15 April 2015

IAEA SAFETY STANDARDS
for protecting people and the environment

Status: Step 11

Review by Committees

Still subject to technical editorial review.

Safety of Nuclear Fuel Cycle Research and Development Facilities

DRAFT SPECIFIC SAFETY GUIDE XXX
DS381

IAEA
INTERNATIONAL ATOMIC ENERGY AGENCY

FOREWORD

by Yukiya Amano

Director General

EDITORIAL NOTE

An appendix, when included, is considered to form an integral part of the standard and to have the same status as the main text. Annexes, footnotes and bibliographies, if included, are used to provide additional information or practical examples that might be helpful to the user.

The safety standards use the form 'shall' in making statements about requirements, responsibilities and obligations. Use of the form 'should' denotes recommendations of a desired option.

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. This Safety Guide on the Safety of Nuclear Fuel Cycle Research and Development Facilities (R&D facilities) supplements the Safety Requirements publication on the Safety of Nuclear Fuel Cycle Facilities NS-R-5 Ref. [1] including Appendix V. It addresses all the stages in the life cycle of R&D facilities whether at the laboratory, pilot or demonstration scales, from design through to preparations for decommissioning.

1.2. R&D facilities receive, handle, process and store a variety of nuclear materials including uranium, other actinides and fission products or activated materials in multiple physical forms such as powders, liquids and gases. These can present diverse hazards such as:

(1) Nuclear and radiological hazards;

(2) Toxic hazards from bioactive or chemical materials (e.g. HF, UF_6 or ammonia);

(3) Explosive or flammable properties of reactive substances in different forms (e.g. hydrogen, nitric acid, metallic powders).

1.3. Another feature of many R&D facilities is the diversity of research and operational personnel, organized in different teams with potentially different training, expertise, experience, expectations and goals. This may lead to situations where hazards are not properly recognized and controlled. This guide covers two types of R&D facility, classified as Case 1 and Case 2 and illustrated in Annex I, and also applies to the experiments undertaken within them, using a graded approach:

– Case 1: Small scale experiments and fundamental research studies conducted on chemical, physical, mechanical and radiological properties of specific nuclear materials like prototype nuclear fuels (before and after reactor irradiation) or investigations of nuclear materials or wastes arising from new processes.

– Case 2: Research and development on processes and equipment envisaged for use on an industrial scale (e.g. pilot facilities for waste treatment).

1.4. R&D facilities can operate over extended periods of time to provide analytical services, materials or testing services and their inventories of radioactive and toxic materials can be significant. Consequently all of the IAEA generic requirements for the management of activities, learning from experience, inspection and maintenance apply to R&D facilities. The

relevant specific requirements for facility types where similar operations are carried out also apply to R&D facilities in Case 2.

1.5. R&D facilities may support all stages of the nuclear fuel cycle, from fundamental research to applied research, fuel processing, material examination and fuel safety, chemical analysis and the development of instrumentation. A variety of physicochemical processes may be employed to study different types of fuels or materials that may also be hazardous. Particular care should be taken when researching new or novel processes and when establishing the safety of developing processes, to ensure that the safety assessment and safety measures are appropriate to the state of knowledge. These issues should also be considered when applying a graded approach.

OBJECTIVE

1.6. The objective of this Safety Guide is to provide guidance based on experience gained from Member States and considering the present state of technology to ensure safety at all stages of the life cycle of R&D facilities. This guidance specifies engineering, actions, conditions and procedures to meet the requirements established in Ref [1]. This Safety Guide is intended to be of use to researchers, designers, operating organizations, and regulators for ensuring the safety of R&D facilities.

1.7. In this publication, the operating personnel, researchers, contractors and subcontractors working at the R&D facility are collectively referred to as "R&D facility personnel" or simply "personnel". More specific terms may be used where a distinction is necessary.

SCOPE

1.8. This safety guide provides guidance on meeting the safety requirements in Ref. [1]. Sections 5 – 10 of that publication establish requirements common to the whole range of nuclear fuel cycle facilities, i.e. milling, refining, conversion, enrichment, fabrication of fuel, reprocessing of spent fuel, waste treatment, storage and R&D facilities. Appendix V in Ref. [1] establishes the requirements that are specific to R&D facilities.

1.9. This safety guide applies to the facilities defined in paragraph 1.3 with the exception of irradiators, accelerators and research reactors, including criticality mock-ups and radio-isotope producers. It specifically deals with the safe design, construction, commissioning, operation and decommissioning of R&D facilities. This guide is limited to the safety of the R&D facility, the protection of its workers and the surrounding public and the management of any wastes generated. It does not deal with the subsequent impact that the material produced by R&D facilities may have on end-users.

1.10. Full guidance on meeting the requirements for the management system and for the verification of safety established in Ref. [2] is provided in Ref. [3]. Safety requirements for the legal and governmental framework and regulatory supervision (e.g. requirements for the authorization process, regulatory inspection and regulatory enforcement) are established in Ref. [4].

1.11. Safety guidance relevant to R&D facility Case 2 can also be found in the IAEA safety guides for the corresponding type of nuclear fuel cycle facilities, e.g. guidance applicable to fuel fabrication pilot facilities will also be found in the safety guide for fuel fabrication facilities, Ref. [5].

1.12. Sections 3 to 8 of this publication include guidance on radiation protection measures to meet the safety requirements specified in the International Basic Safety Standards for Protection against Ionizing Radiation (Ref. [6]). This standard and the associated guide (Ref. [7]) also present measures for personnel dosimetry, optimization of protection, measures to control and limit the discharge of radioactive materials to the environment and radiation monitoring of the workplace as well as contamination monitoring of the workers, from design through to the decommissioning stage.

1.13. The guidance in this publication provides examples of the application of a graded approach to nuclear fuel cycle R&D facilities. The graded approach is itself is a requirement in many of the IAEA standards, i.e. Requirement 1 of Ref. [8] and Requirement 6 of Ref. [6]. Application of a graded approach ensures that safety measures and safety-related activities are proportionate to the hazards of a facility.

