities, there is no general agreement on the best approach to the safety analysis for design basis accidents and the associated acceptance criteria. However, there is a tendency for the following or similar criteria to be adopted for new advanced facility designs.

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

4.99. To estimate the on-site and off-site consequences of an accident, the wide range of physical processes that could lead to a release of radioactive material to the environment should be modelled in the accident analysis and the enveloping cases encompassing the worst consequences should be determined.

4.100. The following approaches should be considered in the assessment:

(1) An approach using the enveloping case (the worst case approach, e.g. the release of liquid UF_6 from a cylinder filled to the maximum fill limit), with account taken only of those safety features that mitigate the consequences of accidents and/or that reduce their likelihood. If necessary, a more realistic case can be considered that includes the use of some safety features and some non-safety-related features beyond their originally intended range of functions to reduce the consequences of accidents (the best estimate approach).

(2) The worst case approach, with no account taken of any safety feature that may reduce the consequences or the likelihood of accidents. This assessment is followed by a review of the possible accident sequences, with account taken of the emergency procedures and the means planned for mitigating the consequences of the accident.

Assessment of possible radiological or associated chemical consequences

4.101. Safety assessment should address the consequences associated with possible accidents. The main steps in the development and analysis of accident scenarios should include:

(a) Analysis of actual site conditions and conditions expected in the future.
(b) Identification of workers and members of the public who could possibly be affected by accidents; i.e. a 'critical group' of people living in the vicinity of the facility.
(c) Specification of facility configurations, with the corresponding operating procedures and administrative controls for operations.
(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) Specification of the structures, systems and components important to safety that may be credited to reduce the likelihood and to mitigate the consequences of accidents. The structures, systems and components important to safety that are credited in the safety assessment should be qualified to perform their functions in accident conditions.
(f) Characterization of the source term (material, mass, release rate, temperature, etc.).
(g) Identification and analysis of intra-facility transport pathways for material that is released.
(h) Identification and analysis of pathways by which material that is released could be dispersed in the environment.
(i) Quantification of the consequences for the individuals identified in the safety assessment.

4.102. Analysis of the actual conditions at the site and the conditions expected in the future involves a review of the meteorological, geological and hydrological conditions at the site that may influence facility operations or may play a part in transporting material or transferring energy that is released from the facility (see Section 5 of Ref. [1]).

4.103. Environmental transport of material should be calculated with qualified codes or 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.

4.104. The identification of workers and members of the public (the critical group of maximally exposed off-site individuals) who may potentially be affected by an accident involves a review of descriptions of the facility and of demographic information.

MANAGEMENT OF RADIOACTIVE WASTE

4.105. Conversion facilities and enrichment facilities should be designed to minimize the generation of waste both in operation and in decommissioning. For economic and environmental reasons, the recovery of uranium and the reuse of chemicals are common practices in conversion facilities and enrichment facilities. These practices minimize the generation of waste in both solid and liquid forms [8, 9].

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

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

MANAGEMENT OF GASEOUS AND LIQUID RELEASES

4.108. Liquid effluents to be discharged to the environment should be suitably treated to reduce the discharges of radioactive material and hazardous chemicals.

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

OTHER DESIGN CONSIDERATIONS

4.110. In the design of the facility and equipment, including the selection of materials, the need to limit the accumulation of uranium and the ease of cleaning and/or surface decontamination should be taken into account at an early stage.

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

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

Design of the storage area for UF_6 cylinders

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

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

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

4.116. A large aircraft crash on the storage area for UF_6 cylinders is generally not considered as a design basis accident. In accordance with specific site considerations, engineered provisions such as drainage or rafts may minimize the potential of a significant pool fire.

5. CONSTRUCTION

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

5.2. The extent of regulatory involvement in construction should be commensurate with the hazards posed by the facility over its lifetime. In addition to the process by which the operating organization maintains control over construction, frequent visits to the construction site should be used to provide feedback of information to the construction contractor to avoid future operational problems.

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

5.4. The construction and commissioning phases may overlap. Construction work in an environment in which nuclear material is present owing to commissioning can be significantly more difficult and time consuming than when no radioactive material is present.

