IAEA Safety Standards

for protecting people and the environment

Safety of Uranium Fuel Fabrication Facilities

Specific Safety Guide

No. SSG-6

IAEA

International Atomic Energy Agency

IAEA SAFETY RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

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

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

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

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SAFETY OF URANIUM FUEL FABRICATION 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-6

SAFETY OF URANIUM FUEL FABRICATION FACILITIES

SPECIFIC SAFETY GUIDE

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2010

Printed by the IAEA in Austria
May 2010
STI/PUB/1402

IAEA Library Cataloguing in Publication Data

Safety of uranium fuel fabrication facilities. — Vienna : International Atomic Energy Agency, 2009.
p. ; 24 cm. — (IAEA safety standards series,, ISSN 1020–525X ; no. SSG-6)
STI/PUB/1402
ISBN 978–92–0–104609–3
Includes bibliographical references.

1. Nuclear facilities — Safety measures. 2. Uranium as fuel. I. International Atomic Energy Agency. II. Series.

IAEAL 09–00604

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.

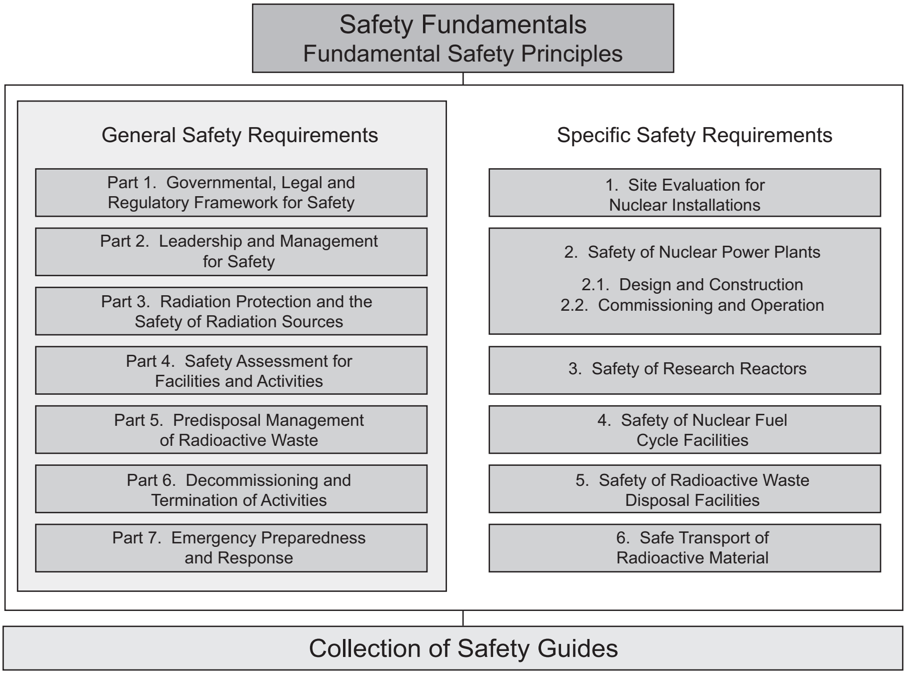

FIG. 1. The long term structure of the IAEA Safety Standards Series.

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).

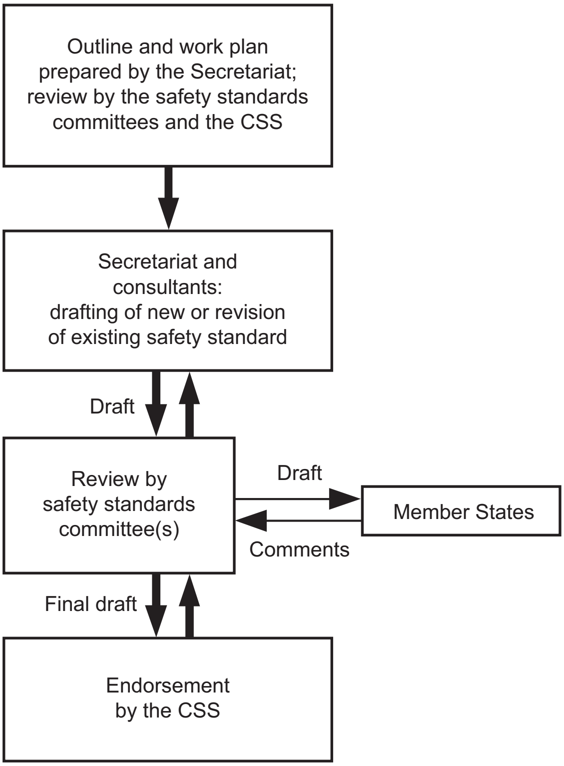

FIG. 2. The process for developing a new safety standard or revising an existing standard.

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 Uranium Fuel Fabrication Facilities makes recommendations on how to meet the requirements established in the Safety Requirements publication on the Safety of Fuel Cycle Facilities [1], and supplements and elaborates on those requirements.

1.2. The safety of uranium fuel fabrication 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 uranium fuel fabrication facility, with emphasis placed on the safety of their design and operation.

1.3. Uranium and the waste generated in uranium fuel fabrication facilities are handled, processed, treated and stored throughout the entire facility. Uranium fuel fabrication facilities may process or use large amounts of hazardous chemicals, which can be toxic, corrosive, combustible and/or explosive. The fuel fabrication processes rely to a large extent on operator intervention and administrative controls to ensure safety, in addition to active and passive engineered safety measures. The potential for a release of energy in the event of an accident at a uranium fuel fabrication facility is associated with nuclear criticality or chemical reactions. The potential for release of energy is small in comparison with that of a nuclear power plant, with generally limited environmental consequences.

