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Safety requirements of uranium fuel fabrication facilities

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Safety requirements of uranium fuel fabrication facilities

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Contents

Foreword

This standard is modified based on the International Atomic Energy Agency (IAEA) Safety Standard SSG-6 “SAFETY OF URANIUM FUEL FABRICATION FACILITIES”(2010 Edition).

Compared with the IAEA safety standard SSG-6, the main changes are as follows:

——some editorial modifications tothe IAEA security standard SSG-6 and the introduction and references of the IAEA security standard SSG-6deleted;

——foreword, scopeand normative references in this standard added;

——High temperature gas cooled reactorremoved from the scope of application;

——Risk of aircraft impact removed from the design basis accident;

——Additional requirements for flood control design in “External Initiating Flood” supplemented;

——some requirements about “design for convenient decommissioning” in the section of Convenient to decommission added.

Annex A, Annex and Annex of this standard are informative annexes.

Safety requirements of uranium fuel fabrication facilities

1 Scope

This standard specifies the safety requirements for the site evaluation, design, construction, commissioning, operation and decommissioning of the uranium fuel fabrication facility.

This standard applies to the operation, processing and storage of ^{235}U uranium fuel component manufacturers with a concentration of no more than 6% low enriched uranium (derived from natural uranium, enriched uranium or reprocessed uranium). Complete fuel assemblies (such asfuel assemblies for pressurized water reactors, boiling water reactors, and heavy water reactor) are stored in fuel fabrication facilities before being transported to nuclear power plants,and such storage facilities are also considered part of the uranium 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.

2 Normative references

The terms in the following documents become the terms of this standard by reference to this standard. For dated references, all subsequent amendments (not including errata content) or revisions do not apply to this standard. However, parties to agreements based on this standard are encouraged to study whether the latest versions of these documents are available. For undated references, the latest edition applies to this standard.

GB 14500 Regulations for radioactive waste management

GB 18871 Basic standards for protection against ionizing radiation and for the safety of radiation sources

GB 50223 Standard for classification of seismic protection of building constructionsEJ/T 20078—2014 Safety requirements of nuclear fuel cycle facilities

EJ 1056 Regulations for radiation protection for uranium processing and fuel fabrication facilities

HAD 002/07 Emergency preparedness and emergency response for operating organization of nuclear fuel cycle facility

HAD 301/01 Standard format and content of safety analysis reports for uranium fuel processing facilities

IAEA Safety Standards Series No. WS-G-2.4Decommissioning of Nuclear Fuel Cycle Facilities

3 General safety recommendations

3.1 large amounts of radioactive material are present in a dispersible form in uranium fuel fabrication facilities. This is more obvious in the early stages of the fuel fabrication process. Typical process routes for uranium fuel fabrication facilities are shown in Annex A. In addition, radioactive materials of different chemical and physical forms in uranium fuel component manufacturers are used with flammable or chemically active materials. Thus, in these facilities, the main hazards are potential criticality and releases of uranium hexafluoride (UF6) and UO2, from which workers, the public and the environment shallbe protected by means of adequate design and construction and by safe operation.

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

3.3 In uranium fuel fabrication facilities, only low enriched uranium is processed, so the potential for off-site radiation caused by accidents is expected to be limited. However, the radiological consequences of an accidental release of reprocessed uranium are more serious.Ifthefacility is allowed to process reprocesseduranium, this shall be taken into account in the safety assessment.

3.4 Uranium fuel fabrication facilities do not pose a potential radiation hazardwith the capacity to cause an accident with a significant off-site release ofradioactive material (in amounts equivalent to a release to the atmosphere of $^{131}I$with an activity of the order of thousands of terabecquerels). However, deviationsin processes may develop rapidly into dangerous situations involving hazardouschemicals.

3.5 When applying the requirements of defence in depth principle in a facility (see 3.2 of EJ/T 20078-2014), risks can be reduced to insignificant levels by design and proper operational procedures (see Chapters 5 and 8), thus the first two levels of defense in depth are the most important.

4 Site evaluation

4.1 The site evaluation process for a uranium fuel fabrication facility involves a large number of standards, and in the initial stages of facility planning, consideration shall be given to the safety importance of the standards and a catalogue of applicable standards shall be developed. In most cases, it is unlikely that all the desirable criteria can be met, but the risks of safety significantexternal events (earthquakes, aircraft crashes, fires and extreme weather conditions) are the major factors in the site evaluation process. These risks shall be considered in conjunction with appropriate design specifications, process and operational limits, and economics. These risks shall be compensated for by appropriate design, process and operational limits and possible economic adjustments.

4.2 The density of population in the vicinity of a uranium fuel fabrication facility and the direction of the prevailing wind at the site shall be considered in the site evaluation process to minimize any possible health consequences for people in the event of a release of hazardous chemicals.

4.3 The site for a uranium fuel fabrication facility shallbe away fromaircraft routes and airports.

4.4 The site for a uranium fuel fabrication facility shall be as convenient as possible for the final decommissioning.

4.5 A full record shall be kept of the decisions taken on the selection of a site for a uranium fuel fabrication facility and the reasons behind those decisions.

5 Design

5.1 General

5.1.1 Safety functions for uranium fuel fabrication facilities

Design of uranium fuel fabrication facilities shall prevent nuclear critical accidents and accident release of hazardous materials. The design shall keep radiation exposures from normal operations as low as reasonably achievable. The loss of safety functions of uranium fuel fabrication facilities can have radiological or chemical hazards to workers, the public or the environment. Therefore, the safety functions of the uranium fuel fabrication facilities are designed to achieve the following objectives (functions):

a) Prevention of criticality;
b) Prevention of internal exposure and chemical hazards;
c) Prevention of external exposure.

5.1.2 Engineering design principles

The following requirements apply:

a) The requirements for preventing criticality as established in 6.5.3 and A.2.3 of EJ/T 20078—2014;
b) The requirements for preventing internal exposure and chemical hazards are given in 6.5.1, 6.6 and

A.2.4 of EJ/T 20078-2014;

c) The requirements for preventing external exposure are given in 6.5.2 of EJ/T 20078-2014. For a facility licensed to use LEU from sources of uranium other than natural uranium, because of the higher specific activity, particular care shall be taken to minimize contamination. The need for shielding shall be considered for the protection of workers from the associated higher dose rates of gamma radiation.

5.1.3 **Design basis accidents and safety analysis**

5.1.3.1 Requirements for design basis accidents are shown in 6.2 of EJ/T 20078-2014.

5.1.3.2 The specification of a design basis accident will depend on the facility design and on national criteria. Particular consideration shall 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) Fire;
f) Natural disasters, such as earthquakes, floods or extreme winds (some old facilities are designed without considering natural disasters, and these natural phenomena shall be considered in the design of new facilities).

5.1.3.3 a) and b) of 5.1.3.2 mainly lead to radiological consequences for on-site workers, but also result in some adverse off-site consequences for people or the environment.c) ~ f) of 5.1.3.2 will lead to the release of chemical substances with both on- and off-site consequences.

5.1.3.4 The events in 5.1.3.2 mayoccur as postulated initiating event (PIE). Selected PIEs are listed in Annex F of EJ/T 20078-2014.

5.1.4 **Structures, systems and components important to safety**

The likelihood of design basis accidentsshall be minimized and their radiological consequences and associated chemical consequences shall be controlled by means of structures, systems and components important to safety and appropriate administrative measures (operational limits and conditions). Annex B presents examples of structures, systems and components important to safety and representative events that may challenge the associated safety functions.