6. COMMISSIONING

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

(1) Inactive or 'cold' commissioning (i.e. commissioning prior to the introduction of uranium into the facility).

In this phase, the facility's systems are systematically tested, from both individual items of equipment and the systems in their entirety. As much verification and testing as possible should be carried out because of the relative ease of taking corrective actions in this phase. However, given the low radiation levels in a conversion facility or an enrichment facility, it would also be acceptable to carry out some of these activities in the subsequent phase.

The operating organization should also take the opportunity to finalize the set of operational documents.

(2) Active or 'hot' commissioning (i.e. commissioning with the use of uranium).

In this phase, the safety systems and measures for confinement and for radiation and chemical protection should be tested. Testing in this phase should consist of: (i) checks for airborne radioactive material and checks of levels of exposure at the workplace; (ii) smear checks on surfaces; (iii) checks for gaseous discharges and releases of liquids; and (iv) checks for the unexpected accumulation of material.

Testing in this second step should be carried out with the use of natural or depleted uranium to prevent risks of criticality, to minimize occupational exposure and to reduce the possible need for decontamination.

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

6.3. The verification process, defined in para. 8.4 of Ref. [1], should be completed prior to the operation stage. The operating organization should use the commissioning stage to become familiar with the facility. The facility management should use the commissioning stage to develop a strong safety culture and good behavioural attitudes throughout the entire organization.

6.4. During commissioning and later during operation of the facility, the estimated doses to workers 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 case) or adding or changing safety features or work practices.

7. OPERATION

CHARACTERISTICS OF CONVERSION FACILITIES AND ENRICHMENT FACILITIES

7.1. The distinctive features of a conversion facility or an enrichment facility that should be taken into account in meeting the safety requirements established in Ref. [1] are:

- — The relatively low radiotoxicity of the radioactive material but with the potential for chemical and toxicological impacts on workers, the public and the environment, mainly due to: (1) large amounts of UF_6 at pressures above atmospheric pressure; (2) reaction products (UO_2F_2, HF) associated with liquid UF_6 operations; and (3) storage and handling of large amounts of solid uranium compounds.
- — The potential for fire and explosions resulting in a release of radioactive material (e.g. an H_2 explosion in a reduction furnace in a conversion facility or a lubrication oil fire in a gaseous diffusion facility).
- — The potential for criticality accidents that may result from enriched uranium operations.
- — Significant chemical hazards, e.g. in conversion facilities, large amounts of anhydrous liquid HF and ammonia may be present; in diffusion enrichment facilities, a potential for a release of ClF_3 may exist.

7.2. In this section, specific recommendations on good practices and additional considerations in meeting the safety requirements for a conversion facility or an enrichment facility are presented.

QUALIFICATION AND TRAINING OF PERSONNEL

7.3. The safety requirements relating to the qualification and training of facility personnel are established in paras 9.8–9.13 and III.18–III.21 of Appendix III of Ref. [1]. Recommendations are provided in paras 4.6–4.25 of Ref. [4]. The training on prevention and mitigation of fires and explosions that could result in a release of radioactive material (para. III.20 of Appendix III of Ref. [1]) should cover: (1) an H_2 explosion in a reduction furnace in a conversion facility; and (2) a lubrication oil fire in a gaseous diffusion enrichment facility. In addition, personnel should be provided periodically with basic training in radiation safety.

GENERAL RECOMMENDATIONS FOR FACILITY OPERATION

7.4. To ensure that the conversion facility or enrichment facility operates well within the operational limits and conditions under normal circumstances, a set of lower level sublimits and conditions, the operating envelope, should be defined. Such sublimits and conditions should be clear, published and well understood by the personnel operating the facility.

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

7.6. Generic limits should also be set for the facility. Examples of such limits are:

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

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

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

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

MAINTENANCE, CALIBRATION AND PERIODIC TESTING AND INSPECTION

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

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

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

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

7.13. Additional precautions may also be necessary for the prevention of a criticality accident (see paras 7.20–7.23).

7.14. Compliance of the operational performance of the ventilation system with the fire protection requirements (see para 4.45) should be verified on a regular basis.

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

Inspection of cylinders in storage

7.16. Paragraph III.22 of Appendix III of Ref. [1] establishes the requirements relating to the inspection of cylinders in storage. Information on maintenance and periodic testing of UF_6 cylinders is provided in Sections 4 and 5 of Ref. [7].