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 at all stages in the lifetime of a uranium fuel fabrication 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 uranium fuel fabrication 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 uranium fuel fabrication facilities are established in Appendix I of Ref. [1]. This Safety Guide provides recommendations on meeting the requirements established in Sections 5–10 and in Appendix I of Ref. [1].

1.6. This Safety Guide deals specifically with the handling, processing and storage of low enriched uranium (LEU) that has a ^{235}U concentration of no more than 6%, derived from natural, high enriched or reprocessed uranium; it does not cover facilities that handle uranium metal fuels. Completed fuel assemblies (e.g. fuel assemblies for pressurized water reactors, boiling water reactors, heavy water reactors, CANDU reactors and advanced gas cooled reactors) are stored at the fuel fabrication facility before being transported to the nuclear power plant. Such a storage facility is considered to be part of the fuel fabrication facility. This Safety Guide is limited to the safety of uranium fuel fabrication facilities; it does not deal with any impact that the manufactured fuel assemblies may have on safety for the reactors in which they are going to be used.

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 include 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 dry and wet process routes of uranium fuel fabrication facilities are shown in a schematic diagram in Annex 1 (see also Ref. [7]).

STRUCTURE

1.10. This Safety Guide consists of eight sections and three annexes. Section 2 provides general safety recommendations for a uranium fuel fabrication 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 uranium fuel fabrication facility and other design considerations. Section 5 addresses 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 uranium fuel fabrication facility. Annex I shows the typical process routes for a uranium fuel fabrication facility. Annex II provides examples of structures, systems and components important to safety in uranium fuel fabrication facilities, grouped in accordance with process areas. Annex III provides examples of parameters for defining the operational limits and conditions for a uranium fuel fabrication facility.

2. GENERAL SAFETY RECOMMENDATIONS

2.1. In uranium fuel fabrication facilities, large amounts of radioactive material are present in a dispersible form. This is particularly so in the early stages of the fuel fabrication process. In addition, the radioactive material encountered exists in diverse chemical and physical forms and is used in conjunction with flammable or chemically reactive substances as part of the process. Thus, in these facilities, the main hazards are potential criticality and releases of uranium hexafluoride (UF_6) and UO_2, from which workers, the public and the environment must be protected by means of adequate design and construction and by safe operation.

2.2. 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 hydrogen fluoride (HF) are also present. In addition, 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 uranium fuel fabrication facilities should also address the potential hazard resulting from these chemicals.

2.3. In uranium fuel fabrication facilities, only low enriched uranium (LEU) is processed. The radiotoxicity of LEU is low, and thus any potential off-site radiological consequences following an accident would be expected to be limited. However, the radiological consequences of an accidental release of 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 such uranium.

2.4. Uranium fuel fabrication facilities do not pose a potential radiation hazard with the capacity to cause an accident with a significant off-site release of radioactive material (in amounts equivalent to a release to the atmosphere of ^{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.

2.5. For 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 uranium fuel fabrication 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. However, as the potential nuclear hazard posed by a uranium fuel fabrication facility is inherently limited, the risks posed by possible external events should be compensated for by means of adequate design provisions and constraints on processes and operations.

3.2. The density of population in the vicinity of the uranium fuel fabrication 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 uranium fuel fabrication facility and the reasons behind those decisions.

4. DESIGN

GENERAL

Safety functions for uranium fuel fabrication facilities

4.1. Safety functions (see Ref. [1], Appendix I, para. I.1), that is 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.

Specific engineering design requirements

4.2. The following requirements apply:

(1) The requirements on prevention of criticality as established in paras 6.43–6.51 and I.3–I.7 of Appendix I of Ref. [1].
(2) The requirements on confinement for the prevention of releases that might lead to internal exposure and chemical hazards as established in paras 6.37–6.39, 6.54–6.55 and paras I.8 and I.9 of Appendix I of Ref. [1].

(3) The requirements on protection against external exposure as established in paras 6.40–6.42 of Ref. [1]. For a facility licensed to use LEU from sources of uranium other than natural uranium, because of the higher specific activity, particular care should be taken to minimize contamination. The need for shielding should be considered for the protection of workers from the associated higher dose rates of gamma radiation.

Design basis accidents and safety analysis

4.3. 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].

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

(a) A nuclear criticality accident;
(b) A release of uranium (e.g. in the explosion of a reaction vessel during the conversion process);
(c) A release of UF_6 due to the rupture of a hot cylinder;
(d) A release of HF due to the rupture of a storage tank;
(e) A large fire;
(f) Natural phenomena such as earthquakes, flooding, or tornadoes[1];
(g) An aircraft crash[2].

4.5. The first two types of events ((a) and (b)) 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 five types of events ((c)–(g)) would lead to chemical releases having both on-site and off-site consequences.

[1] For some facilities of older designs, natural phenomena were not considered. These phenomena should be taken into account in the design of new uranium fuel fabrication facilities.

[2] The consequences of an aircraft crash should be considered even if such an accident is not formally established as a design basis accident.

4.6. The events listed in para. 4.4 may occur as a consequence of a postulated initiating event (PIE). Selected PIEs are listed in Annex I of Ref. [1].