STRUCTURE

1.14. This publication contains guidance specific to nuclear fuel cycle R&D facilities based on relevant IAEA safety requirements listed at the end of this publication. The recommendations in this guide have been referenced to the corresponding requirements, where consistent with the readability of the text. This safety guide covers all stages in the life cycle of a R&D facility, including site evaluation, design, construction, commissioning, operation, and decommissioning. It also provides specific guidance on modifications, maintenance, calibration, testing and inspection as well as emergency preparedness, where such guidance is appropriate.

1.15. General safety guidance for a R&D facility is described in section 2. The safety aspects to be considered during the process of evaluating the site of a facility are described in section 3. Section 4 deals with safety during the design stage and section 5 deals with safety

aspects during the construction stage. Section 6 describes the safety considerations that arise during commissioning. Section 7 contains guidance on practices to ensure safety during facility operation. It also covers the management of facility operations and Emergency Preparedness and Response (EPR). Section 8 provides guidance on meeting safety requirements during the decommissioning of a R&D facility. Annex I shows the typical process route for the two classes of R&D facility covered by this guidance. Annex II gives examples of structures, systems and components important to safety (SSCs) in R&D facilities grouped by process areas. Examples of operating limits and conditions (OLCs) for R&D facilities are provided in Annex III.

1.16. R&D facilities remain subject to the same international agreements and national laws as other types of nuclear facility.

2. GENERAL SAFETY CONSIDERATIONS FOR R&D FACILITIES

GENERAL

2.1. In R&D facilities, fissile and other radioactive materials can be present in different forms with diverse physical and chemical characteristics. The main hazards are criticality, loss of confinement, radiation exposure (both internal and external), fire, chemical or explosive hazards, from which workers, the public, and the environment need to be protected by adequate design, construction and safe operation, Ref. [1].

2.2. The factors affecting the safety of R&D facilities include the following:

(1) The radiological consequences caused by the release of radioactive materials under accident conditions can be significant;

(2) Fissile materials (if present) have the potential to achieve criticality under certain conditions. The sub-criticality of a system depends on many parameters, including the fissile mass, concentration, geometry, volume, isotopic composition, density and the presence of neutron absorbers, see Ref. [9];

(3) When irradiated fuel is used, the radiation levels and the risk of internal and external radiation exposures are significantly increased;

(4) The chemical toxicity of material used in R&D facilities has to be considered (e.g. uranium hexafluoride, which if released, reacts with the moisture in the air to form hydrogen fluoride and soluble uranyl fluoride). Therefore, the safety analysis of R&D facilities should also address impacts resulting from these chemicals and their potential mixing (e.g. in waste or liquid release);

(5) Products, sub-products, or waste arising from research and development programmes on exotic nuclear materials, such as those listed below, should be included in safety assessments;

(a) Non-standard MOX or UO_2 fuel fabrication, or new fuel matrices, e.g. carbides, nitrides, metallic forms;

(b) Isotopes with particular constraints for disposal , e.g. long half-life transuranics (like curium), fission products (like ^{99}Tc), or activated materials such as trace materials in cladding;

(c) Materials without an agreed national disposal route, e.g. graphite or aluminum in waste;

(d) Uranium with enrichments > 5%;

(e) Materials in the Th - ^{233}U fuel cycle that contain high-energy gamma emitters like ^{232}U.

R&D FACILITY LICENSING

2.3. A complete set of national safety regulations should be developed and implemented to assure that the safety of R&D facilities is maintained for its full life cycle, see Section 3 of Ref. [1]. The regulatory body should establish the basic requirements for protection of workers and members of the public against the R&D facility hazards (e.g. based on assessments of the doses arising from normal operations and postulated accidents). These requirements should be consistent with internationally agreed approaches.

2.4. The licensing of R&D facilities should be based on a complete and adequate safety case produced by suitably qualified personnel. This safety case should include the safety analysis report, any operational limits and conditions and a listing of the safety procedures to be followed. The safety analysis report should cover the safety of normal operations and accidents. Postulated initiating events should be analyzed to ensure that accidents are adequately prevented, detected and their consequences are mitigated. Detailed requirements for the licensing documentation[1], are established in Sections 2 and 9 of Ref. [1].

2.5. Requirement 23 of Ref. [8] states that “The results of the safety assessment shall be used to specify the programme for maintenance, surveillance and inspection; to specify the

[1] The licensing documentation is the safety case for the facility or site that is provided to the regulatory body for the purposes of obtaining an authorization. If approved by the Regulatory body, the licensing documentation may not be changed without formal modification and re-approval. An approved “safety case” is the same as “licensing documentation” and these titles are used interchangeably in this guide.

procedures to be put in place for all operational activities significant to safety and for responding to anticipated operational occurrences and accidents; to specify the necessary competencies for the personnel involved in the facility or activity and to make decisions in an integrated, risk informed approach". Licensed operations will be conducted as defined in the safety analysis report and the operational limits and conditions. The R&D facility management team should be trained on the content and use of the safety analysis report and operational limits and conditions, in accordance with Ref. [3].

2.6. Through the licensing approval, the operating organization is committed to involve the regulatory authority in the case of new research programmes which are outside of the scope of the existing R&D facility safety case, in accordance with national practices for the authorization of modifications.

2.7. The licensing documentation should be sufficiently broad in scope to capture the anticipated development of research and development programmes and take account of the additions or changes to safety requirements that could be expected. Nevertheless, the definition of licensing scope should be sufficiently detailed to ensure clarity and avoid ambiguity.

2.8. The safety approach (as documented in the safety analysis report) for a R&D facility should provide the same level of safety assurance whether the R&D facility performs small-scale academic research or is a major nuclear pilot plant. This equivalence of standard is achieved with application of a graded approach.

2.9. When deactivating or reactivating parts of an existing R&D facility, the safety assessment of the facility should be reviewed and updated, addressing any aging or obsolescence issues and should cover potential legacy waste and decommissioning needs as far as achievable. Radioactive or hazardous materials, including any registered radioactive sources should be relocated to safe storage before deactivating parts of a R&D facility.

2.10. According to paragraph 3.9 (e) of Ref. [6], an environmental impact assessment should be carried out by the operating organization as part of the licensing process for the R&D Facility. The prospective assessment for radiological environmental impacts should be commensurate with the magnitude of the possible radiation risks arising from the R&D facility, applying a graded approach.