CONTROL OF MODIFICATIONS

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

7.18. Modification control forms should be scrutinized by and be subject to approval by qualified and experienced persons to verify that the arguments used to demonstrate safety are suitably robust. This should be considered particularly important if the modification could have an effect on criticality safety. The depth of the safety arguments and the degree of scrutiny to which they are subjected should be commensurate with the safety significance of the modification.

7.19. The modification control form should also specify which documentation will need to be updated as a result of the modification. 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.

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

7.21. The modifications made to a facility should be reviewed on a regular basis to ensure that the combined effects of a number of modifications with minor safety significance do not have hitherto unforeseen effects on the overall safety of the facility.

RADIATION PROTECTION

7.22. In a conversion facility or an enrichment facility, the main radiological hazard for both the workforce and members of the public is from the inhalation of airborne material containing uranium compounds. In conversion facilities, insoluble compounds of uranium such as the uranium oxides UO_2 and U_3O_8 pose a particular hazard because of their long biological half-lives (and therefore effective half-lives)[2]. Thus, close attention should be paid to the confinement of uranium powders and the control of contamination in the workplace. In enrichment facilities most uranium compounds have a short biological half-life. The chemical hazards for the uranium compounds found in enrichment facilities dominate the radiological hazards.

7.23. In conversion facilities and enrichment facilities, in normal operation, the main characteristic that needs to be taken into account in the development of measures for radiation protection is that the external and internal dose rates are relatively low. It is required to put in place emergency arrangements for criticality incidents, which are the only events in which a high external dose rate would be encountered.

7.24. Interventions for maintenance and/or modifications are major activities that require justification and optimization of protective actions, as specified in Ref. [5]. The procedures for intervention should include:

- — Estimation of the external exposure prior to an intervention in areas such as those for the processing and handling of ashes containing thorium gamma emitters arising from the fluorine reactor in conversion facilities;
- — Preparatory activities to minimize the doses due to occupational exposure, including:
  - Identifying specifically the risks associated with the intervention;
  - Specifying in the work permit the procedures for the intervention (such as for the individual and collective means of protection, e.g. use of masks, clothing and gloves, and time limitation);

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

— Measurement of the occupational exposure during the intervention;
— Implementation of feedback of information for identifying possible improvements.

7.25. The risks of exposure of members of the public should be controlled by ensuring that, as far as reasonably practicable, radioactive material is removed from ventilation exhaust gases to prevent its being discharged to the atmosphere. "The monitoring results from the radiation protection programme shall be compared with the operational limits and conditions and corrective actions shall be taken if necessary" (para. 9.43 of Ref. [1]). Furthermore, these monitoring results should be used to verify the dose calculations made in the initial environmental impact assessment.

Control of internal exposure

7.26. 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 carried out at ventilation hoods and entrances to containment areas. Pressure drops across air filter banks should be checked and recorded regularly.
(c) A high standard of housekeeping should be maintained at the facility. Cleaning techniques should be used that do not give rise to airborne radioactive material, e.g. the use of vacuum cleaners with HEPA filters.
(d) Regular contamination surveys of areas of the facility and equipment should be carried out to confirm the adequacy of cleaning programmes.
(e) Contamination zones should be delineated and clearly indicated.
(f) Continuous air monitoring should be carried out to alert facility operators if levels of airborne radioactive material exceed predetermined action levels.
(g) Mobile air samplers should be used at possible sources of contamination as necessary.
(h) An investigation should be carried out promptly in response to readings of high levels of airborne radioactive material.
(i) Personnel and equipment should be checked for contamination and should undergo decontamination if necessary, prior to their leaving contamination zones. Entry to and exit from the work area should be controlled to prevent the spread of contamination. In particular, changing rooms and decontamination facilities should be provided.

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

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

7.28. The extent of the monitoring should be commensurate with the levels of airborne radioactive material and the contamination levels of workplaces.

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

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

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

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

Control of external exposure

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

— Operations involving recently emptied cylinders;
— Storage of bulk quantities of uranium;
— Handling of UF_6 cylinders;
— Handling of ashes from fluorination.