Structures, systems and components important to safety

4.7. 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 (see paras 6.5–6.9 and Annex III of Ref. [1])). Annex II of this Safety Guide presents examples of structures, systems and components important to safety and representative events that may challenge the associated safety functions.

SAFETY FUNCTIONS

Prevention of criticality

4.8. "For the prevention of criticality by means of design, the double contingency principle shall be the preferred approach" (Ref. [1], para. 6.45). Paragraphs I.3 and I.4 of Appendix I of Ref. [1] establish general requirements for the prevention of criticality in uranium fuel fabrication facilities. Paragraph I.5 of Appendix I of Ref. [1] establishes requirements for the control of system parameters for the prevention of criticality. Some examples of the parameters subject to control are the following:

- Mass and degree of enrichment of fissile material present in a process and in storage between processes, e.g. powder in rooms and vessel scrubbers and pellets in storage;
- Geometry (limitation of the dimensions or shape) of processing equipment, e.g. by means of safe diameters for storage vessels, control of slabs and appropriate separation distances between containers in storage;
- Concentration of fissile material in solutions, e.g. in the wet process for recycling uranium;
- Presence of appropriate neutron absorbers, e.g. in the construction of storage areas, drums for powder and fuel shipment containers;
- Degree of moderation, e.g. by means of control of moisture levels and of the amount of additives in powder.

4.9. The aim of the criticality analysis, as required in para. I.6 of Appendix I of Ref. [1], 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 the fissionable material 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.

4.10. 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.

4.11. 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:

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

4.12. The following are recommendations for conducting a criticality analysis for a uranium fuel fabrication facility to meet the safety requirements established in Ref. [1], Appendix I, paras I.6 and I.7:

— *Mass.* The mass margin should be around 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 analysis should cover possible changes in dimensions due to operation (e.g. bulging of slab tanks or slab hoppers).
— *Concentration and density.* The analysis should cover a range of: (i) uranium concentrations for solutions; and (ii) powder and pellet densities plus moderators for solids, to determine the most reactive conditions that could occur.
— *Moderation.* The analysis should cover the presence of moderators that are commonly present in uranium fuel fabrication facilities, such as water, oil and other hydrogenous substances, or that may be present in accident conditions (e.g. water from firefighting). Special consideration should be

given to cases of inhomogeneous moderation, in particular when transfers of fissile material take place.

— *Reflection.* The most conservative margin should be retained of those resulting from different assumptions such as: (i) a hypothetical thickness of water around the processing unit; and (ii) consideration of the neutron reflection effect due to the presence of human beings, organic materials, wood, concrete, steel of the container, etc., around the processing unit.
— *Neutron absorbers.* The neutron absorbers that may be used in uranium fuel fabrication facilities include cadmium, boron, gadolinium and polyvinyl chloride (PVC) used in 'spiders' inside powder drums, plates in the storage areas for pellets or fuel assemblies and borosilicate glass rings ('Raschig' rings) in tanks for liquids. The effects of the inadvertent removal of the neutron absorbers should be considered in the analysis.

Confinement to protect against internal exposure and chemical hazards

4.13. To meet the requirement on protection of workers, the public and the environment against releases of hazardous material as established in para. 6.37 of Ref. [1], the use of and the inventory of liquid UF_6 in the facility should be kept to a minimum. As such a uranium fuel fabrication facility should be designed to minimize, to the extent practicable, contamination of the facility and the environment, and to include provisions to facilitate decontamination and the eventual decommissioning of the facility.

4.14. The use of an appropriate containment system should be the primary method for protection against the spreading of dust contamination from areas where significant amounts of either uranium powders or hazardous substances in gaseous form are held. When practicable, and to improve the effectiveness of the static containment system (physical barriers), a dynamic containment system should be used to create pressure gradients to cause a flow of air towards parts of equipment or areas that are more contaminated. A cascade of reducing absolute pressures can thus be established between the environment outside the building and the hazardous material inside.

4.15. In the design of the ventilation and containment systems for the uranium fuel fabrication facility, account should be taken of criteria such as: (i) the desired pressure difference between different parts of the premises; (ii) the air replacement ratio in the facility; (iii) the types of filters to be used; (iv) the maximum differential pressure across filters; (v) the appropriate flow velocity at the openings in the ventilation and containment systems (e.g. the acceptable range of air speeds at the opening of a hood); and (vi) the dose rate at the filters.

Protection of workers

4.16. 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. Uranium fuel fabrication 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.

4.17. The need for the use of protective respiratory equipment should be minimized through careful design of the containment and ventilation systems.

4.18. 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 barrier. 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 filters will result in the safe shutdown of equipment in the affected area.

4.19. 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 concentrations or gas concentrations in ventilation systems should be installed as necessary.

4.20. Alarm systems should be installed to alert operators to fan failure or to high or low differential pressures. At the design stage, provision should also be made for the installation of equipment for monitoring airborne uranium concentration and/or gas concentration. 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]).

4.21. 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 fireproof dampers and should be constructed from non-flammable materials.

4.22. To facilitate decontamination and eventual decommissioning of the facility, the walls, floors and ceilings in areas of the uranium fuel fabrication facility where contamination is likely should be made non-porous and easy to clean. This may be done by applying special coatings, such as epoxy, to surfaces. In addition, all surfaces that could become contaminated should be made readily accessible to allow for periodic decontamination as necessary.

Protection of the environment

4.23. 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. The design should also provide for monitoring of the environment of the facility and detection of breaches in the barriers.