5.2 Safety functions

5.2.1 Prevention of criticality

5.2.1.1 For the prevention of criticality by means of design, the double contingency principle shall be the preferred approach. Operational parameters shall be controlled within sub-critical limits during normal operation to achieve critical safety for anticipated operational events. Here are some examples of application of typical parameters:

a) Mass control, 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;
b) Geometry control, 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;
c) Concentration control, concentration of fissile material in solutions, e.g. in the wet process for recycling uranium;
d) Neutron absorbers: presence of appropriate neutron absorbers, e.g. in the construction of storage areas, drums for powder and fuel shipment containers;
e) Moderation restriction: e.g. by means of control of moisture levels and the amount of additives in

powder.

5.2.1.2 The aim of criticality analysis is to demonstrate that the design of the equipment is such that the values of the controlled parameter are always maintained in the subcritical range. This aim is usually achieved by determining the effective multiplication factor (keff), 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 keffshall be compared with the design limit.

5.2.1.3 Several methods can be used to perform the criticality analysis, such as the use of experimental data, reference books or consensus standards, calculations, etc.

5.2.1.4 The methods of calculation vary widely in basis and form. The general procedure followed by critical safety analysis shall be:

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

5.2.1.5 The criticality analysis of uranium fuel fabrication facilities shall consider the following factors separately or in combination:

a) Mass. The mass margin shall 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;
b) Geometry of processing equipment. The analysis shall cover possible changes in dimensions due to operation (e.g. bulging of slab tanks or slab hoppers);
c) Concentration and density. The analysis shall cover:
    1) uranium concentrations for solutions;
    2) powder and pellet densities plus moderators for solids, to determine the most reactive conditions that could occur.
d) Moderation. The analysis shall 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 shall be given to cases of inhomogeneous moderation, in particular when transfers of fissile material take place;
e) Reflection. The most conservative margin shall be retained of those resulting from different assumptions, such as a hypothetical thickness of water around the processing unit, consideration of the neutron reflection effect due to the presence of human beings, organic materials, wood, concrete, and steel of the container;
f) 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 shall be considered in the analysis.

5.2.2 **Protection against internal exposure and chemical hazards**

5.2.2.1 **Overview**

5.2.2.1.1 To meet the requirement on protection of workers, the public and the environment against releases of hazardous material, the use of and the inventory of liquid UF6 in afacilityshall be kept to a minimum. As such a uranium fuel fabrication facility shall 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.

5.2.2.1.2 The use of a suitable containment system is the primary means of preventing the spread of dust pollution from areas containing large amounts of uranium compound dust or other hazardous gaseous substances. To improve the effectiveness of the static containment system (physical barriers), a dynamic containment system shall be used to create pressure gradients to cause a flow of air towards parts of equipment or areas that are more contaminated. A cascade of reducing absolute pressures can thus be established between the environment outside the building and the hazardous material inside.

5.2.2.1.3 In the design of the ventilation and containment systems for a uranium fuel fabrication facility, it shall consider:

a) Pressure difference between different parts of the premises;
b) Air replacement ratio in the facility;
c) Types of filters to be used;
d) Maximum differential pressure across filters;
e) Appropriate flow velocity at the openings in the ventilation and containment systems (e.g. the acceptable range of air speeds at the opening of a hood);
f) Dose rate at the filters.

5.2.2.2 **Protection of workers**

5.2.2.2.1 Ventilation systems shall be used to reduce one of the means by which workers are exposed to radiation exposure and exposure to hazardous chemicals (which may become airborne and may be inhaled by staff). Uranium fuel fabrication facilities shall be designed with appropriately sized ventilation and containment systems in areas of a facility identified as having potential for giving rise to significant concentrations of airborne radioactive materials and other hazardous materials.

5.2.2.2.2 Inclusion and ventilation systems shall be carefully designed to minimize the need to use protective breathing equipment.

5.2.2.2.3 Unless it can be shown that the ventilation ducts and air flow rate are designed to prevent uranium powder from depositing in the pipeline, the main filter shall be located as close as possible to the source of contamination in areas where uranium aerosols may be present. Multiple filters in series shall be used to avoid reliance on a single barrier. In addition, duty and standbyfilters and fans shall be provided to ensure continuous functioning of the ventilation system; if not available, it shall be ensured that failure of the duty fan or filters will result in the safe shutdown of equipment in the affected area.

5.2.2.2.4 If necessary, monitor equipment shall be installed in the ventilation system, such as differential pressure gauges (on filters, between rooms and inside and outside the glove box), equipments measuring uranium concentration or gas concentration.

5.2.2.2.5 Alarm system shall be installed to alert operators when the exhaust fan fails or the pressure differential is exceeded. At design stage, uranium aerosol contamination monitoring equipment and/or gas monitoring equipment shall be installed. The monitoring point shall be selected at a location that could correspond most accurately to the exposure of the staff and can detect the leak as quickly as possible.

5.2.2.2.6 To prevent fire from spreading through the ventilation ducts and maintainthe integrity of the firewall, and considerthe corrosion of hydrogen fluoride, etc., the ventilation system shall be equipped with fire dampers as much as possible and shall be made of non-combustible materials.

5.2.2.2.7 To facilitate decontamination and eventual decommissioning of a facility, the walls, floors and ceilings in areas of the uranium fuel fabrication facility where contamination shall 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 shall be made readily accessible to allow for periodic decontamination as necessary.

5.2.2.3 **Protection of the environment**

5.2.2.3.1 The number of physical barriers used in the containment system shall be adapted to safety significance of the hazard. According to the principle of redundancy (see G.1 of EJ/T 20078-2014), the minimum number of barriers is two. The optimal number of barriers is usually three. The design shall also provide monitoring of the environment surrounding the facility and detection of damage to the containment barrier.

5.2.2.3.2 If all containment barriers are destroyed, the radioactive material produced by the accident will spread uncontrollably into the environment. The barrier includes the process equipment itself, the room or the building. In addition, the ventilation system reduces the environmental emissions of radioactive materials to a very low level by discharging the exhaust gases through a gas purification device (such as a filter) and then discharging them from the chimney. In such cases, the ventilation system may also be regarded as a containment barrier.

5.2.3 **Protection against external exposure**

5.2.3.1 The external dose can be controlled by a combination of time, distance and shielding. For storage areas of cylinders, consideration shall be given to installing shields or setting stay restrictions, especially for empty cylinders that have containedreprocessed uranium, because some by-products of irradiation will remain in the cylinder. Similar precautions shall be taken in areas of the facilitywith high uranium density and large quantities (such as pellets and fuel storage areas).

5.2.3.2 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 shall be taken to limit the exposure of workers to the decay products (208Tl and 212Bi) of 232U. 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.

5.3 Postulated initiating events

5.3.1 Internal initiating events

5.3.1.1 **Fire and explosions**

5.3.1.1.1 **General requirements**

5.3.1.1.1.1 Uranium fuel fabrication facilities shallbedesignedforfire protection in order to protect workers, the public and the environment. Fires in uranium fuel fabrication facilities can destroy containment barriers, which can lead to the spread of radioactive or toxic substances, or can affect systems or parameters used for critical control (e.g. the dimensions of processing equipment or the moderation control system), leading to criticality accident.

5.3.1.1.1.2 The fire hazards that are specifically encountered in a uranium fuel fabrication facility, such as hazards due to solvents and hydrocarbon diluents, H2O2, anhydrous ammonia (NH3, 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, shall be given due consideration at the design stage for the facility.