2.11. Paragraph 9.35 of Ref. [1] states that "The operating organization shall establish a process whereby its proposals for changes ….. are subject to a degree of assessment and scrutiny…" and a R&D facility should be subject to a change management process like other

nuclear facilities. When there is change of use of a R&D facility (or part of), an appropriate modification programme should be implemented, with peer review by suitably qualified personnel. Where the increase in scale is large, the operating organization should plan the increase in stages where possible, in order to permit feedback and validation of each stage. Guidance on the configuration and audit of such changes are provided later in this publication.

2.12. The licensing documentation should also take into account the aspects arising from the decommissioning and radioactive waste management at the facility.

2.13. The licensing documentation should demonstrate that arrangements for emergency preparedness and response are in place and are commensurate with the hazards associated with the facility in accordance with Ref. [10] and Ref. [11].

2.14. Ref. [1] establishes a requirement to review safety periodically, in accordance with the national regulatory requirements. This also applies to R&D facilities because these facilities can operate for a long time and may also be subject to many modifications and changes of use.

MANAGEMENT SYSTEM

2.15. In accordance with the requirements of Paragraph 4.5 of Ref. [1], the overall responsibility for safety of R&D facilities rests with the operating organization. Paragraph 4.7 of Ref. [1] also states that "The operating organization shall clearly specify the responsibilities and accountabilities of all staff involved in conducting or controlling operations that affect safety. The person with the responsibility for direct supervision shall be clearly identified at all times". These management processes and organizational provisions should also reflect the requirements of Ref. [2].

2.16. These processes and provisions apply throughout the lifetime of the facility, to operations, maintenance and to experiments, from its siting to its decommissioning.

2.17. Leadership in the facility should encourage a positive safety culture and R&D facility personnel should always have an attitude of technical inquisitiveness and conservatism. This is an important contribution to safety culture that should be maintained by adequate training and encouragement.

2.18. Operating organizations and regulatory authorities should promote the sharing of operational experience feedback on safety with other R&D facilities worldwide. Whether full-scale plant or individual experiments, the operating organization should make use of the safety experiences of existing facilities as far as practicable.

2.19. Self-assessment and challenge of the safety performance within the sub-organizations of the R&D facility should be developed and promoted by the operating organization.

2.20. R&D facilities should take advantage of existing infrastructural support. Emergency Planning & Preparedness should take into account all other facilities at the site, their interactions and ability to support the R&D facility.

2.21. Due consideration should be given to the minimization, processing (i.e. pretreatment, treatment) of radioactive waste that will be produced during operation and decommissioning of the R&D facility, as well as any legacy material.

2.22. The safety of existing R&D facilities should be reassessed and, if necessary, the facilities modified to meet current (or updated) safety standards as far as reasonably achievable. As an alternative, equivalent compensatory measures should be provided.

2.23. In a R&D facility, the use of remote handling operations, adequate shielding and confinement of contaminated atmospheres should be considered to reduce occupational exposures from radioactive materials and to ensure safe operations, especially in experiments using highly toxic or radioactive materials.

3. SITE EVALUATION

3.1. Ref. [12] establishes generic requirements for the safety evaluation of sites for most land-based nuclear installations including fuel-cycle facilities. The site evaluation process for a R&D facility may depend upon a large number of criteria, some of which are specific to the site and others are related to the facility. At the earliest stage of planning for a R&D facility, a list of these criteria should be prepared and considered in accordance with their safety significance and agreed with regulatory bodies. In most cases, it is unlikely that all the criteria can be met, and the risks posed by certain externally generated initiating events (e.g., earthquake, aircraft crash, fire, extreme weather conditions) and the resulting consequences will dominate the choice of a site. Refs. [13], [14], [18] and [21] provide guidance on safety criteria used in this process.

3.2. A R&D facility may be a stand-alone facility, in which case the site should be capable of supporting the necessary infrastructure (e.g., for off-site emergency response). However, many R&D facilities are a part of another site, for which siting criteria have already been determined. Interactions with facilities nearby should be considered:

- Existing nuclear facility: In this case, the siting criteria should be encompassed by the evaluation studies of the existing facilities.

- Non-nuclear site (e.g., hospitals, universities, or research centers): The main siting issue can be the feasibility of necessary emergency arrangements, such as those for evacuation where appropriate. This may require specific design provisions or other emergency provisions for conformity with Ref. [10] and Ref. [11].

3.3. Requirements for the evaluation of a site for a nuclear fuel cycle R&D facility are provided in Ref. [12]. Where the facility is a pilot for a nuclear fuel cycle facility of another type, reference should also be made to the relevant Specific Safety Guide, e.g. Refs. [5], [15] and [16].

3.4. The siting of a R&D facility should allow the implementation of physical security measures in accordance with the guidance provided in the IAEA Nuclear Security Series publications Ref. [17].

4. DESIGN

GENERAL

4.1. The structures, systems, components, the management system and procedures for a R&D facility should be designed in an integrated manner that ensures safe operation, prevents events that could compromise safety, and mitigates the consequences of such events were they to occur. This design process usually begins with an analysis of potential internal accidents (or faults) and external events. It should proceed to the identification of safety functions that provide defence in depth, usually within boundaries defined by OLCs or safety case limits.

4.2. For the implementation of the defence in depth requirements (Section 2 of Ref. [1]), the first two levels are the most significant, as the risks are mainly eliminated by design and appropriate operating procedures (see Sections 4, 6 and 7 of Ref. [1]). However, all levels of defence in depth should be considered during the design and safety analysis process.

Main Safety functions for R&D facilities

4.3. The main safety functions (see paragraphs 6.37 to 6.53 and paragraphs V.1 to V.10 of Ref. [1]) are those functions, the loss of which, may lead to radioactive releases or exposures having possible radiological consequences for workers, the public and/or the environment, namely:

(1) Prevention of criticality;

(2) Confinement of radioactive material, including the removal of decay heat, for the prevention of potentially harmful releases;

(3) Protection against external radiation exposure;

4.4. Depending of the type of R&D facility, releases of radioactive, toxic or biologically active materials are all potentially harmful. The safety measures identified in the design of the R&D facility should comprise those individual items important to safety and operating limits and conditions which, when taken as a whole, provide the main safety functions above. The remainder of this section describes those accidents, events and particularly those safety functions which may be especially relevant to a R&D facility.