4.24. Uncontrolled dispersion of radioactive 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, or the room or the building itself. In addition, ventilation of the containment systems, by the discharge of exhaust gases through a stack via gas cleaning equipment such as a filter, reduces the normal environmental discharges of radioactive material to very low levels. In such cases, the ventilation system may also be regarded as a containment barrier.

Protection against external exposure

4.25. External exposure can be controlled by means of an appropriate combination of requirements on distance, time and shielding. The installation of shielding or the setting of restrictions on occupancy should be considered for areas used for storing cylinders, in particular empty cylinders that have contained reprocessed uranium since some by-products of irradiation will remain in the cylinder. Similar precautions should be taken in areas of the facility where the uranium has a high specific density and significant amounts of uranium are present (e.g. in storage areas for pellets and fuels).

4.26. When the UO_2 is of low density (as is the case in conversion or blending units for instance), the shielding provided by the vessels and pipework of the uranium fuel fabrication facility will normally be sufficient to control exposure. In cases where reprocessed uranium is used, specific precautions should be taken to limit the exposure of workers to the decay products (^{208}Tl and ^{212}Bi) of ^{232}U.

Such precautions may include administrative arrangements to limit the period of time for which uranium is stored on the site or the installation of shielding.

POSTULATED INITIATING EVENTS

Internal initiating events

Fire and explosions

4.27. Uranium fuel fabrication 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 uranium fuel fabrication facilities may 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 or the parameters used for the control of criticality (e.g. the moderation control system or the dimensions of processing equipment).

4.28. The fire hazards that are specifically encountered in a uranium fuel fabrication facility, such as hazards due to solvents and hydrocarbon diluents, H_2O_2, anhydrous ammonia (NH_3, which is explosive and flammable), sulphuric acid or nitric acid (which pose a danger of ignition by reaction with organic materials), zirconium (a combustible metal, especially in powder or chip forms) and hydrogen, should be given due consideration at the design stage for the facility.

Fire hazard analysis

4.29. As an important aspect of fire hazard analysis for a uranium fuel fabrication facility, areas of the facility that require special consideration should be identified. Special fire hazard analyses should be carried out for:

(a) Processes involving hydrogen, such as conversion, sintering and reduction of uranium oxide;
(b) Processes involving zirconium in powder form or the mechanical treatment of zirconium metal;
(c) Workshops such as the recycling shop and laboratories where flammable liquids and/or combustible liquids are used in processes such as solvent extraction;
(d) The storage of reactive chemicals (e.g. NH_3, H_2SO_4, HNO_3, H_2O_2, pore formers and lubricants);

(e) Areas with high fire loads, such as waste storage areas;
(f) Waste treatment areas, especially those where incineration is carried out;
(g) 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;
(h) Control rooms.

4.30. 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. Fire hazard analysis 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.

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

4.32. 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

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

4.34. To accomplish the two-fold aim of fire prevention and mitigation, 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.

4.35. Fire extinguishing devices, automatic or manually operated, with adequate extinguishing agent, should be installed in zones where the outbreak of a fire is possible (see Ref. [1], Appendix I, para. I.10). In particular, “The installation of automatic devices with water sprays shall be carefully assessed for areas where uranium may be present, with account taken of the risk of criticality” (Ref. [1], Appendix I, para. I.11). Consideration should be given to minimizing the environmental impact of the water used to extinguish fires.

4.36. 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. The fire dampers 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.

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

Explosions

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

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

(a) Gases (e.g. hydrogen used in the conversion process and sintering furnaces, heating gas, cracked ammonia gas containing a mixture of hydrogen and nitrogen);
(b) Chemical compounds such as ammonium nitrate used in recycling workshops.

4.40. In such situations, consideration should be given to the use of an inert gas atmosphere or dilution systems and to the ability of the components of the system to withstand explosions (e.g. explosions in sintering furnaces). Recycling systems should be regularly monitored to prevent the deposition of ammonium nitrate. "In areas with potentially explosive atmospheres, the electrical network and equipment shall be protected in accordance with the industrial safety regulations" (Ref. [1], Appendix I, para. I.12).

Flooding

4.41. Flooding in a uranium fuel fabrication facility may lead to the dispersion of radioactive material and to changes in the conditions for neutron moderation.

4.42. 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.

4.43. 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

4.44. Leaks from equipment and components such as pumps, valves and pipes can lead to the dispersion of radioactive material (e.g. UO_2, U_3O_8 powder and UF_6) and toxic chemicals (e.g. HF), and to the unnecessary generation of waste. Leaks of hydrogenous fluids (water, oil, etc.) can alter the neutron moderation in fissile material and thereby reduce criticality safety. Leaks of flammable gases (H_2, natural gas, propane) or liquids can lead to explosions and/or fires. Leak detection systems should be deployed where leaks could occur.

4.45. Vessels containing significant amounts of nuclear material in liquid 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.

4.46. 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

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

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

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

— Loss of compressed gas control for safety valves and dampers. In accordance with the safety analysis, valves should be used that are designed to fail to a safe position.
— Loss of cooling or heating water. Adequate backup capacity or a redundant supply should be provided in the design.
— Loss of breathing air. Backup capacity or a redundant supply should be provided to allow work in areas with airborne radioactive material to continue to be carried out.