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

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

7.36. External exposure should be controlled by:

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

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

CRITICALITY CONTROL

7.38. In conversion facilities and enrichment facilities that process uranium with a ^{235}U concentration of more than 1%, it is particularly important that the procedures for controlling criticality hazard are strictly applied (paras 9.49 and 9.50 of Ref. [1]).

7.39. In addition to the requirement established in para. III.23 of Appendix III of Ref. [1], operational aspects of the control of criticality hazards in conversion facilities and enrichment facilities should include:

— Anticipation of unexpected changes in conditions that could increase the risk of a criticality accident; for example, unplanned accumulation of uranium fluorides (e.g. in ventilation ducting), inadvertent precipitation of material containing uranium in storage vessels or loss of neutron absorbers;
— Management of the moderating materials; for example, before a new product cylinder is used in the facility, checks should be undertaken to ensure that no hydrogenous material is present in the cylinder (e.g. water or oil);
— Management of mass in transfer of uranium (procedures, mass measurement, systems and records) for which safe mass control is used;
— Reliable methods for detecting the onset of any of the foregoing conditions;
— Periodic calibration or testing of systems for the control of criticality hazards;
— Evacuation drills to prepare for the occurrence of a criticality and/or the actuation of an alarm.

7.40. The tools used for the purposes of accounting for and control of nuclear material, such as instruments used to carry out measurements of mass, volume or isotopic compositions and software used for accounting 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. This arises in particular in connection with floor sweepings and similar waste material.

7.41. Criticality hazards may be encountered when carrying out maintenance work. For example, if “uranium has to be removed from vessels or pipe work, only approved containers shall be used” (para III.24 of Appendix III of Ref. [1]). Waste and residues arising from decontamination activities should be collected in containers with a favourable geometry.

INDUSTRIAL AND CHEMICAL SAFETY

See also para. 7.3.

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

— Chemical hazards due to the presence of HF (e.g from UF_6), F_2, HNO_3, NH_3 and uranium compounds;
— Explosion hazards due to H_2, NH_3 ammonium nitrate, methanol, solvents and oxidants present in diffusion cascades;
— Asphyxiation hazards due to the presence of nitrogen or carbon dioxide.

7.43. The threshold of HF that a human can detect by smelling is lower than the occupational exposure level. As a consequence, specific routine occupational measurements for HF need not be implemented. In addition, releases of UF_6 generate a visible white cloud of UO_2F_2 particulates and HF that can easily be seen, leading to the requirement established in para. III.19 of Ref. [1]: “see, evacuate or shelter, and report”.

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

7.45. Fire hazard analyses should be repeated periodically to incorporate changes that may affect the potential for fires (see para. 4.38).

RISK OF OVERFILLING OF CYLINDERS

7.46. The corresponding requirement is established in para. III.27 of Ref. [1]. Fill limits for cylinders should be established to ensure that, when UF_6 expands (by around 35%) on liquefaction, hydraulic rupture does not occur. Further, heating after liquefaction is required for hydraulic rupture to occur.

7.47. In a conversion facility or an enrichment facility, the weight of a cylinder being filled should be monitored, generally by means of weighing scales.

RISK OF OVERHEATING OF CYLINDERS

7.48. The requirements on the risk of overheating of cylinders are established in paras III.28 and III.29 of Appendix III of Ref. [1]. “In the event of an overfilled cylinder, UF_6 in excess shall be transferred by sublimation only” (e.g. by evacuation to a cooled low pressure receiving vessel).

HANDLING OF CYLINDERS CONTAINING LIQUID UF_6

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

ON-SITE HANDLING OF SOLID UF_6

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

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

7.52. Consideration should be given to the impact of a fire on a cylinder containing solid UF_6 (e.g. a fire involving a transporter for UF_6 cylinders).

TAILINGS STORAGE

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

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

7.55. Periodic inspections of the tailings storage area should be conducted to check standards of housekeeping and ensure that there is no fire load in the storage area.

MANAGEMENT OF RADIOACTIVE WASTE AND EFFLUENTS

7.56. The requirements relating to the management of radioactive waste and effluents in operation are established in paras 9.54–9.57 of Ref. [1].