5.3.1.1.2 **Fire hazard analysis**

5.3.1.1.2.1 A very important aspect of fire hazard analysis is the identification of areas that require special consideration. Special fire hazard analysis shall be conducted for:

a) Processes involving hydrogen, such as conversion, sintering and reduction of uranium oxide;
b) Processes involving the machining of zirconium powder or zirconium metal;
c) Workshops involving flammable liquids and/or combustible liquids, such as flammable liquids and/or flammable liquid recovery shop and laboratories used in solvent extraction;
d) Storage of reactive chemicals (e.g. NH3, H2SO4, HNO3, H2O2, 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 with safety-related equipment (items such as air filtering systems, whose degradation may lead to radiological consequences that are considered to be unacceptable);
h) Control rooms.

5.3.1.1.2.2 Fire hazard analysis involves identifying the cause of the fire, assessing the potential consequences, and assessing the probability or frequency of the fire when feasible. Fire hazard analysis is used to evaluate the inventory of fuels and initiation sources, and to determine the appropriateness and adequacy of fire protection measures. Computer modeling of fires may sometimes be used in support of the fire hazard analysis.

5.3.1.1.2.3 The estimation of the likelihood of fires can provide valuable information for making decisions or identifying weak points that have not yet been discovered. When a fire can have serious safety consequences, even if the estimated likelihood may seem low, reliable protection measures shall be taken, such as dividing the fire zone to prevent or reduce the spread of the fire.

5.3.1.1.2.4 The fire hazard analysis shall also include a review of the measures taken during the design phase for fire prevention, detection and suppression.

5.3.1.1.3 **Fire prevention, detection and mitigation**

5.3.1.1.3.1 Fire prevention is the most important aspect of fire protection. In the design ofa facility, comprehensive measures shall be taken to ensure that no fires occur and the risk of fire is limited; although fires may occur despite prevention, measures shall be taken to minimize the impact of fire.

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

a) Separation of the areas where non-radioactive hazardous material is stored from the process areas;
b) Minimization of the fire load of individual rooms;
c) Selection of materials based on functional requirements and fire rating, including materials used for building components, penetrations and cables related to safety critical building structures, systems and components;
d) Compartmentalization of buildings and ventilation ducts as far as possible to prevent the spreading of fires. Buildings shall be divided into fire zones. Measures shall 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 shall have;
e) Suppression or limitation of the number of possible ignition sources such as open flames or electrical sparks.

5.3.1.1.3.3 Fire extinguishing devices, automatically or manually operated, with adequate extinguishing agent, shall be installed in zones where the outbreak of a fire is possible. 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. Consideration shall be given to minimizing the environmental impact of the water used to extinguish fires.

5.3.1.1.3.4 The design of ventilation systems shall be given particular consideration with regard to fire prevention. Ventilation ducts and filter units are part of the dynamic containment and shall be properly designed to avoid becoming a weak link in the system. Fire dampers shall be mounted in the ventilation system unless the likelihood of widespread fires is acceptably low. The fire dampers shall close automatically on receipt of a signal from the fire detection system or by means of temperature sensitive fusible links. Spark arrestors shall be used to protect the filters if necessary. The required operational performance of the ventilation system shall be specified so as to comply with fire protection requirements.

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

5.3.1.1.4 **Explosions**

5.3.1.1.4.1 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.

5.3.1.1.4.2 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) Solid compounds such as ammonium nitrate used in recycling workshops.

5.3.1.1.4.3 In such situations, consideration shall 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 shall 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.

5.3.1.2 **Flooding**

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

5.3.1.2.2 In facilities where vessels and/or pipes containing water are present, the criticality analyses shall take into account the presence of the maximum amount of water that could be contained within the room under consideration, as well as the maximum amount of water in any connected rooms.

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

5.3.1.3 **Leaks and spills**

5.3.1.3.1 Leaks from equipment and components such as pumps, valves and pipes can lead to the dispersion of radioactive material (e.g. UO2, U3O8 powder and UF6) 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 (H2, natural gas, propane) or liquids can lead to explosions and/or fires. Leak detection systems shall be deployed where leaks could occur.

5.3.1.3.2 Vessels containing significant amounts of nuclear material in liquid form shall be equipped with level detectors and alarms to prevent overfilling and with secondary containment features such as bunds or drip trays of appropriate capacity and configuration to ensure criticality safety.

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

5.3.1.4 **Loss of support systems**

5.3.1.4.1 Safety-critical buildings, systems, and components shall perform their safety functions when they lose support systems (such as power systems, air compressor systems, fluid cooling or heating systems); otherwise, fail-safe designs shall be used.

5.3.1.4.2 To fulfill the requirement, an emergency power supply shall be provided for:

a) Criticality accident detection and alarm systems;
b) Monitoring systems for radiation protection and environmental protection;
c) Ventilation system necessary for sealing hazardous materials;
d) Detection and alarm systems for leaks of hazardous materials (including explosive gases);
e) Some process control components (e.g. heating elements and valves);
f) Fire detection and alarm systems;
g) Fire pumps, if fire water is dependent on off-site electric power.

5.3.1.4.3 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:

a) Interruption of the gas supply to the safety valves and dampers: According to the safety analysis, a fail-safe valve shall be used;
b) Loss of cooling or heating water: Adequate backup capacity or a redundant supply shall be provided in the design;
c) Loss of breathing air: Backup capacity or a redundant supply shall be provided to allow work in areas with airborne radioactive material to continue to be carried out.

5.3.1.5 **Insufficient or excessive amounts of process media**

Insufficient or excessive amounts of process media such as hydrogen, nitrogen or steam can have an impact on safety, and at least the following hazards shall be considered in safety assessments:

a) Incomplete chemical reactions, potentially leading to a release of UF6 into the off-gas treatment system;
b) Loss of leaktightness of equipment used for transporting uranium powder if a nitrogen flow is used for sealing;
c) Due to excessive process gas, geometric safety or slow control failure is caused, resulting in loss of critical safety;
d) Increase of levels of airborne contamination and/or concentration of hazardous material due to overpressure of the equipment;
e) Reduced concentration of oxygen in the air in the working area due to the release of a large amount of nitrogen.

5.3.1.6 The pressure and flow of the process gas shall be continuously controlled. If flow and pressure deviations occur, the shutdown and/or lockout procedure shall be initiated automatically.

5.3.1.7 **Mechanical failure**

5.3.1.7.1 Particular consideration shall 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.

5.3.1.7.2 The design shall minimize potential mechanical impact on containers filled with hazardous materials by mobile devices such as vehicles and cranes. The design shall minimize the movement of heavy objects above the containers and pipes containing large quantities of hazardous or radioactive materials to prevent heavy drops from causing severe radioactive releases.

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

5.3.2 **External initiating events**

5.3.2.1 **Earthquakes**

5.3.2.1.1 A uranium fuel fabrication facility shall design for design basis earthquakes to ensure that ground motion during the earthquake does not induce a loss of confinement capability (especially for confinement of UF6 and HF) or criticality accident (i.e. the loss of critical safety functions caused by earthquakes, such as geometry and moderation) with possible significant consequences for site personnel or members of the public.

5.3.2.1.2 In order to clarify the design basis earthquake of the plant, the main characteristics of the crustal movement (strength, magnitude and source distance) and local specific geological features shall be determined. The method used shall be based on theoretically assessing seismic factors based on historical data at the location. Where historical data are insufficient or there is a large amount of uncertainty, attempts shall be made to collect paleo-earthquake data to determine the strongest earthquakes that have been experienced in the history of the area over a longer period of time. Since the auditing agency usually considers the results based on historical data assumptions and the results based on paleo-earthquake data when approving the design, different methods can be combined.