Loss or excess of process media

4.49. The loss of process media such as hydrogen, nitrogen or steam or any excess of these media may have consequences for safety. Some examples are:

— Incomplete chemical reactions, potentially leading to a release of UF_6 into the off-gas treatment system;
— Loss of leaktightness of equipment used for transporting uranium powder if a nitrogen flow is used for sealing;
— Loss of criticality safety due to loss of safe geometry or loss of moderation control by excess of process gases;
— Increase of levels of airborne contamination and/or concentration of hazardous material in the work areas of the facility because of overpressure in the equipment;
— Reduction of oxygen concentration in breathing air in the work areas of the facility due to a release of large amounts of nitrogen.

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

Mechanical failure

4.51. Particular consideration should be given to the containment for the highly corrosive HF (in vessels, pipes and pumps) and to powder transfer lines where abrasive powder will cause erosion.

4.52. 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.

4.53. 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

4.54. A uranium fuel fabrication facility should be designed for the design basis earthquake to ensure that an earthquake motion 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.

4.55. 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.

4.56. 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.

4.57. 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

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

4.59. 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

4.60. Typically, the extreme weather conditions assumed in the design and in the evaluation of the response of a uranium fuel fabrication facility are wind loading, tornadoes, tsunamis, extreme rainfall, extreme snowfall, extreme temperatures and flooding.

4.61. 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.

4.62. 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.

4.63. A uranium fuel fabrication 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 safe shutdown of the facility in accordance with the operational limits and conditions.

Tornadoes

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

4.65. 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

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

4.67. If safety limits for humidity and/or the 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

4.68. 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 or the interspersed moderation effect of the snow, if relevant, should be considered.

Floods

4.69. 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 above the flood level or at a sufficient elevation to avoid major damage from flooding.
— 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 consideration. The buildings of the facility are designed to withstand the water wave arising from the breach of the dam. In such cases the equipment — especially that used for the storage of fissile material — should be designed to prevent any criticality accident.

Accidental aircraft crashes

4.70. The likelihood and possible consequences of impacts onto the 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 (bullet (h)) of Ref. [1].

4.71. 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 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

4.72. 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 operating procedures or automatic systems.

4.73. 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

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

4.75. 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

4.76. 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 (e.g. conversion), 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

4.77. Safety related I&C systems for normal operation should include:

(1) Process control instrumentation. Indicating temperatures, pressures, flow rates, concentrations of chemicals and/or radioactive material, tank levels, etc.
(2) Control and monitoring of ventilation. Mainly of differential pressures across high efficiency particulate air (HEPA) filters, prefilters, enclosure exhausts and air flows, as necessary.
(3) Radiation dosimetry.
    — Sensitive films and/or dosimeters with real time displays and/or alarms, especially in areas with inspection equipment such as X ray generators and active sources (for monitoring external exposure).
    — Continuous sampling of filters for retrospective measurement and/or real time measurement with alarms for the detection of releases of radioactive material (for monitoring internal exposure).
(4) Gaseous and liquid effluents. Real time measurements are necessary if there is a risk of authorized limits being exceeded; otherwise retrospective measurements on continuously sampled filters or probes should be sufficient.

Safety related I&C systems for anticipated operational occurrences

4.78. In addition to the listing provided in para. 4.77, safety related I&C systems for use in anticipated operational occurrences should include the following provisions:

— All rooms with fissile and/or toxic chemical material should be equipped with fire alarms (except where the permanent presence of operators is sufficient).
— Gas detectors should be used in areas where a leakage of gases (e.g. H_2 or heating gas) could produce an explosive atmosphere.

Safety related I&C systems for design basis accident conditions

4.79. The safety related I&C systems for design basis accident conditions should include provisions in addition to the previous listings to address the following situations:

(1) Criticality. The requirement on I&C systems relating to criticality control is established in para. I.13 of Appendix I of Ref. [1].
(2) Chemical release. The requirement on I&C systems relating to monitoring for chemical releases is established in para. I.14 of Appendix I 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

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

4.81. 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.

4.82. 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 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

4.83. Safety analysis for uranium fuel fabrication 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.

4.84. 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

4.85. A facility specific, realistic, enveloping and robust (i.e. conservative) assessment of internal and external occupational exposure and public exposure 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

4.86. 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

4.87. For uranium fuel fabrication 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.

4.88. The consequences of design basis accidents for a uranium fuel fabrication facility 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 or hazardous chemicals, the distance between the individuals exposed or affected and the source of the release, pathways for the transport of material to the individuals and the exposure times.

4.89. 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.

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

(a) 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).

(b) An approach using the enveloping case (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 an assessment 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 chemical consequences

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

(a) Analysis of the 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 the accident 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 of 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 are credited to reduce the likelihood and/or to mitigate the consequences of accidents. These structures, systems and components important to safety that are credited in the safety assessment should be qualified to perform their functions in the accident conditions.
(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.

4.92. 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]).

4.93. 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.

4.94. 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

4.95. Uranium fuel fabrication facilities should be designed to minimize the generation of waste both in operation and in decommissioning. For economic and environmental reasons, the recovery of nuclear material and the reuse of chemicals are common practices in uranium fuel fabrication facilities. These practices minimize the generation of waste in both solid and liquid forms [8, 9].

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

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

4.97. In the case of uranium fuel fabrication facilities, the nuclear material to be recovered is uranium both from scraps (i.e. products that are out of specification and that are not directly recycled in the fuel fabrication process) and as secondary outputs from ventilation filters or from cleaning of the facility. The process of recovering uranium from scraps may include dissolution and solvent extraction, which generate liquid effluents. An appropriate balance should 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

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

4.99. 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 by continuous sampling.