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

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

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

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

7.61. Information on the management of waste and effluents can also be found in Refs [8, 9].

EMERGENCY PLANNING AND PREPAREDNESS

7.62. The requirements for emergency planning and preparedness are established in paras 9.62–9.67 and paras III.31 and III.32 of Appendix III of Ref. [1]. The conditions for declaration of an off-site emergency at a conversion facility or an enrichment facility may include large releases of UF_6, HF, F_2 and NH_3 and also, depending on national requirements and facility specific considerations, criticality accidents, large fires (e.g. in the solvent extraction units of a conversion facility) or explosions.

8. DECOMMISSIONING

8.1. Requirements for the safe decommissioning of a conversion facility or an enrichment facility are established in Section 10 and paras III.33–III.35 of Appendix III of Ref. [1]. Recommendations on decommissioning of nuclear fuel cycle facilities, including conversion facilities and enrichment facilities, are provided in Ref. [10].

8.2. Owing to the low specific activity of the depleted, natural and LEU that is processed at conversion facilities and enrichment facilities, most of the waste resulting from the decommissioning of such facilities will be in the low level waste category.

PREPARATORY STEPS

8.3. The preparatory steps for the decommissioning process should include the following:

— A post-operational cleanout should be performed to remove all the gaseous UF_6 and the bulk amounts of uranium compounds and other hazardous materials from the process equipment. The corresponding requirement is established in para. III.33 of Appendix III of Ref. [1].
  - In conversion facilities, the first step is to carry out dry mechanical cleaning, to minimize the generation of liquid waste. The uranium resulting from the dry mechanical cleaning process should be recovered.

  - In diffusion enrichment facilities, ClF_3 or F_2 is used to convert solid uranium fluorides (e.g.UF_4, UF_5, UO_2F_2) into gaseous UF_6. In addition, flushing with a gas (e.g. N_2 or dry air) that does not react with UF_6 and other gases present in the facility should be used to remove the residual UF_6 and HF. The UF_6 and other gases are pumped and recovered in cold traps and chemical traps. If the complete recovery of uranium compounds by the use of ClF_3 or F_2 is not feasible, dry mechanical decontamination should be performed.
  - In centrifuge enrichment facilities, gaseous UF_6 is pumped out and recovered in cold traps. In addition, flushing with an inert gas (e.g. N_2) should be used to remove the residual UF_6 and HF.
- 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;
- The facility should be decontaminated to the levels required by the regulatory body for cleanup operations or the lowest reasonably achievable level of residual contamination;
- Risk assessments and method statements for the licensing of the decommissioning process should be prepared.

DECOMMISSIONING PROCESS

8.4. The decommissioning of the facility should contain the following successive steps: dismantling, dry cleaning and further dismantling (for conversion facilities and diffusion enrichment facilities only) and wet cleaning.

8.5. It should be ensured that personnel carrying out the decommissioning of the facility have the necessary training, qualifications and experience for such work. These personnel should have a clear understanding of the management system under which they are working to maintain acceptable environmental conditions and to implement the relevant environmental, health and safety standards.

8.6. Paragraphs III.34 and III.35 of Appendix III of Ref. [1] establish the requirements for active decommissioning.

8.7. In the decommissioning process, particular consideration should be given to:

— Preventing the spread of contamination by means of appropriate techniques and procedures;
— Appropriate handling and packaging of waste as well as planning for the appropriate disposal of radioactive waste;
— Safe storage of contaminated material and radioactive waste that cannot be decontaminated or disposed of immediately.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Fuel Cycle Facilities, IAEA Safety Standards Series No. NS-R-5, IAEA, Vienna (2008).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Legal and Governmental Infrastructure for Nuclear, Radiation, Radioactive Waste and Transport Safety, IAEA Safety Standards Series No. GS-R-1, IAEA, Vienna (2000).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, The Management System for Facilities and Activities, IAEA Safety Standards Series No. GS-R-3, IAEA, Vienna (2006).

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

[5] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANISATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGANIZATION, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Occupational Radiation Protection, IAEA Safety Standards Series No. RS-G-1.1, IAEA, Vienna (1999).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Manual on Safe Production, Transport, Handling and Storage of Uranium Hexafluoride, IAEA-TECDOC-771, IAEA, Vienna (1994).