5.3.2.2 A well-conserved seismic spectrum shall be used to calculate the structural response to ensure the stability of the building at the time of the earthquake and to ensure the integrity of the final seal. Certain safety-critical buildings, systems, and components shall meet seismic safety requirements. This requirement applies primarily to storage equipment and containers containing large quantities of radioactive or toxic chemicals. The design calculations for buildings and equipment shall be verified. If an earthquake occurs, unacceptable release of radioactive materials or toxic substances will not occur, and the risk of a critical accident is very low.

5.3.2.3 **External fires and explosions**

5.3.2.3.1 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.

5.3.2.3.2 To demonstrate that the risk of these external hazards is below acceptable levels, the operating organization shall identify all potential hazards and assess the order of impact. The radiological and chemical consequences of all damages shall be evaluated and the consequences shall be within acceptable standards. Toxicity hazards shall be assessed to verify that the specific gas concentration meets the licensing criteria. It shall be ensured that external harmful gases do not adversely affect workers or adversely affect plant control capabilities. The operating organization shall conduct an investigation into the operation of the transportation of potentially dangerous devices and hazardous materials in the vicinity of the facility. In the event of an explosion, a risk assessment shall be carried out using the overpressure criteria. In order to evaluate the possible effects of flammable liquids, collapses (such as chimneys) and missiles generated by explosions, their distance from the facility and their probability of causing physical damage shall be evaluated.

5.3.2.4 **Extreme weather conditions**

5.3.2.4.1 **Overview**

5.3.2.4.1.1 Design and safety evaluation of a uranium fuel fabrication facility shall concern are wind loading, tornadoe, tsunamis, rainfall, snowfall, extreme temperature and flooding.

5.3.2.4.1.2 For such extreme weather conditions, deterministic design basis value is generally used to determine and assess the impact of these events on facility safety. Follow the rules in the National Building Code when obtaining design baseline data for evaluation.

5.3.2.4.1.3 Design measures vary with the type of hazard and its impact on facility safety. For example, extreme wind loads are related to transient structural loads, so the design of an extreme wind load event shall be designed in the same way as other potential transient load events, such as earthquakes. However, extreme precipitation or extreme temperatures have a development process, so there is time to take operational actions to limit the consequences of such events.

5.3.2.4.1.4 A uranium fuel fabrication facility shall be protected against extreme weather conditions by means of appropriate design provisions. These shall generally include:

a) The ability of structures important to safety to withstand extreme weather loads;
b) The prevention of flooding of the facility;
c) The safe shutdown of the facility in accordance with the operational limits and conditions.

5.3.2.4.2 **Extreme wind**

5.3.2.4.2.1 Protection against extreme winds (such as tornadoes) depends on meteorological conditions in the area where the uranium fuel fabrication facility is located. Buildings and ventilation systems shall be designed to meet special regulations related to extreme wind hazards.

5.3.2.4.2.2 Since extreme winds (storms) can blow and push objects such as cars or utility poles, the possibility of collision of these missiles shall be considered during the design phase, taking into account not only the initial impact but also role of the secondary fragments from the flying of concrete walls or other types of power.

5.3.2.4.3 **Extreme temperature**

5.3.2.4.3.1 The duration of very low or very high temperatures shall be considered in the design of the support system equipment to avoid unacceptable effects such as freezing of the cooling circuit or adverse effects on the drainage and cooling system.

5.3.2.4.3.2 If safety limits for humidity and/or temperature are specified in the building or compartment, the air conditioning system shall be designed to operate effectively under extreme heat or humidity conditions.

5.3.2.4.4 **Snowfall**

Snowfall and its effects shall 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, shall be considered.

5.3.2.4.5 **Flood**

The flood control design of a uranium fuel fabrication facility shall be carried out according to the flood of no less than 200 years, and shall be checked according to the largest recorded flood. Two approaches are proposed to deal with this type of danger:

a) nuclear facilities are sited at specific locations or at a sufficient elevation to avoid major damage from flooding;

b) When a dam is built on an anticipated nuclear facility site or an upstream river at an existing nuclear facility site, the design of the building shall be considered to withstand flooding caused by the dam. In such cases the equipment, especially that used for the storage of fissile material, shall be designed to prevent any criticality accident.

5.4 Instrumentation and control (I&C)

5.4.1 Instrumentation

5.4.1.1 The appropriate instrumentation shall be installed to monitor the facility and system parameters beyond the normal operating range, expected operating event range, and design basis accident coverage, to ensure that adequate facility status information is available, and to ensure that appropriate actions are taken in accordance with operational procedures or relying on automated systems.

5.4.1.2 Instrumentation shall provide all key parameters that affect the overall safety status of the process and facility (internal and external exposure, effluent discharge and ventilation conditions) and obtain all necessary information about the safe and reliable operation of the facility. It shall be possible to automatically measure safety important parameters and record the results.

5.4.2 Control systems

5.4.2.1 Passive and active engineering controls are more reliable than administrative controls and shall be preferred for control in normal operational states and in accident conditions. Automatic systems shall 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.

5.4.2.2 In order to monitor the effects of automatic control actions, the operator shall be able to obtain the appropriate information. The layout of instrumentation and the manner of presentation of information shall provide the operating personnel with an adequate impression of the status and performance of the facility. Appropriate equipment shall be installed to provide an effective visual signal (and an audible signal if necessary) when the operating conditions deviate from normal operating conditions and may affect safety.

5.4.3 Control rooms

Control rooms shall be provided to centralize the main data displays, controls and alarms for general conditions at the facility. Occupational exposure shall 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 shall 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 shall be taken into account in the design of control rooms.

5.4.4 Safety related I&C systems for normal operation

Safety related I&C systems for normal operation shall include:

a) Process control instrumentation, indicating temperatures, pressures, tank levels, etc;

b) Control and monitoring of ventilation. used mainly to control and monitor differential pressures across high efficiency particulate air (HEPA) filters, prefilters, pressure difference of the exhaust enclosure and air flows, as necessary;

c) Radiation dosimetry:

   1) 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);

   2) 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).

d) 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 shall be sufficient.

5.4.5 Safety related I&C systems for anticipated operational occurrences

In addition to 5.4.4, safety related controls during anticipated operational events shall also include:

a) All rooms with fissile and/or toxic chemical material shall be equipped with fire alarms (except where the permanent presence of operators is sufficient);

b) Gas detectors shall be used in areas where a leakage of gases (e.g. H2 or heating gas) could produce an explosive atmosphere.

5.4.6 Safety related I&C systems for design basis accident conditions

In addition to the above, safety related controls for design basis accident conditions shall also include:

a) Criticality: Radiation detectors (gamma detectors and/or neutron detectors) shall be installed in all areas where there is a large amount of fissile material, with an audible alarm that initiates immediate evacuation from the affected area, and where necessary, visible alarm, unless it can be proved that a critical event is extremely unlikely;

b) Release of chemical substances:Detectorsshall be installed and restricted in areas where there is a large amount of chemical hazardous substances, unless chemical release is highly unlikely;

c) Release of effluents. The devices used for measuring releases of gaseous and liquid effluents in operational states shall 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 shall be used to estimate the releases of gaseous and liquid effluents.

5.5 Human factor considerations

5.5.1 Human factors and human-machine interfaces shall be considered throughout the design process. Ergonomic principles shall be applied in control room and dashboard design. It shall be able to provide the operators with clear display signals and sound signals of important safety parameters.

5.5.2 The design shall minimize the number of workers required for normal operation and expected operational events and accident conditions, such as advancing successful operations with appropriate automatic actions. For the anticipated and predictable human error, the necessity of using appropriate controls (such as linkages, keys and passwords) shall be considered in the design.

5.5.3 The human factors involved in operation, non-stop inspection, periodic testing and maintenance shall be considered during the design phase, including:

a) Possible effects on safety of unauthorized human actions (consider the convenience of operator regulation and the tolerance of personnel negligence);

b) The potential for occupational exposure.