OTHER DESIGN CONSIDERATIONS

4.100. 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.

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

5. CONSTRUCTION

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

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 prevent future operational problems.

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

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

6. COMMISSIONING

6.1. For a uranium fuel fabrication 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 (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 uranium fuel fabrication facility, it would also be acceptable to carry out some of these activities in the subsequent phase. The operating organization should 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 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 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 URANIUM FUEL FABRICATION FACILITIES

7.1. The distinctive features of a uranium fuel fabrication facility that should be taken into account in meeting the safety requirements established in Ref. [1] are:

- — The relatively low radiotoxicity of LEU, which is processed, handled and stored in large inventories in finely divided and dispersible forms.
- — The potential for chemical and toxicological impacts on workers, the public and the environment due mainly to hydrogen fluoride, uranium hexafluoride, hydrogen, nitric acid and ammonia).
- — The potential for fire and explosions resulting in a release of radioactive material (e.g. a hydrogen explosion in a conversion process or a sintering furnace).

7.2. In a uranium fuel fabrication facility, automation serves mainly to improve productivity and is used less than in other types of fuel cycle facilities; more emphasis is placed on administrative measures to ensure safe operation.

7.3. In this section, specific recommendations on good practices and additional considerations in meeting the safety requirements for a uranium fuel fabrication facility are presented.

QUALIFICATION AND TRAINING OF PERSONNEL

7.4. The safety requirements relating to the qualification and training of facility personnel are established in paras 9.8–9.13 and in paras I.15–I.16 of Appendix I of Ref. [1]. Recommendations are provided in paras 4.6–4.25 of Ref. [4]. In addition, personnel should be provided periodically with basic training in radiation safety.

GENERAL RECOMMENDATIONS FOR FACILITY OPERATION

7.5. To ensure that the uranium fuel fabrication facility operates well within the operational limits and conditions under normal circumstances, a set of lower level sublimits and conditions should be defined. Such sublimits and conditions should be clear and should be made available to and well understood by the personnel operating the facility.

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

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

- — The maximum enrichment of uranium allowed at the facility;
- — The specification for UF_6 cylinders and the maximum inventory of UF_6 cylinders allowed in the storage area;
- — The maximum allowed throughputs and inventories for the facility.

7.8. Consideration should be given to ensuring that uranium, especially uranium powder or pellets, is present only in areas designed for the storage or handling of uranium. 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.

7.9. Operating procedures to control process operations directly should be developed. The procedures should include directions for attaining a safe state of the facility from all anticipated operational occurrences and accident conditions. In a uranium fuel fabrication facility, the safe operational state attained after any anticipated operational occurrence is often the shutdown state. Nevertheless, specific operating procedures should be used for the shutdown of certain equipment such as UF_6 vaporizers, rotary kilns for uranium dioxide and sintering furnaces. Procedures of this type should include the actions required to ensure criticality safety, fire protection, emergency planning and environmental protection.

7.10. 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

7.11. When carrying out maintenance in a uranium fuel fabrication facility, particular consideration should be given to the potential for surface contamination or airborne radioactive material, and to specific chemical hazards such as hazards due to hydrogen fluoride, ammonia, hydrogen and nitric acid.

7.12. 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 response procedures.
- Reinstallation of equipment, e.g. reassembly, reconnection of pipes and cables, testing, cleaning the job site and monitoring after recommissioning.

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 4.36) 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. Particular consideration should be given to fatigue affecting equipment and to the ageing of structures.

CONTROL OF MODIFICATIONS

7.16. A standard process for any modification should be applied in a uranium fuel fabrication facility. This process should use a modification control form or equivalent management tool. The modification control form should contain a description of what the modification is and why it is being made. The main purpose of the modification control form is to provide the basis for a safety assessment of 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.

7.17. 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.

7.18. 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.

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

7.20. 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 unforeseen effects on the overall safety of the facility.

RADIATION PROTECTION

7.21. In a uranium fuel fabrication facility, the main radiological hazard for both the workforce and members of the public is from the inhalation of airborne material containing uranium compounds. 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)[3] and their typically relatively small particle size (typically a few micrometres in diameter) when encountered in uranium fuel fabrication facilities (see para. I.22 of Appendix I of Ref. [1]).

7.22. Interventions for maintenance and/or modifications are 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 the intervention.
- — 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).
- — Measurement of the occupational exposure during the intervention.
- — Implementation of feedback of information for identifying possible improvements.

7.23. 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.

7.24. “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.

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[3] 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.

Control of internal exposure

7.25. 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. during periodic testing, inspection or maintenance).
(k) Personal protective equipment (e.g. respirators, gloves and clothes) should be made available for dealing with releases of chemicals or radioactive material from the normal means of confinement in specific operational circumstances (e.g. during maintenance or the cleaning of process equipment before changing enrichment levels).
(l) Personal protective equipment should be maintained in good condition, cleaned as necessary, and should be periodically inspected.
(m) Any staff having wounds should protect them with an impervious covering for work in contamination zones.

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

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

7.28. 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.

7.29. 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.

7.30. 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.

7.31. Estimates should be regularly made, by means of monitoring data on effluents, of radiation doses due to internal exposure received by members of the public who live in the vicinity of the site.

Control of external exposure

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

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

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

7.34. External exposure should be controlled by:

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

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

CRITICALITY CONTROL

7.36. In a uranium fuel fabrication facility, it is particularly important that the procedures for controlling criticality hazard are strictly applied (paras 9.49 and 9.50 of Ref. [1]).