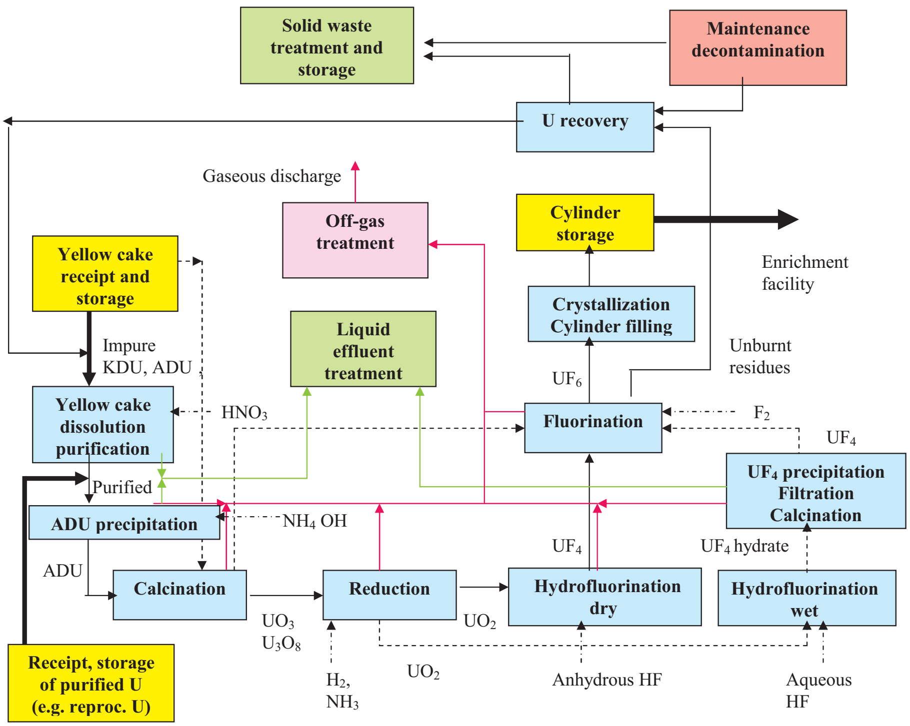
[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Minimization of Waste from Uranium Purification, Enrichment and Fuel Fabrication, IAEA-TECDOC-1115, IAEA, Vienna (1999).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Recycle and Reuse of Materials and Components from Waste Streams of Nuclear Fuel Cycle Facilities, IAEA-TECDOC-1130, IAEA, Vienna (1999).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Nuclear Fuel Cycle Facilities, IAEA Safety Standards Series No. WS-G-2.4, IAEA, Vienna (2001).