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

a) Design of working conditions to ergonomic principles:

1) The operator–process interface, e.g. electronic control panels displaying all necessary information and no more.

2) 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.

5.6 Safety analysis for uranium fuel fabrication facilities

5.6.1 Overview

5.6.1.1 Safety analysis for uranium fuel fabrication facilities shall be performed in two major steps:

a) The assessment of occupational exposure and public exposure for operational states of a facility and comparison with authorized limits for operational states;
b) Determine the radiological and chemical consequences of a particular design basis accident (or the equivalent) for the public and staff and confirm that they are within the limits specified by the regulatory body.

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

5.6.1.3 The safety analysis report for uranium fuel fabrication facilities shall meet HAD 301/01.

5.6.2 **Safety analysis for normal operational states**

5.6.2.1 **Occupational exposure and exposure of the public**

5.6.2.1.1.1 Estimates of occupational exposure and exposure of the public shall be specific, realistic, comprehensive and conservative.

5.6.2.1.1.2 Calculations of the source term shall use: the material with the highest specific activity, the licensed inventory of the facility and the maximum material throughput that can be processed by the facility. The poorest performances of barriers in normal operation shall be used in the calculations. A best estimate approach may also be used.

5.6.2.1.1.3 Calculations of the estimated doses due to occupational exposure shall be made on the basis of the conditions at the most exposed workplaces and shall 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.

5.6.2.1.1.4 Calculations of the estimated doses to the public (i.e. a 'critical group' of people living in the vicinity of the facility) shall be made on the basis of maximum estimated releases of radioactive material to the air and to the water and maximum depositions to the ground. Conservative models and parameters shall be used to calculate the estimated doses to the public.

5.6.2.2 **Releases of hazardous chemical material**

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

5.6.3 **Safety analysis for accident conditions**

5.6.3.1 **Methods and assumptions for safety analysis for accident conditions**

5.6.3.1.1.1 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 materials or hazardous chemicals, the distance between the individuals exposed or affected and the source of the release, pathways for the transport of material to the individuals and the exposure times.

5.6.3.1.1.2 In order to estimate the on- and off-site consequences, the model of the accident analysis shall cover a variety of event sequences that may result in the release of radioactive material into the environment and give enveloping cases.

5.6.3.1.1.3 The following approaches shall 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 nonsafety-related features beyond their originally intended range of functions to reduce the consequences of accidents (the best estimate approach);
b) An enveloping case (worst case method) that does not consider any safety device that mitigates the consequences of an accident or reduces the probability of an accident, and then evaluates the sequence of the accident, considering emergency procedures and planning methods for mitigating the consequences of the accident.

5.6.3.2 **Assessment of possible radiological or chemical consequences**

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

a) Analysis of actual site conditions and expected site conditions;
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.
d) Identify and analyze facility conditions, including internal initiating events and external initiating events that result in potential adverse effects of release or release of energy, and the range of emitted (radiation) time and exposure time predicted from a reasonable scenario;
e) Describe in detail the safety-critical structures, systems, and components that can be trusted to reduce the consequences of accidents and reduce the probability of accidents. These safety-critical building structures, systems and components shall 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.

5.6.3.2.1.2 Analysis of actual and expected site conditions includes review of site meteorological, geological, and hydrological conditions that may affect the operation of the facility or play an important role in the transport or energy transfer of the material released by the facility.

5.6.3.2.1.3 Environmental migration calculations shall be performed using approved procedures or using data obtained from approved procedures, taking into account site meteorological and hydrological conditions that result in the highest public dose.

5.6.3.2.1.4 The identification of staff and the public (the key group of persons who are the most exposed off-site personnel) who may be affected by the accident shall include a review of the facility description and demographic information.

5.7 **Management of radioactive waste**

5.7.1 The management of radioactive waste shall meet the requirements of relevant standards such as GB 18871 and GB 14500.

5.7.2 Under the premise of ensuring waste safety, the principle and practice of minimizing radioactive waste shall be adhered to, firstly to ensure the minimization of radioactive waste generated during the operation and decommissioning of uranium fuel fabrication facilities. Strengthen the operation and decommissioning period of uranium fuel component manufacturing plants to further reduce the generation of radioactive waste. For economic and environmental reasons, uranium recovery and chemical reuse are typically carried out in uranium fuel component manufacturing plants to minimize the amount of solid and liquid waste.

5.7.3 It is good practice to reduce the radioactive waste at the in-plant waste treatment facility and minimize its chemical activity. Some elements of the waste treatment facility are:

a) A dedicated workshop for waste treatment;
b) Equipment for decontamination;
c) The means for conditioning waste;
d) Devices for measuring activity;
e) A system for ensuring the identification and traceability of and record keeping for waste products;
f) Sufficient capacity for storage of waste.

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

5.7.5 Waste pre-treatment and disposal routes shall be considered to reduce the impact on the overall environment.

5.8 Management of gaseous and liquid releases

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

5.8.2 Monitoring equipment shall 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.

5.9 Convenient decommissioning

5.9.1 Design features considered for convenient decommissioning including:

a) Ability to maintain and monitor over long distances;
b) Compartmentalization of process functions;
c) Protective layers and linings in the process and process areas where liquid may be present;
d) Easy access to process equipment, structures, systems and components;
e) Materials or equipmentscan be easily removed and/or decontaminated;
f) Internal decontamination mechanisms;
g) Possible processes for reducing the amount of waste;
h) Configuration, dimensional positioning and layout of process equipment;
i) Recyclability of the waste generated or the temporarily stored waste;
j) Lifting and handling equipment;
k) Ventilation and effluent systems;
l) Ease of removingmodular construction of structures, systems, equipment and components that are not easily decontaminated (e.g.mechanical and electronic components that are easily separated).

5.10 Other design considerations

5.10.1 Consideration shall be given to limiting uranium accumulation, ease of cleaning, and surface decontamination in the initial stages of facility and equipment design, including material selection.

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

6 Construction

6.1 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 facilities and for their installation shall be the same as or more stringent than those used for the non-nuclear chemical industry, and shall be specified as part of the design (e.g. seismic design).

6.2 The scope of the management regulations to be followed during construction shall be compatible with the hazards presented by the facility during its lifetime. In order to improve future operational safety, in addition to the operating unit's procedures for maintaining control over construction, the construction site shall be inspected frequently and fed back to the design department.

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

6.4 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.

7 Commissioning

7.1 For a uranium fuel fabrication facility, the commissioning shall be divided into two main phases: ‘cold’ commissioning (i.e. commissioning prior to the introduction of uranium into the facility) and ‘hot’ commissioning (i.e. commissioning with the use of uranium).

7.2 During the cold test phase, the facilities of each facility are tested in a planned manner from both individual items of equipment to the systems in their entirety. Since it is relatively easy to implement any required corrective actions at this stage, as much verification and testing as possible shall be performed. Of course, due to the low radiation levels of uranium fuel component manufacturers, some of these activities can also be carried out in the next phase. The operating organization shall seize the opportunity to solidify the operational documents.

7.3 The safety test performed during the hot test phase shall be mainly for the inspection of the seal and the inspection of the radiation protection and chemical protection, which shall include:

a) Airborne radioactive material and checks of levels of exposure at the workplace;
b) Surface contamination monitoring (smear inspection or direct measurement);
c) Gaseous discharges and releases of liquids;
d) Checks for the unexpected accumulation of material.