Specific engineering design requirements

4.5. The following specific engineering design requirements in Ref. [1] apply for each of the main safety functions:

– The requirements on prevention of criticality as established in paragraphs 6.43–6.51 and V.4–V.6.

– The requirements on confinement of radioactive materials as established in paragraphs 6.37–6.39, 6.52 and V.7.

– The requirements on protection against exposure as established in paragraphs 6.40–6.42 and V.8.

4.6. The design should give consideration to the handling of various types of radioactive materials. Due to the nature of the work done in R&D facilities there are often design and engineering provisions for flexibility and adaptation against future requirements or dismantling. These provisions should be a) designed to enhance safety b) operated to ensure safety is maintained over the lifetime of the facility, and; c) not used for unassessed materials without a modification proposal/safety assessment.

Design basis accidents and safety analysis

4.7. In the context of nuclear fuel cycle facilities, design basis accidents (DBA), design basis events (DBE) and their equivalents, present challenges against which a facility is designed according to established design criteria such that the consequences are kept within defined limits. The specific safety requirements relating to design basis accidents (or

equivalent) are established[2] to ensure that the design keeps radiation exposures from normal operation and accident conditions as low as reasonably achievable. Refs. [13], [14] and [18] provide guidance on specific DBEs of potential relevance.

4.8. In addition to the radiological hazards outlined above, particular consideration should be given to the following hazards:

(a) Internal and external human induced phenomena such as fire, chemical explosion or accidental aircraft crash;

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

(c) Human errors and organizational failings;

(d) Chemical or toxic releases, Ref. [19].

4.9. The analysis should take account of events that might be consequences of other events, such as a flood following an earthquake, or multiple events initiated within the facility from one external event, such as fire or multiple leaks caused by an earthquake.

Structures, systems and components important to safety

4.10. The design measures identified by the safety analysis are intended to prevent any abnormal situation where the safety margin has been reduced, to detect this situation and to mitigate its consequences should it progress further. These are often implemented by means of structures, systems and components important to safety, which are also known as items important to safety, see paragraphs 6.6 and 6.8–6.12 of Ref. [1]. Annex II in in this guide presents examples of representative safety functions and their associated structures, systems and components.

SAFETY FUNCTIONS

Prevention of criticality

General

4.11. For R&D facilities, criticality prevention should be strictly addressed according to paragraphs 6.45 and 6.49 of Ref. [1]. In addition, R&D facilities in Case 2 should fulfil the requirements in appendices I, II, III or IV of Ref. [1], which define requirements applicable to specific types of pilot facility (e.g. for a pilot MOX facility handling fissile material, the requirements in Appendix II of Ref. [1] apply). In many R&D facilities handling fissile materials, sub-critical mass control is used as a ‘deterministic” safety measure not usually

[2] See paragraphs 6.4–6.9, V.1 of Appendix V and III.10 III-10 of Annex III in Ref. [1].

available in full scale facilities. As far as possible, the control of masses in an area should be independent of all other factors. A number of such areas may coexist independently in a single facility with suitable interface controls. The rest of this section describes the basis of control by mass and other factors in more detail and concludes with guidance regarding criticality detection and emergencies.

Design for Criticality Prevention

4.12. Paragraph 6.45 in Ref. [1] establishes requirements for all fuel-cycle facilities where criticality is considered; "For the prevention of criticality by means of design, the double contingency principle shall be the preferred approach" and paragraph 6.47 states that "Criticality evaluations and calculations shall be performed on the basis of making conservative assumptions". When the requirements for a specific pilot facility type are not applicable, the requirements for the control of criticality in Appendix V.1, V.4 and V.5 of Ref. [1] should be used. Some examples of the parameters that should be controlled to prevent a criticality include the following:

(a) Mass: In R&D facilities, mass margins[3] should be based on representative material with the lowest critical mass. The margin should be not less than 100% of the normal value in operation (unless the likelihood of double batching is demonstrated to be sufficiently remote), or a mass margin equal to the physical mass that can be accumulated.

(b) Geometry or Shape: The analysis should give consideration to the layout of the facility, the dimensions and locations of pipes, vessels, and other laboratory equipment. For example, control by geometry could be used in the design of furnaces, dissolvers, and other equipment or processes.

(c) Density and forms of materials: The analysis will consider the range of densities for different forms of materials (e.g., powder, pellets or rods) used in a R&D facility.

(d) Concentration and density in analytical laboratory and in liquid effluent units: The analysis will consider the range of fissile material in solution as well as any potential precipitates (e.g. recovery of Pu in waste streams).

(e) Moderation: The analysis should consider a range of moderation to determine the most reactive conditions that could occur. Water, oil and similar hydrogenous substances are common moderators which are present in R&D facilities, or may be present under accident conditions (e.g. water from firefighting paragraph V.6 in Ref. [1]). Non

[3] Mass Margin: The difference between the safety limit (maximum amount allowed within OLCs) and the sub-critical limit (effective neutron multiplication factor $K_{eff} < 1$, often taken as $K_{eff} < 0.95$)

homogenous distributions of moderators with fissile material should be considered (e.g. organic binders and porosity enhancing agents used in pelletizing process).

(f) Moisture content in powder material: The analysis will consider the range of moisture content for powder material used in a R&D facility.

(g) Reflection: The most conservative margin should be retained out of those resulting from different assumptions such as: (i) a hypothetical thickness of water around the processing unit; and (ii) consideration of the actual neutron reflection effect due to e.g. the presence of personnel, organic materials, shielding materials, concrete or steel of the containment in or around the processing unit.

(h) Neutron absorbers: If claims are made for neutron absorbers in the safety analysis, their effectiveness should be verified depending on the relevant operating conditions identified in Appendices I – IV in Ref. [1]. Neutron absorbers such as cadmium and boron may be used in R&D facilities and the safety analysis should incorporate their effect as neutron absorbers; however, ignoring their effects would still yield conservative results. The use of mobile or easily displaced or removed solid absorbers should be avoided.