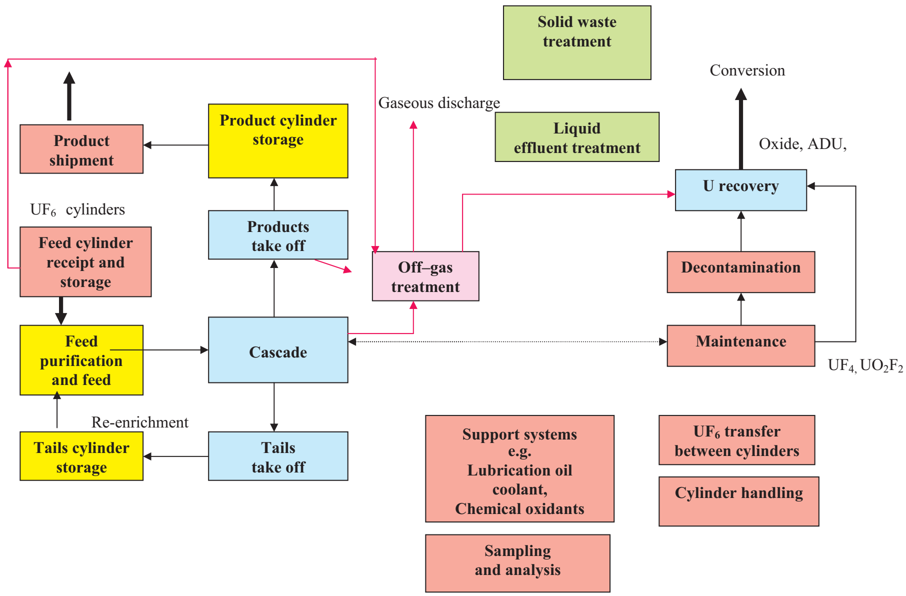
Annex I

TYPICAL PROCESS ROUTES IN A CONVERSION FACILITY



Annex II

TYPICAL PROCESS ROUTES IN AN ENRICHMENT FACILITY



Annex III

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

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

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Receipt and storage of yellow cake				
	Powder containers	Release of uranium	2	Mass, enrichment, concentration
Dissolution, purification and storage of yellow cake				
Dissolution	Dissolver and facilities for off-gas treatment	Release of uranium and nitrogen oxide (NOx)	2	Concentration of nitrogen oxide in gaseous effluent
Purification	— Fire detectors; — Flameproof apparatus	Fire	2	
Receipt and storage of purified uranium, e.g. reprocessed uranium				
Receipt of uranium nitrate (enriched uranium)	Checking device for ^{235}U content	Processing of uranium beyond safety limits	1	Enrichment, concentration

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Intermediate storage of uranium nitrate	Tank, drip tray, leak detector	Breach of tank	2	Integrity of tank, valves and lines
ADU precipitation				
	Vessels, filter, drying device	Release of uranium	2	Integrity of tank, valves and lines
Calcination				
	Kiln	Release of uranium	2	Integrity of kiln; relative pressure of room or kiln; Concentration of nitrogen oxide in gases
Reduction				
	Rotary kiln or flowing bed reactor	Release of uranium	2	Relative pressure of kiln versus of room
	Reduction furnace; in-line oxygen monitor H_2 detection devices in rooms	— Explosion — Release of uranium powder	2	O_2 amount, H_2 concentration, relative pressure kiln versus room

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
	Off-gas treatment units	Release of uranium powder	2	Uranium concentration
Dry hydro fluorination				
	— Hydro fluorination reactor; — Facilities for off-gas treatment	Release of HF	2	HF, uranium content in gases
	Shielding	Increase in dose rate	3	Thickness
Wet hydro fluorination				
	— Hydro fluorination reactor; — Facilities for off-gas treatment	Release of HF	2	HF, uranium content in gases
Fluorination				
	— Fluorination reactor; — Washing column for off-gas treatment	Release of F_2, HF and UF_6	2	F_2, uranium content in gases

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Crystallization and cylinder filling				
	High pressure measuring device; Cylinder and valve; Weight measuring device; UF_6 level detector in intermediate product take off tank to confirm transfer into cylinders; Pipes, vessels and valves containing UF_6; UF_6 release detection system	Release of UF_6 (breach of confinement): — Defective cylinder leads to breach; — Overfilling; — UF_6 left in process gas lines leading to a release of UF_6; — Release of liquid UF_6	2	Pressure; Visual cylinder inspection; Weight limits
	Vessels, piping	Release of UF_6	2	Integrity of tank, valves and lines
	Leak detection	Release of uranium and HF	2	HF concentration
Handling and storage of cylinders				
	UF_6 cylinders	Release of uranium and HF	2	Thickness

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
	Means of transportation, cranes, etc.	Breach of cylinder; Valve wrenching	2	Position of valve protector
Recovery of uranium				
Solvent extraction	Vessels and drip trays; Leak detectors	Breach of vessels; Spills of solutions of radioactive material	2	Integrity of vessels and valves
Solvent extraction	Mixer settlers or extraction columns	Fire Releases	2	Temperature
Intermediate storage of unburnt residues	Shielding	Increase in dose rate	3	Thickness
Off-gas treatment				
	Aerosol and gas measuring devices	Release of HF, F_2 and uranium	2	Uranium content in released air
	Columns, piping	Release of uranium and HF	2	HF content in released air

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Treatment of liquid effluents				
	Tank, piping	Release of uranium and other impurities	2	Uranium concentration; Uranium content in released water
	Measuring devices for radioactive and chemical impurities	Release of uranium and other impurities	2	
	Exhaust pipe	Release of uranium and other impurities	2	
Building				
	Areas for nuclear and chemical activities	Loss of integrity	2	Leaktightness
Pipes containing water or solutions				
	Piping	Loss of integrity	1	Thickness