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

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

7.4.1 The operating organization shall use the commissioning period to train the operating personnel in the operation and maintenance of the facilities. Training shall also include verification of operational documentation such as operational procedures, maintenance procedures, emergency procedures, management procedures, and operational limits and conditions.

7.4.2 The verification shall be completed before the official operation. The commissioning phase also provides conditions for the operating organization to be familiar with the facility. Facility managers shall use this phase to establish a positive safety culture and good code of conduct throughout the plant.

7.5 During commissioning and later during operation of the facility, the estimated doses to workers that were calculated shall be compared with the actual doses or dose rates. If, in operation, the actual doses are higher than the calculated doses, corrective actions shall 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.

8 Operation

8.1 Overview

8.1.1 The distinctive features of a uranium fuel fabrication facility that shall be taken into account in meeting the safety requirements:

a) To process, handle and store in large inventories in finely divided and dispersible forms, the relatively low radiotoxicity of LEU;
b) 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);
c) 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).

8.1.2 Compared to other types of fuel cycle facilities, uranium fuel component manufacturers use less automated systems to ensure safety; More emphasis is placed on management measures to ensure safe operation.

8.1.3 To meet safety requirements, this chapter gives specific recommendations on good practices and additional considerations.

8.2 Qualification and training of personnel

8.2.1 The safety requirements relating to the qualification and training of facility personnel are established in 9.1.3 of EJ/T 20078-2014.

8.2.2 In a uranium fuel fabrication facility, special attention shall be paid to the training and qualification of personnel engaged in radiological hazards (mainly criticality and pollution) and specific conventional hazards (such as chemical hazards or fires).

8.2.3 Improper response to fires and explosions in the facility can exacerbate the consequences of events such as radiological hazards, including chemical hazards. The operating organization shall organize specialized training and drills for staff and external fire and rescue teams.

8.2.4 Staff shall be regularly trained on basic radiation safety

8.3 General recommendations for facility operation

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

8.3.2 An operational document shall be developed listing all limits and conditions for the operation of the facility. See Annex C for operational limits and conditions in each process area of a uranium fuel fabrication facility.

8.3.3 General limits shall also be set for a facility. Examples of such limits are:

a) The maximum enrichment of uranium allowed at the facility;
b) The specification for UF6 cylinders and the maximum inventory of UF6 cylinders allowed in the storage area;
c) The maximum amount of process allowed and the maximum amount of facilities.

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

8.3.5 An operational procedure that directly controls the operation of the process shall be established. The procedure shall include guidance on the safe state of all anticipated operational events and accident conditions. This type of procedure shall include the measures required to ensure criticality, fire, contingency planning and environmental protection.

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

8.4 Maintenance, periodic testing and inspection

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

8.4.2 Maintenance shall follow good practices, with particular consideration given to:

a) Work control: 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;
b) Equipment isolation: disconnection of electrical cabling and heat and pressure piping, and venting and purging of equipment;

c) Testing and monitoring: checks before commencing work, monitoring during maintenance and checks for recommissioning;
d) Safety precautions at work: clearly describe safety precautions to ensure that personnel protection equipment and emergency procedures are available and effective;
e) Reinstallation of equipment: reassembly, reconnection of pipes and cables, testing, cleaning the job site and monitoring after recommissioning.

8.4.3 Attention shall be paid to the operation of radioactive sources and X-ray equipment used by uranium fuel component manufacturers for specific purposes, such as equipment for weld inspection.

8.4.4 In order to verify that the facility is operating in accordance with operational limits and conditions, a plan for periodic inspection of the facility shall be in place. Inspections shall be performed by suitably qualified and experienced personnel. Particular consideration shall be given to fatigue affecting equipment and to the ageing of structures.

8.5 Control of modifications

8.5.1 A standard process for any modification shall be applied in a uranium fuel fabrication facility. This process shall use a modification control form or equivalent management tool. The modification control form shall 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 shall be used to identify all the aspects of safety that may be affected by the modification, and to demonstrate that adequate and sufficient safety provisions are in place to control the potential hazards.

8.5.2 Modification control forms shall 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 shall 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 shall be commensurate with the safety significance of the modification.

8.5.3 The change control order shall also indicate which changes will result in which changes need to be made. Control procedures shall be in place to ensure that the appropriate documentation is modified within a reasonable timeframe after the change.

8.5.4 The change control order shall clearly state the commissioning checks required by the changed system before it can be applied for re-run.

8.5.5 The modifications made to a facility shall 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.

8.6 Radiation protection

8.6.1 Overview

8.6.1.1 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 UO2 and U3O8 pose a particular hazard because of their long biological half-lives (and therefore effective half-lives) and their typically relatively small particle size (typically a few micrometres in diameter) when encountered in uranium fuel fabrication facilities. Therefore, close attention shall be paid to the sealing of uranium powder and pollution control in the working area.

8.6.1.2 The exposure of uranium fuel component manufacturers and the public shall be controlled, individual dose limits shall be established in accordance with GB 18871 and EJ 1056, and individual dose management target values shall be established based on the principles of radiation protection optimization.

8.6.1.3 Radiation protection during maintenance and/or modifications shall be in accordance with the legitimacy judgment and optimal protective measures specified in GB 18871. Radiation protection during repair/change shall include:

a) Estimation of the external exposure prior to the intervention;
b) Preparatory activities to minimize the doses due to occupational exposure, including:
   1) Identify specific risks;
   2) Specify protective procedures (individual and collective means of protection, such as protective masks, protective clothing, protective gloves, time limits) within the scope of the work permit.
c) Measurement of the occupational exposure during the intervention;
d) Implementation of feedback of information for identifying possible improvements.

8.6.1.4 Local exhaust shall be removed as far as reasonably practicable before being released into the atmosphere, so that the risk of exposure to public personnel is controlled.

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

8.6.2 **Control ofInternal exposure**

8.6.2.1 Internal exposure shall be controlled by the following means:

a) Performance targets shall be set for all parameters relating to internal exposure, e.g. levels ofcontamination;
b) Vents and ventilation systems shall be inspected, tested, and serviced regularly to ensure designrequirements are met. Regular airflow checks shall be performed on the air inlets of the hood and the sealing barrier. At the same time, the pressure drop across the air filter group shall be checked and recorded in accordance with the routine system;
c) A high standard of housekeeping shall be maintained at the facility. Cleaning techniques shall 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 shall be carried out to confirm the adequacy of cleaning programmes;
e) Contamination zones shall be delineated and clearly indicated;
f) Continuous air monitoring shall be performed and the facility staff shall be alerted ifthe airborne radioactive material exceeds the predetermined level of action;
g) Mobile air samplers shall be used at possible sources of contamination as necessary;
h) An investigation shall be carried out promptly in response to readings of high levels of airborne radioactive material;
i) Contamination checks shall be carried out before personnel and equipment leave the boundary of the contaminated area and decontamination if necessary. The entrance and exit control of the work area shall be carried out to prevent the spread of pollution. In particular, dressing rooms and decontamination equipment shall be provided;
j) Temporary means of ventilation and means of confinement shall 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 shall be made available for dealing with releases of chemicals or radioactive materials from the normal means of confinement in specific operational circumstances (e.g. during maintenance or the cleaning of process equipment);
l) Personal protective equipment shall be maintained in good condition, cleaned as necessary, and shall be periodically inspected;
m) Any staff having wounds shall protect them with an impervious covering for work in contamination zones.

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

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

8.6.2.4 The method of assessing internal exposure dose can be based on collecting air sampling data from the work site, combined with worker occupancy data. This method shall be reviewed and assessed by the regulatory body.

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

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

8.6.2.7 Estimates shall 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.

8.6.3 **Control of external exposure**

8.6.3.1 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 shall be noted that the processing of recycled uranium will require much more extensive measures for controlling external exposure.