(i) Neutron interaction: Consideration should be given to neutron interaction between all locations of fissile materials in the R&D facility and all potential locations that may be involved. Specific consideration should be given to the layout of the R&D facility and any possible changes. Physical locators are preferred to floor markings as a means of indicating or ensuring the placement of equipment with potential neutron interactions.

(j) Fissile content: For any fissile material (e.g. fresh or irradiated fuel), the maximum fissile content (e.g. level of enrichment) in any part of the facility should be used in all assessments unless the extreme improbability of having this isotopic composition in a particular area of the facility is demonstrated in accordance with the double contingency principle, see paragraph 6 of Appendix III in Ref. [1].

Criticality Safety Analysis

4.13. The criticality safety analysis should demonstrate that the design of equipment is such that the values of control parameters are always maintained in the sub-critical range for all operational states (i.e. normal operation and anticipated operational occurrences) and during and after DBA conditions, or their equivalent. This should be achieved by determining the effective multiplication factor K_{eff}, which depends on the mass, the distribution and the nuclear properties of the fissionable material, and all other materials with which it is

associated. The calculated value of K_{eff} is then compared with the value specified by the design limit or national regulations, whichever is the lower.

4.14. A number of methods can be used to perform criticality safety analysis, e.g. the use of experimental data, reference books or recognized standards, hand calculations or calculation by means of deterministic or probabilistic computer codes. Any method used to carry out the analysis should use conservative data and assumptions and should be fully verified and validated for the application. For detailed guidance see Ref. [9].

4.15. The method employed should be appropriate to the type of material(s) being handled in the R&D facility. The general procedure to be followed in this analysis should include the use of:

(a) A conservative approach, taking into account:

- Uncertainties in physical parameters, optimum moderation conditions and potential non-homogenous distributions of moderators;
- Anticipated operational occurrences and their combinations;
- Facility states that result from external and internal hazards.

(b) Appropriate computer codes that are verified and validated (i.e. compared with benchmarks to determine the effects of code bias and code uncertainties on calculated K_{eff}) within their applicable range and using appropriate cross section libraries. Detailed guidance is provided in paragraphs 4.20 - 4.25 of Ref. [9].

4.16. For a process where fissile materials are handled in a discontinuous manner (including batch processing or waste packaging), the process and its installations should meet the safety requirements for criticality management at all times. The R&D facility design, including any accountancy support systems should provide the necessary accountancy equipment and have clear and easily identifiable boundaries. Care should be taken at interfaces to ensure that transfers of fissile material meet criticality control requirements for both areas. The effect of potential delays in handover or associated checks should be considered in the safety analysis so that any negative consequences of accumulations of fissile material can be avoided.

Mitigation of Criticality Event

4.17. Information regarding the need to install criticality accident alarm systems can be found in Ref. [20]. Where such systems are installed, the R&D facility should be designed to include safe evacuation routes to personnel regrouping areas. These routes should be clearly marked and personnel should be trained in criticality evacuation procedures.

4.18. Consideration should be given to the provision of remote mitigation devices, e.g., to empty a vessel containing the solution initiating the event or to absorb the neutron flux.

Protection of people and the environment from radiation

4.19. Protection against radiation exposure relies on an appropriate combination of controls on source magnitude, time of exposure and the shielding or distance between the subject and the source. These should be used separately, or in combination.

4.20. Consideration should be given to maintenance, calibration, periodic testing and inspection, with the aim of minimizing dose to workers. Requirements for the design of items important to safety to minimize exposure during maintenance are established in paragraph 6.19 of Ref. [1]. Examples of such provisions include connection junctions at containment boundaries and easily cleanable surfaces.

4.21. The potential for accumulation of radioactive material in:

1. Process equipment;
2. Fume-hoods, gloveboxes and hot cells;
3. Secondary systems (e.g. ventilation ductwork);

should be minimized and, where appropriate, provisions made for its removal or reduction.

4.22. Consideration should be given to the remote operation of services and experimental equipment where possible.

4.23. Requirements for the classification of areas for control of radiation and contamination are established in paragraph 6.41 of Ref. [1]. This requirement may be graded to avoid excessive restriction on the movement of personnel. However, any grading should be justified as even small quantities of alpha active material can cause a significant contamination hazard.

4.24. Background radiation controls in R&D facilities often rely on analytical data from samples. If possible, an instrumental method of analysis that does not require sampling should be chosen. Where samples need to be taken, their number and sizes should be kept to a minimum consistent with providing sufficient, timely information for the optimization of dose and protection. The requirements for radiation protection during operation established in Ref. [1], which include housekeeping, waste management and dose control, also apply to analytical facilities.

4.25. “Radiation levels shall be monitored so that any abnormal conditions would be detected and workers may be evacuated. Areas of potential exposure for workers shall be

appropriately identified and marked", see paragraph 6.42 in Ref. [1]. Radiation protection monitoring should be provided consistent with national regulations and international practices including:

- Fixed gamma/neutron monitors and stationary samplers for activity in air, (beta/gamma, alpha) for access and evacuation purposes.
- Mobile gamma/neutron area monitors and mobile sampler for activity in air, (beta/gamma, alpha) for evacuation purposes during maintenance.
- Personal monitoring consistent with the radiation type(s) present in the R&D facility,

4.26. All estimates of source terms should include allowance for the ingrowth of radioactive decay products (such as ^{241}Am) over the lifetime of the facility.

Confinement of radioactive materials

4.27. In accordance with paragraphs 6.37-6.38 of Ref. [1], containment should be the primary method for protection against the escape of radioactive material. Containment should be provided (as required) by complementary static and dynamic confinement systems

- The static containment system should consist of at least two independent static barriers between radioactive material and the environment;
- A dynamic containment system can also be used to create airflow towards areas that are more contaminated.