7.37. Operational aspects of the control of criticality hazards in uranium fuel fabrication facilities should include:

— Anticipation of unexpected changes in conditions that could increase the risk of a criticality accident; for example, unplanned accumulation of uranium powder (e.g. in ventilation ducting), inadvertent precipitation of material containing uranium in storage vessels or loss of neutron absorbers.
— Management of the moderating materials, particularly water; for example, decontamination of gloveboxes and ventilation hoods, or in laboratories, and leakages of oils from gear boxes or use of a water based firefighting system (e.g. automatic sprinklers).
— 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.

7.38. The tools used for the purposes of accounting for and control of nuclear material, such as the instruments used to carry out measurements of mass, volume or isotopic composition 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.

7.39. Criticality hazards may be encountered when carrying out maintenance work. Waste and residues arising from decontamination activities should be collected in containers with a favourable geometry (see para. I.20 of Appendix I of Ref. [1]).

INDUSTRIAL AND CHEMICAL SAFETY

See also para. 7.4.

7.40. The chemical hazards found in uranium fuel fabrication facilities may be summarized as follows:

— Chemical hazards due to the presence of hydrogen fluoride (e.g. from uranium hexafluoride), ammonia, nitric acid, sulphuric acid, potassium hydroxide, sodium hydroxide and uranium compounds.
— Explosion hazards due to hydrogen, ammonium nitrate, ammonia, methanol and solvents and liquefied petroleum gas (LPG).
— Asphyxiation hazards due to the presence of nitrogen or carbon dioxide.

7.41. Fire hazard analyses should be repeated periodically to incorporate changes that may affect the potential for fires (see para. 4.30).

7.42. 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. hydrogen fluoride, ammonia, nitric acid, sulphuric acid, potassium hydroxide and sodium hydroxide. Both the radiological and the chemical effects of uranium should be considered, as necessary, as part of the health surveillance programme.

MANAGEMENT OF RADIOACTIVE WASTE AND EFFLUENTS

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

7.44. 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.

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

7.46. One easy way to minimize the generation of solid radioactive waste is to remove as much outer packing as possible before material is transferred contaminated areas. Processes such as incineration, metal melting and compaction can be used to reduce the volume of waste. 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 waste generation.

7.47. Quality control regimes should be applied to the treatment and disposal of waste from all streams to ensure compliance with authorizations for disposal.

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

EMERGENCY PLANNING AND PREPAREDNESS

7.49. The requirements for emergency planning and preparedness specific to uranium fuel fabrication facilities are established in paras 9.62–9.67 and paras I.23 and I.24 of Appendix I of Ref. [1].

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

8. DECOMMISSIONING

8.1. Requirements for the safe decommissioning of a uranium fuel fabrication facility are established in Section 10 of Ref. [1]. Recommendations on decommissioning of nuclear fuel cycle facilities, including uranium fuel fabrication facilities, are provided in Ref. [10].

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

PREPARATORY STEPS

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

- Post-operational cleanout to remove all bulk amounts of uranium and other hazardous materials.
- 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.
- Decontamination of the facility to reach the levels required by the regulatory body for cleanup operations or the lowest reasonably achievable level of residual contamination.
- Preparation of risk assessments and method statements for the licensing of the decommissioning process.

DECOMMISSIONING PROCESS

8.4. It should be ensured that personnel deployed for 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.

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

- — Preventing the spread of contamination by means of appropriate techniques and procedures. In particular, the amount of liquids (water and chemicals) used for decontamination should be minimized to reduce the generation of waste.
- — The 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.

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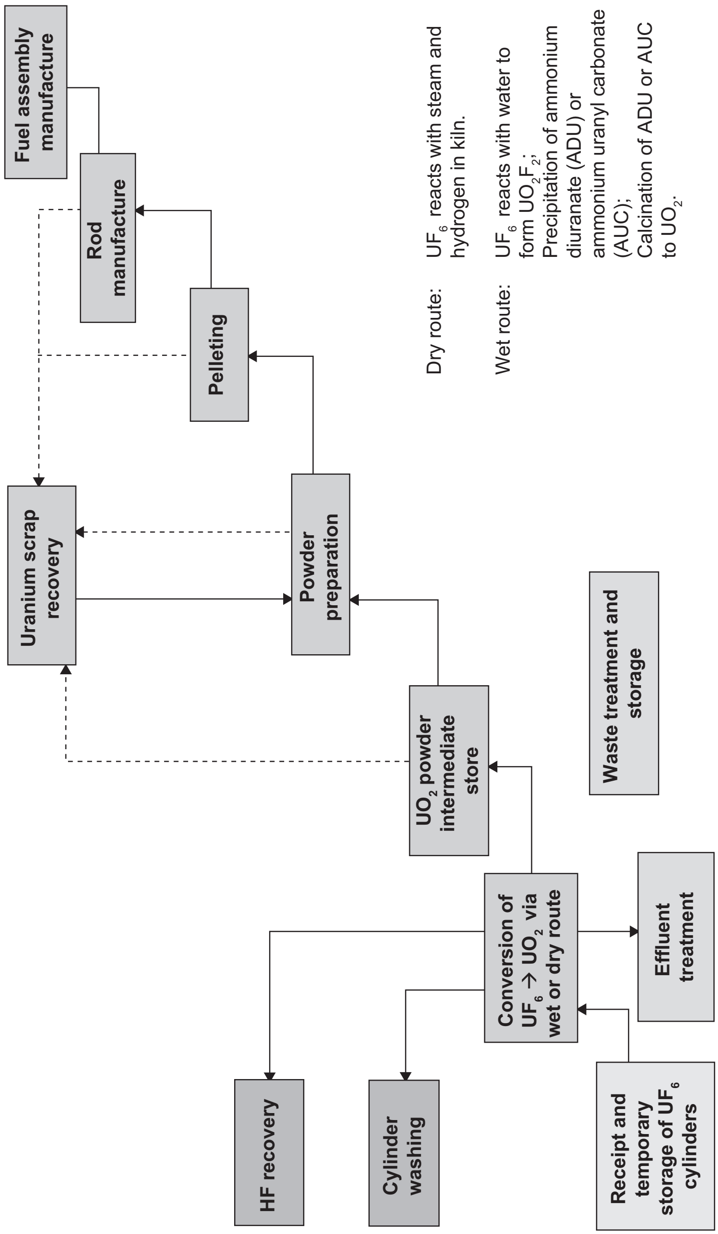
Annex I