8.6.3.2 Radioactive sources are also used for special purposes in a uranium fuel fabrication facility, such as:

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

8.6.3.3 External exposure shall be controlled by:

a) Ensuring that locations containing significant amounts of uranium are remote from areas of high occupancy;
b) Removing uranium from vessels adjacent to work areas in use for extended maintenance work;
c) Replacing the source by qualified and experienced personnel;
d) Performing routine radiation dose rate measurements.

8.6.3.4 Additional control measures shall be taken if uranium from non-natural sources is supplied as a facility feed. This material has a higher specific activity than uranium from natural sources, so it is possible to greatly increase both external and internal exposures. Uranium from non-natural sources may also introduce additional radionuclides into the waste stream. A comprehensive dose assessment of doses due to occupational exposure and exposure of the public shall be carried out before the first introduction of uranium from non-natural sources.

8.7 Criticality control

8.7.1 All activities involving fissile materials shall be carried out in accordance with the principle of eliminating critical accidents. Written procedures shall be in place to control all operational activities related to nuclear criticality safety, specifying the methods, specific parameters and acceptance criteria for control. Measures to ensure strict implementation of critical safety operational limits and conditions in uranium fuel fabrication facilities are particularly important.

8.7.2 The operational critical control of a uranium fuel fabrication facility shall include:

a) 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, loss of neutron absorbers and compensating deformation of containers and pipes that are prone to fissile materials;
b) Management of moderating materials, particularly water; for example, decontamination of gloveboxes and ventilation hoods, or in laboratories, and leakages of oils from gear boxes or use of a water based firefighting system (e.g. automatic sprinklers);
c) Use of safety quality control for mass management (procedures, mass measurements, systems and records) during uranium transfer;

d) Reliable methods for detecting the onset of any of the foregoing conditions;
e) Regularly calibration or test systems used to control critical hazards;
f) Evacuation drills to prepare for the occurrence of a criticality and/or the actuation of an alarm.

8.7.3 Instruments used in nuclear material accounting and control, such as mass, volume or isotope measurement instruments and accounting software, are also used in critical safety applications. However, when there is uncertainty in the properties of uranium-containing materials, conservative parameters such as enrichment and density shall be used. Special attention shall be paid to the use of conservative parameters when handling floor sweeps and similar waste.

8.7.4 Additional critical risks are encountered when performing maintenance work. Waste and residues from the decontamination line shall be collected in well-spaced containers. If uranium is removed from the vessel or pipe, only approved containers shall be used.

8.8 Industrial and chemical safety

8.8.1 The general chemical hazards of uranium fuel fabrication facilities are summarized as follows:

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

8.8.2 Fire hazard analysis shall be repeated on a regular basis (see 5.3.1.1.2.2) to incorporate changes that may affect the probability of fire.

8.8.3 Health surveillance procedures shall be established in accordance with regulations to monitor the health of workers who are susceptible to uranium and related chemicals (such as hydrogen fluoride, ammonia, nitric acid, sulfuric acid and sodium hydroxide). The radiological and chemical effects of uranium shall be part of the health surveillance process.

8.9 Management of radioactive waste and effluents

8.9.1 The operation of the facility shall control the generation of radioactive waste and minimize the generation of all types of radioactive waste to the greatest extent possible, ensuring that radioactive effluents discharged into the environment are as low as reasonably achievable(ALARA), easy to handle and dispose of waste, and facilitate the decommissioning of future facilities.

8.9.2 The management of solid, liquid and gaseous waste within the facility and ultimately from the facility shall be in accordance with the requirements specified in GB 18871. Emissions from radioactive effluents and chemical hazardous effluents shall be monitored and recorded in detail to verify compliance with relevant regulatory requirements. The details of monitoring and recording shall be reported to the regulatory body periodically.

8.9.3 Radioactive and chemical gases shall be treated and disposed of in a suitable location through a high efficiency particulate air filter and chemical scrubbing system. Performance standards shall be established to specify the level of replacement of the filter or scrubber filter. After the filter is replaced, it shall be tested to ensure that the filter is properly installed.

8.9.4 Process waste shall be treated effectively and, if possible, recycled and reused. This is especially important for hydrogen fluoride. Care shall be taken to ensure that hydrogen fluoride is formally suitable for reuse.

8.9.5 One easy way to minimize the generation of solid radioactive waste is to remove as much outer packing as possible before material is transferred to 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 shall be treated to allow its further use. Cleaning methods shall be adopted at the facility that minimize waste generation.

8.9.6 Waste treatment and disposal shall adopt quality control measures to meet disposal requirements.

8.10 Emergency planning and preparedness

8.10.1 For contingency planning and preparation applicable to a uranium fuel fabrication facility, see 9.9.1 to 9.9.5 and A.3.5 of EJ/T 20078-2014.

8.10.2 According to the potential dangers of the facility, the operating organization shall prepare a corresponding contingency plan and maintain coordination with other units responsible for the emergency (including government departments); at the same time, the operating organization shall establish the necessary emergency organization to clarify the emergency. Management responsibilities, related requirements for emergency preparedness and response plans can be found in HAD 002/07.

8.10.3 Taking into account the specific site conditions, if necessary, the contingency plan shall include emergency response arrangements for non-radioactive hazards and radioactive hazards, such as a large amount of radioactive or chemical contamination in the event of a fire, or simultaneous radioactive or chemical contamination of toxic and/or asphyxiating gases.

8.10.4 The emergency planning shall include a method of informing all field personnel to take appropriate action in the event of an emergency.

8.10.5 If necessary, the emergency planning shall be verified through exercises after the introduction of the radioactive material into the facility. After this, emergency drills shall be conducted at appropriate intervals, and some exercises shall be witnessed by the regulatory body. Some exercises shall be conducted in conjunction with local, regional or national emergency response units and shall include participation by as many relevant units as possible. The emergency planning shall be reviewed periodically and updated based on the experience gained.

8.10.6 Instruments, tools, equipment, documentation, and communication systems used in emergency response shall remain available and shall be maintained in good operating order to ensure their availability in emergency response.

8.10.7 Emergency plans for the release of nuclear critical accidents, radioactive and chemical hazardous substances (mainly fluorine gas, uranium hexafluoride, hydrogen fluoride and ammonia) and fire spreads and explosions shall be available.

8.10.8 Extinguishing media that may increase the risk of nuclear criticality shall not be used in fire protection measures in locations where fissile material is present.

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

9 Decommissioning

9.1 Overview

9.1.1 The requirements for safe decommissioning of uranium fuel fabrication facilities are given in chapter 10 of EJ/T 20078-2014. Suggestions and guidance can be found in the IAEA Safety Standard WS-G-2.4.

9.1.2 Due to the low radioactivity of low enriched uranium processed by uranium fuel fabrication facilities, the decommissioning of uranium fuel component manufacturers is not as difficult as some other fuel cycle facilities. The large amount of solid radioactive waste generated by the facility is low and intermediate level waste or exempt waste.

9.1.3 For a new uranium fuel fabrication facilities, the “benchmark” background radiographic characteristics of the site and facility itself shall be determined. This shall include appropriate radiological monitoring of the site where the proposed facility is located and the surrounding area to determine the level of radiation baseline used for the future impact of the assessment facility on the site. This may be crucial to make decisions about the acceptability of decommissioning recommendations in the future. Quantification of natural radioactivity in building materials used for construction may be useful for determining the level of de-control and target removal levels during decommissioning of the facilities in the future.

9.1.4 Decommissioning can be facilitated by planning and preparing for the entire life of the facility, which is to minimize the impact of decommissioning activities on end use and the environment.