4.28. Dynamic containment cannot be provided for some circumstances. Sealed containers and isolated equipment, for instance, cannot be directly connected to a ventilation system. Also, it is sometimes impossible to provide ventilation for maintenance operations in open areas. Task assessments should be performed to ensure the safety of the personnel and the public against unexpected leakage or release from a source in these circumstances. Closed or sealed items should be treated as contaminated based upon their history and appropriate precautions specified in their handling, opening or unsealing. Consideration should be given in design to the provision of equipment capable of determining the radioactivity inside such items. Wastes and other potentially contaminated containers should be appropriately characterized and labelled[4] at (and with) the time and place of origin to avoid unexpected contamination release. Labels and containers can be colour-coded and the colours may be specified to match equipment and pipework.

[4] Where practicable, labels and bar-codes should be etched onto the surface of containers. Materials used for labels, inks and glues should be compatible with the containers to which they are applied. Inks should be long-lasting (pigment based).

4.29. In R&D facilities, the control of decay heat should normally rely on limiting the inventory of radioactive material in locations such as in hot cells and gloveboxes. Where there is a potential for overheating, engineered cooling systems should be provided, e.g. for interim storage of waste. Where there is a potential for overheating, the possibility of chemical reaction at high temperature or high pressure in sealed containers should also be considered and provisions to manage this should be provided.

4.30. The first static barrier could include hoods, hot cells, gloveboxes, fuel cladding, vessels, pipework or other containers. The second static barrier should consist of rooms around the hoods, hot cells, and gloveboxes and/or the building walls. The design of static containment should take into account typical openings between different confinement zones (e.g. doors, penetrations).

4.31. The dynamic containment should create a gradient of reducing absolute pressures (i.e., creating negative pressure) between the environment outside the building and the radioactive or hazardous material inside the hood, hot cell, or glovebox. Backflow of gaseous or particulate contamination should be prevented. The exhaust air should be filtered (see paragraph 4.35.

4.32. Specific attention should be paid (particularly at the design phase) to maintaining containment during operations that involve the transfer of radioactive materials through or outside of the static confinement. Where appropriate, equipment should be designed to withstand radiation damage and contamination by highly radiotoxic nuclides.

4.33. The design of confinement areas should include contamination monitoring devices covering all locations inside the R&D facility and outside the primary confinement boundary provided by vessels, gloveboxes, hoods, pipework (and closures such as valves or blanking plates), ventilation ducting and the primary filters.

4.34. The design of the R&D facility should facilitate operations such as maintenance and decontamination. Consequently, the design should employ compartmentalization as one of the means available for dose optimization.

4.35. Airborne contamination (from liquids or dispersible solids) should be prevented or minimized where possible. The ventilation system should include filters, in series, to protect the workers and the public/environment by filtering the air during normal operation and to assure the continuity of the static barriers. Filters should also be used when airflow passes through confinement barriers e.g. at cooling inlets and where air exits the facility.

4.36. Where radioactive gases or particulates are generated, paragraph 6.38 in Ref. [1] states that "…the performance of air purification systems, shall be commensurate with the degree of the potential hazards…" The materials of the system should be resistant to any corrosive gases present. The ventilation system should include a final monitoring stage. The ventilation system should be designed according to accepted standards, e.g. those of the International Organization for Standardization (ISO) and national nuclear standards.

4.37. The potential for failure of a fully loaded filter should be considered. Additional standby fans and filters should be provided as specified in the safety analysis. These should be capable of maintaining ventilation during filter changing. Fans should be supplied by emergency power such that, in the case of loss of electrical power, the standby ventilation system begins operation within an acceptable delay. The safety analysis should indicate what period of delay may exist between the loss of the primary ventilation system and initiation of the standby ventilation, and this may define an operating limit or a condition. Local monitoring and alarm systems should be installed to alert operators to system malfunctions resulting in high or low flows or differential pressures. A detailed analysis should be undertaken for filters for which heavy use is planned.

4.38. To reduce risks related to transfer operations involving radioactive material, the number of transfer operations should be minimized in the design of the facility. To reduce the complexity of transfer operations, R&D facilities should be designed to accommodate standardized means of transportation of radioactive material, on-site and off-site. Where possible, fixed equipment should be provided for the monitoring of such transfers.

Protection of the workers from contamination and internal exposure

4.39. The first static barrier is normally the most important for protecting the workers. Its design requirements should be specified to assure and to control the efficiency of this barrier. Its design specifications should include: welding specifications; choice of materials; effectiveness of confinement; ability to withstand seismic loads; design of equipment (inside equipment for hoods, hot cells, and gloveboxes); specification of seals for electrical and mechanical penetrations; and the ability to perform maintenance and monitoring. For contained systems, leak-tightness should achieve a high standard of confinement.

4.40. For hoods, gloveboxes, and hot cells, the effectiveness of confinement is determined by the air velocity through any opening. The dynamic containment system should also be designed to minimize occupational exposure to hazardous material that may escape the first confinement barrier and be inhaled by the workers.

4.41. At the design stage, provisions should be made for the installation of equipment to monitor airborne contamination. These should provide an immediate alarm on detection of airborne contamination with a low threshold. Monitoring points should be chosen which would best represent the normal and foreseeable accident exposures of personnel undertaking operations, maintenance, experiments etc. See paragraph 6.39 in Ref. [1] and the section covering external radiation exposure in this publication.

4.42. Where radioactive powders or liquids are handled in the R&D facility or experiment, the installation of collection equipment (such as drip drays) should be considered to prevent the accidental spreading of material.

4.43. For normal operation, the need for use of protective respiratory equipment should be minimized through careful design of static and dynamic confinement systems.

Protection against external radiation exposure

4.44. The design of any radiation shielding should ensure compliance with occupational exposure targets (see Section 6 and paragraph V.1 of Ref. [1]) based on assumptions regarding the movement of material, occupancy time and sources to be handled. External radiation exposure can be controlled through a combination of source removal, reduction, distance, shielding and administrative controls. Provision of shielding should also be considered in material storage areas. The requirement for dose minimization should also take the maintenance personnel into account.

4.45. In high radiation areas (such as those handling spent fuel), the protection of workers should rely primarily on shielding. The design of the shielding should consider both the inventory and the location of radioactive material, including deposited radionuclides. In medium or low activity areas (such as a teaching laboratory), a combination of shielding and administrative controls should be utilized for protection of workers for both whole body and extremity doses. A general design guide is to shield as close as practical to the source.