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

Annex IV

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

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Receipt and storage of feed cylinders				
	Weighing scales; Cylinder and valve; Isotope measuring device	Breach during the heating; Defective cylinder leads to breach; Criticality event in the process	1, 2	Limit on cylinder weight; Visual inspection of cylinders; Limit on feed enrichment

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Feed purification				
	Pressure measuring device for cold cylinders; Temperature measuring device of UF_6; Pressure measuring device of UF_6; UF_6 leak detectors; Shielding (if reprocessed uranium); Feed connector and piping; UF_6 cylinder; Autoclave isolation valve system	Explosion (F_2); Heating trip, cylinder breach; Heating trip, cylinder breach; Personnel exposure; Personnel exposure; Release into the second containment barrier	1, 2, 3	Pressure and temperature limits; Detection limits for UF_6 detectors; Visual inspection and pressure test of the feed connectors; Pressure check of feed cylinder; Remove light gases to the required level for centrifuge enrichment facilities

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

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
	— Heat exchanger tubes in contact with UF_6; — Temperature and pressure measuring devices.	Reaction of UF_6 with water leading to buildup of uranic deposits; Introduction of moderator of the introduction of Freon® leading to an explosion	1, 2	— Maintenance of the integrity of the tubes — Pressure and temperature limits
	In-line analysers to monitor for hydrocarbons or Freon® and for detecting ingress of oil or Freon®	Reaction of UF_6 with oil leading to criticality and/or explosion	1, 2	Limit on hydrocarbon concentrations
Product take-off				
	Low pressure and temperature measuring devices; High pressure measuring device; Cylinder and valve; Weighing scales; UF_6 level detector in intermediate product take off tank to confirm correct transfer into cylinders; Pipes, vessels and valve containing UF_6; UF_6 release detection system;	Moderation control to prevent HF condensation; UF_6 release (breach of confinement); Defective cylinder leads to breach; Overfilling; UF_6 left in process gas lines leading to release of UF_6; Release of liquid UF_6	1, 2	Vapour pressure of HF Pressure Visual empty cylinder inspection Weight limit

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Off-gas treatment				
	Cold traps and/or chemical traps; Temperature measuring device for cold traps; Measuring device for effluents discharged to atmosphere	Release of uranium to secondary containment barrier or atmosphere; External radiation dose from any accumulated uranium or uranium daughter isotopes	1, 2, 3	Temperature measuring device of cold traps
Tailings take-off				
	High pressure measuring device; Cylinder and valve; Weighing scales; UF_6 level detector in intermediate product take off tank to confirm adequate transfer into cylinders; Pipes, vessels and valve containing UF_6; UF_6 release detection system.	Release of UF_6 (breach of confinement); Defective cylinder leads to breach; Overfilling; UF_6 left in process gas lines leading to release of UF_6; Release of liquid UF_6	2	Pressure Visual empty cylinder inspection Weight limit

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

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Off-gas treatment				
	Differential pressure; Activity measurements and alarms; HF concentration measurements; Safe geometry scrubbers	Blocked or torn filters: failure of ventilation or discharge to atmosphere Criticality	1, 2	High and low pressure alarms Safe dimension of apparatus
Sampling and transfer of liquid UF_6				
	Pressure measuring device for the cold cylinder; Temperature measuring device in the cylinder during heating; Pressure measuring device of UF_6; UF_6 leak detectors; Pipes, vessels and valve containing UF_6	Explosion (F_2); Cylinder breach; Cylinder breach; Personnel exposure; Release into the second containment barrier	1, 2, 3	Pressure and temperature limits; Detection limits for UF_6 detectors; Visual inspection and pressure test of connectors
Cylinders handling				
	Valve protectors for liquid UF_6; Devices for moving cylinders containing liquid UF_6, such as cranes, carts and transporters	Release of uranium and HF	2, 3	Procedures

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

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

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged	Parameters for defining operational limits and conditions
Power supply system				
	Emergency power supply system	Loss of criticality safety and radiation protection control	2	Maximum time for power supply reconstitution

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

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