9.1.5 As an important factor in facilitating decommissioning, the as-built drawings of the facility and relevant knowledge from the operational phase shall be preserved. The number of experienced personnel and records that can be retained from the operational phase will directly affect the progress of decommissioning. Delays in decommissioning will increase the likelihood of significant personnel and information loss.

9.2 **Preparatory steps**

The preparatory steps shall include:

a) Post-operational cleanout to remove all bulk amounts of uranium and other hazardous materials;
b) Contaminated parts of the ground (surface and underground), groundwater, buildings and equipment contaminated by radioactive materials or chemical substances and their pollution levels shall be identified through a comprehensive on-site source survey;
c) 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;
d) Preparation of a risk assessment and safety analysis report to obtain a decommissioning approval document for the decommissioning process.

9.3 **Decommissioning process**

9.3.1 Personnel performing decommissioning of the facility shall be assured of the necessary training, certification and experience in this work. Retired Decommissioned staffshall be well aware of the regulations and standards that are applicable to environmental, health and safety standards that are followed during decommissioning.

9.3.2 During decommissioning, special attention shall be paid to:

a) Avoiding the spread of pollution by appropriate techniques and means, in particular to minimize the amount of liquid (water and compounds) to reduce the production of effluents;
b) Properlydisposaling of waste and packaging of waste, as well as properlydisposaling of radioactive waste arrangements;
c) Contaminated materials that cannot be disposed of immediately, and safe storage of radioactive wastes.

AnnexA

(Informative annex)

Typical Process Routes in a Uranium Fuel Fabrication Facility

The figure of typical process routes in a uranium fuel fabrication facility is shown in Figure A.1.

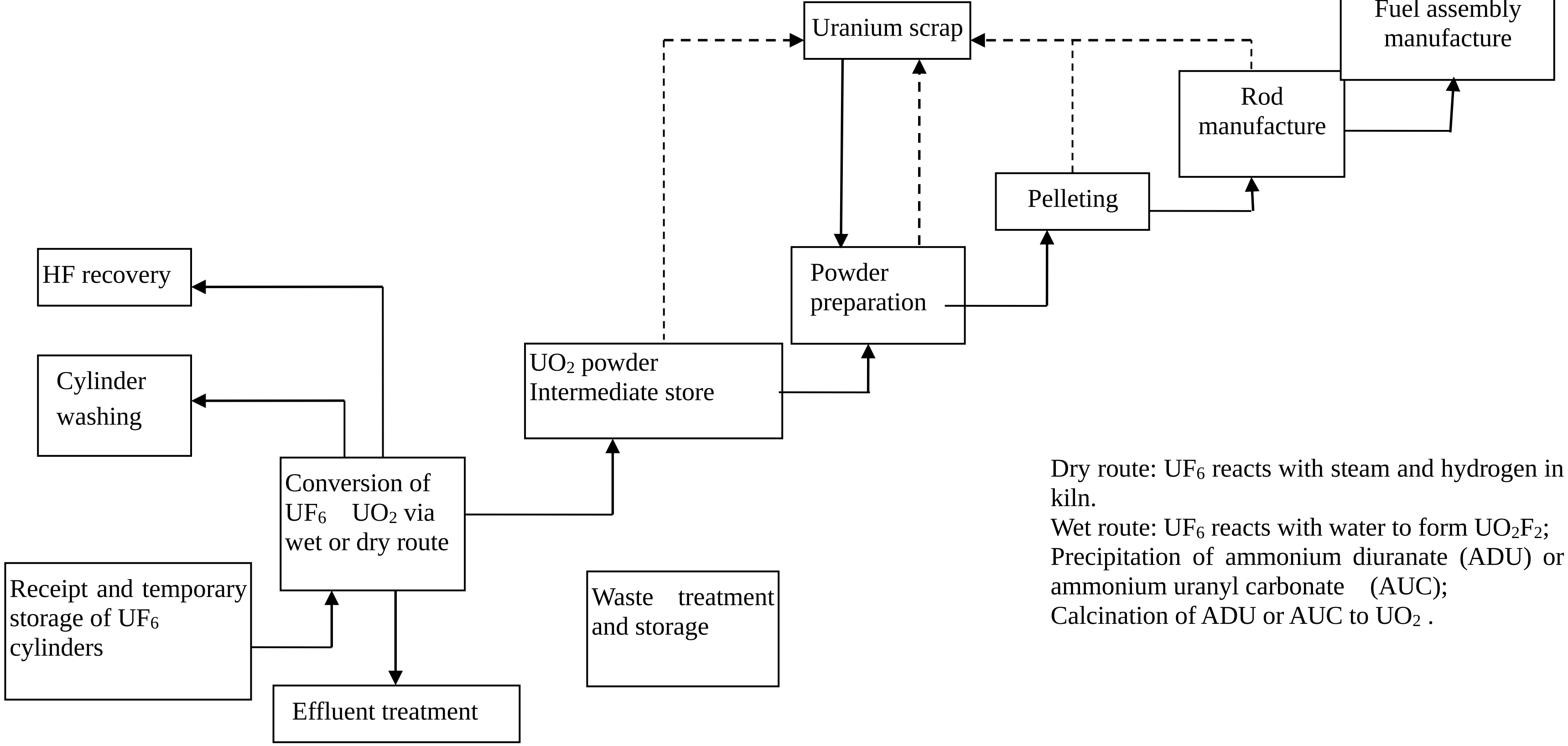

Figure A.1 Typical process routes in a uranium fuel fabrication facility

AnnexB
(informative annex)
Examples of Structures, Systems and Components Important to Safety and Representative Events that Pose Possible Challenges to Safety Functions

The examples of structures, systems and components important to safety and representative events that pose possible challenges to safety functions areshown in Table B.1.

Table B.1 Examples of structures, systems and components important to safety and representative events that pose possible challenges to safety functions

Process area	Structures, systems and components important to safety	Events	Threatened security features
Receipt and temporary storage of UF_6 cylinders	Transport cylinder	Rupture of cylinder	2
	Device for measuring enrichment of ^{235}U	Processing of uranium beyond safety limits	2
	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	2
	Measurement device to determine the humidity of the powder	Degradation of criticality safety margin (moisture)	1
	Tanks for HF	Release of HF	2
	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
	Presses	Release of uranium	2
	Sintering furnaces	Explosion	2

Table B.1 (Cont.)

Process area	Structures, systems and components important to safety	Events	Threatened security features
Powder preparation	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 Process area	Press, sintering furnace, grinding machine	See other process areas above	1,2
	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)	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)	1,2
Radioactive waste treatment	Treatment facilities	Release of uranium Release of chemicals Fire	1,2
	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

Table B.1 (Cont.)

Process area	Structures, systems and components important to safety	Events	Threatened security features
Ventilation system	Fan for exhaust air, stack	Uncontrolled release	2
	Measurement devices for radioactivity in exhaust air	Release of uranium	2
Treatment 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
Note: Safety function including: 1. Criticality prevention; 2. Confinement to protect against internal exposure and chemical hazards; 3. Protection against external exposure.			

AnnexC
(informative annex)
Examples of Parameters for Defining Operational Limits and Conditions for Uranium Fuel Fabrication Facilities

The examples of parameters for defining operational limits and conditions for uranium fuel fabrication facilities are shown in Table C.1.

Table C.1 Examples of parameters for defining operational limits and conditions for uranium fuel fabrication facilities

Process area	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
Laboratory	Mass of uranium Uranium content in waste Levels of surface contamination of radioactive sources

Table C.1 (Cont.)

Process area	Parameters for defining operational limits and conditions
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