4.46. For the determination of radiological hazards, the potential for radiation from deposited radionuclides inside pipes, equipment, hoods, gloveboxes and hot cells should be taken into account. The interior surfaces of equipment such as gloveboxes can be covered or coated to prevent accumulation of deposits from processed materials or their decay products. Shielding (or provisions to add shielding easily) can be provided where radioactivity may accumulate.

Environmental protection

4.47. Paragraph V.7 in Ref. [1] requires that a graded approach is taken to the provision of barriers for the confinement of radioactive materials, dependent on the magnitude of the

radiological hazard. Uncontrolled dispersion of radioactive substances to the environment from accidents can occur if a containment barrier is impaired. The barriers that should provide environmental protection include rooms and the wider building structure. In addition, the ventilation components that scrub or filter gases before discharge through a stack should reduce normal environmental discharges of radioactive materials to acceptable levels[5].

4.48. The design of a R&D facility should provide measures for continuous monitoring and control of the stack exhaust and for the monitoring of the environment around the facility. Further requirements on environmental protection that are also relevant to R&D facilities of Case 2 are also defined in paragraphs I.9, II.14, III.9, IV.7 and IV.8 of Ref. [1].

POSTULATED INITIATING EVENTS

4.49. Annex 1 of Ref. [1] lists a number of postulated initiating events that could be applicable to a R&D facility and further guidance on the related hazards is provided below. The systems that should be designed to continue operating in order to maintain the R&D facility and experiments in a safe state, during and immediately following an event include:

- Heat removal systems in storage areas to remove decay heat from heat generating materials, and from heat producing experimental apparatus;
- Dynamic containment systems (i.e. ventilation) should continue to operate to prevent radioactive material leakage from the facility;
- Safety monitoring systems;
- Systems that provide chemical safety under high temperature conditions;
- Inert gas feed systems e.g: to hot cells or gloveboxes.

Internal hazards

Fire Hazard Analysis

4.50. R&D facilities should be designed to control fire hazards in order to protect R&D facility personnel, the public and the environment. Fire can lead to dispersion of radioactive and/or toxic materials by destroying the containment barriers (static and/or dynamic) or cause a criticality accident by modifying the safe conditions of geometry, moderation or control system. Fire hazards are often associated with the presence of flammable or combustible materials such as chemical reagents, electrical cabling and shielding particularly associated with hoods, gloveboxes, and hot cells. A fire hazards analysis should be performed in order to

[5] In this context, acceptability may include regulatory limits and considerations of the optimisation of protection.

identify appropriate measures which should be taken to ensure that the fire is prevented; and if it occurs, it is mitigated with minimization of resulting contamination spread.

4.51. The fire hazards analysis should identify any areas that require special consideration. Locations subject to analysis should include:

a) Areas where radioactive materials are processed and stored;

b) Those facilities processing radioactive and other materials as powder or producing powder;

c) Workshops, laboratories, and storage areas containing flammable and/or combustible liquids, solvents and resins and reactive chemicals, or involving mechanical treatment of pyrophoric metals or alloys (e.g. cuttings, shavings);

d) Areas with high combustible loadings, e.g. waste storage areas;

e) Waste treatment areas, especially if incineration is used;

f) Rooms housing safety-related equipment, i.e. items such as air filtering systems and electrical switch rooms, whose degradation might have radiological or criticality consequences;

g) Process control rooms and supplementary control rooms where appropriate;

h) Evacuation routes.

4.52. The fire hazards analysis should identify potential causes of fires i.e. any fuels or oxidizing agents present. The potential consequences of fires should be assessed with, where appropriate, an estimation of the frequency or probability of the occurrence. The analysis should also assess the inventory of radioactive materials, ignition sources and combustible materials nearby, and determine the adequacy of protective features.

4.53. Modelling may be used to support the fire analysis. Requirement 18 in Ref. [8] states "Any calculational methods and computer codes used in the safety analysis shall undergo verification and validation". The results of the method can provide valuable information on which to base decisions or to identify weaknesses that might otherwise have gone undetected. Even if the frequency of a fire occurring may be low, it may have significant consequences with regard to nuclear safety and, as such, certain protective measures should be undertaken such as delineating fire compartment areas.

4.54. Analysis of fire hazards should also include a review of the provisions made for preventing, detecting, mitigating and fighting fires.

Fire prevention, detection and mitigation

4.55. Prevention is the most important aspect of fire protection. R&D facilities should be designed to limit fire risks by taking measures to ensure that fires do not break out. Should a fire break out despite the precautions taken, measures should be in place to detect the fire and minimize its consequences.

4.56. For limiting risks and consequences of a fire, a number of general and specific measures should be taken, including the following:

(a) The amount of flammable and combustible material in individual rooms, hoods, gloveboxes, and hot cells should be minimized to the extent practicable.

(b) The storage of non-radioactive hazardous material should be separated from the process areas;

(c) In gloveboxes and hot cells, where there is a high likelihood of fire (e.g. cutting of metal clad fuel elements), inert atmospheres with oxygen monitoring alarms should be used to minimize the risk of spreading a fire;

(d) Materials should be chosen according to functional criteria and fire-resistance ratings;

(e) Compartmentalization of buildings and ventilation ducts as far as possible in order to prevent spreading of fires. Buildings should be divided into fire areas. If a fire starts within a given 'fire' area, its capability to spread beyond the area boundary should be eliminated or curtailed. The higher the fire risk, the greater the number of such fire areas a building should have. Utility lines penetrating fire compartment boundaries (e.g. electricity, gases or process lines) should be designed to ensure that fire does not spread.

(f) Ignition sources such as open flames or electrical sparks should be limited to the extent practicable (e.g., use of electrical earthing or grounding devices).

(g) There should be fire detection systems inside rooms where radioactive materials are handled. Provision of detectors inside cells, gloveboxes and ventilation ducts should also be considered.