TYPICAL PROCESS ROUTES IN A URANIUM FUEL FABRICATION FACILITY



Annex II

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

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

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged
Receipt and temporary storage of UF_6 cylinders	Means of transport	Rupture of cylinder	2
	Device for measuring enrichment of ^{235}U	Processing of uranium beyond safety limits	1
	Cylinder weighing scale	Rupture of cylinder	1, 2
	Shielding	Increase in dose rate	3
Conversion area	Vaporization furnace	Rupture of cylinder	1, 2
	Cylinder leak detection device	Release of uranium or HF	1, 2
	Cylinder high temperature detection device	Rupture of cylinder	1, 2
	Reaction vessel and rotary kiln	Release of uranium, HF and process gases; Degradation of criticality margin (moisture, geometry)	1, 2
	Kiln low temperature detection device	Water condensation in the kiln	1
	H_2 detection device	Explosion	2
	Measurement device to determine the humidity of the powder	Degradation of criticality safety margin (moisture)	1
	Tanks for HF	Release of HF	2

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged
	Facilities for treatment of off-gases	Release of HF to the environment	2
Intermediate storage of uranium oxide powder	Powder containers	Release of uranium Degradation of criticality safety margin (neutron absorber)	1, 2
	Scales	Degradation of criticality safety margin (mass)	1
	Shelves	Release of uranium Degradation of criticality safety margin (geometry)	1, 2
	Shielding	Increase in dose rate	3
Powder preparation	Storage areas, blenders, granulators, pipes	Release of uranium Bulging of vessel	2 1
	Device to control the amount of additives	Degradation of criticality safety margin (moisture)	1
	High moisture detection device in uranium powder hoppers	Degradation of criticality safety margin (moisture)	1
Pelleting shop	Presses	Release of uranium	2
	Sintering furnaces	Explosion	2
	H_2 detection device	Explosion	2
	Grinding machines	Release of uranium	2
	Sludge recovery from wet grinding	Degradation of criticality safety margin (geometry)	1
	Pellet storage	Degradation of criticality safety margin (geometry, neutron absorber)	1
Laboratory	Press, sintering furnace, grinding machine	See other process areas above	1, 2

Process area	Structures, systems and components important to safety	Events	Safety function initially challenged
	Storage shielding	Increase in dose rate	3
Fuel rod manufacturing	Rod loader	Release of uranium	2
	Welding machines	Release of uranium Fire due to zirconium particles	2
	Rod scanner	External exposure	3
	Fuel rod storage	Degradation of criticality safety margin (geometry, neutron absorber, moisture)	1
	Storage shielding	Increase in dose rate	3
Fuel assembly manufacturing	Assembling lines	Degradation of criticality safety margin (geometry, neutron absorber) Fire due to zirconium particles	1
	Cranes	Dropped assembly	1, 2
	Washing facilities	Degradation of criticality safety margin (geometry, neutron absorber)	1
	Fuel assembly storage	Degradation of criticality safety margin (geometry, moisture)	1
	Storage shielding	Increase in dose rate	3
Uranium scrap recovery	Furnaces, vessels, pipes	Release of uranium Degradation of criticality safety margin (geometry, mass) Explosion (H_2, chemicals) Fire	1, 2
Radioactive waste treatment	Treatment facilities	Release of uranium Release of chemicals Fire	1, 2

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

Annex III

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

Process area (including storage areas)	Parameters for defining operational limits and conditions
Area for receipt and temporary storage of UF_6 cylinders	Limited moderation Enrichment Mass UF_6 composition Surface contamination
Building	Leaktightness
Conversion area	Limited moderation Pressure Temperature Composition of the process gas HF content in the process off-gas Uranium content in by-products Surface contamination
Intermediate storage of uranium oxide powder	Limited moderation Mass in buckets Mass of absorber in drums Geometry of shelves Levels of surface contamination
Powder preparation	Geometry of slab hopper Integrity of powder lines and powder containers Amount of the additives (moderator) Limited moderation Mass in buckets Mass of absorber in drums Humidity of powder
Pelleting shop	Humidity of powder Mass in buckets Mass of absorber in drums Geometry of shelves Height of green pellets in sintering boats Temperature of sintering furnace Composition of atmosphere in sintering furnace Height of pellet tray stacks Geometry of shelves Levels of surface contamination

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

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