(h) Fire extinguishing devices, automatically or manually operated, with the use of an appropriate extinguishing material should be installed in areas where a fire is possible and where the consequences of a fire could lead to the dispersion of contamination outside the first static barrier. Paragraph V.6 of Ref. [1] states that "the choice of fire extinguishing media (e.g. water, inert gas or powder) and the safety of their use shall be addressed." The installation of automatic devices with water sprays should be

carefully assessed for areas where fissile materials may be present, with account taken of the risk of criticality. Extinguishing gas may be preferable for hoods, gloveboxes and hot cells.

(i) Where extinguishing devices are installed inside hoods, gloveboxes or cells, the possible spread of contamination due to reversing dynamic containment or uncontrolled water flows should be assessed.

(j) Where inert gas is used as a fire suppressant, consideration should be given to the integrity of the gas supply by providing suitable backup or diversity.

(k) Where "active" firefighting systems are used in radioactive environments special consideration should be given during design to the requirements for their commissioning and subsequent examination, inspection, maintenance and testing.

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

(m) Suitable monitoring equipment should be installed and the remote control of ventilation should be considered. Smoke particulates can lead to the rapid loading (blinding) of filters and consideration should be given to the need to reduce flows as above and other design means to reduce the challenge to filters in the event of a fire.

Explosions

4.57. A number of considerations related to chemical, toxic, flammable and explosive substances are required in paragraph 6.54 of Ref. [1]. Examples of such materials in R&D facilities include: extraction solvents, hydrogen, hydrogen peroxide, nitric acid, degradation products and pyrophoric materials (e.g. metallic hydrides, dust or particles).

4.58. Consideration should also be given to the following:

(a) Fault scenarios such as leakage leading to the contact of incompatible materials;

(b) Use of blow-out panels to mitigate the effects of explosions;

(c) Identification of parameters (e.g. concentration, temperature) to prevent situations leading to explosion;

(d) Use of inert atmospheres;

(e) Controlling levels of humidity.

4.59. In addition, effective air-locks should be provided between the flammable atmosphere and other areas, see paragraph 6.55 in Ref. [1].

Internal Flooding

4.60. Flooding in R&D facilities can lead to the dispersion of radioactive materials and changes in the moderation of any fissile material present. Rainwater, groundwater, heating / cooling fluids are all capable of flooding a facility unexpectedly and even condensation can be hazardous in some circumstances. Water can cause harm to equipment, including electrical damage and corrosion, and could contaminate emergency supplies. References to water in the following paragraphs should be read as any moderating fluid.

4.61. Where fissile material is present, criticality assessment should be undertaken to consider the risk of flooding. Equipment should not have water supply connections during normal conditions unless criticality assessments take into account the presence or leakage of water e.g. use of full disconnection or limited water volumes should be considered.

4.62. In R&D facilities where there are vessels and/or pipes with moderating fluids such as water, or where fissile materials are stored, the criticality safety analyses should consider the presence of the maximum amount of fluid within the considered location, as well as in connected locations (e.g. via transfer tunnels).

4.63. The walls (and floors if needed) of locations with potential for flooding should withstand the water load and other safety related equipment and should not be affected by flooding (e.g. installation of sumps or floor drain system to remove water).

Leaks and spills

4.64. Leaks from equipment and components such as pumps, valves and pipes can lead to dispersion of radioactive and fissile materials, toxic chemicals and the creation of unnecessary waste. Leaks of hydrogenous fluids (water, oil, etc.) can change the neutron moderation in fissile material, and reduce criticality safety. Leaks of flammable gases (H_2, natural gas, propane) or liquids can lead to explosions and/or fire. Leak detection systems should be used in such cases.

4.65. Vessels containing significant quantities of nuclear materials in liquid form should be equipped with alarms to prevent overfilling and with drip trays of appropriate capacity (e.g.

capacity equals or exceeds the volume of the vessel) and configuration to ensure criticality safety.

4.66. In-leakage of coolants should also be considered where there may be physical or chemical incompatibility with the materials or equipment present, including precipitation of fissile materials.

4.67. Spillage may occur from cans, drums and waste packages during transit within the R&D facilities and/or in stores. Appropriate mechanical protection and containment should be provided during material movements.

Loss of support systems

4.68. To fulfil the requirement established in paragraph 6.28 of Ref. [1], support systems supplies to the R&D facility should be robust. Typical support systems include electricity, water, compressed air, ventilation and inert gases.

4.69. Electrical power supplies to R&D facilities should meet accepted industry codes and standards and the provision of diverse or remote electrical supplies should be considered. In the event of loss of normal power and depending on the status of the R&D facility, an emergency power supply should be provided to certain structures, systems and components important to safety, including the following:

(a) Ventilation fans and monitoring systems for the confinement of radioactive material;

(b) Heat removal systems;

(c) Emergency control systems;

(d) Fire detection and alarm systems;

(e) Monitoring systems for radiation protection;

(f) Alarm systems for criticality accidents.

4.70. The loss of general supplies such as gas for actuators of the instrumentation and control, water for process equipment and ventilation systems, heating, breathing air and compressed air may also have consequences for safety. In the design of a R&D facility, suitable measures to ensure safety should be provided. For example:

(a) Loss of gas supply to gas actuated safety valves and dampers: In accordance with the safety analysis, valves should be used that are designed to fail to a safe position.

(b) Loss of water or heating: Adequate backup capacity or a redundant supply should be provided for in the design.

(c) Loss of breathing air: Adequate backup capacity or a secondary supply should be provided to allow work in areas with airborne radioactive material to be terminated safely and workers to evacuate.

Loss or excess of process media

4.71. Consideration should be given to the loss and excess of process media or additives, which may have safety consequences. Examples include:

- Process gas supplies, e.g. hydrogen, nitrogen, helium or argon;
- Overpressure in glove gloveboxes may cause an increase of airborne contamination and/or concentration of hazardous materials;
- Release of large amounts of nitrogen, helium or argon in working areas may result in reduction of the oxygen concentration in breathing air.

Loss of heat removal

4.72. Consideration should be given to processes that generate heat and ventilation systems that require cooling. A loss of cooling can challenge main safety functions by reducing the safety margin for confinement (and for criticality where there are fissionable materials). A large pilot plant can have significant heat loads and might be shut-down quickly if there is a loss of a service such as power. The provision of an alternative means of cooling should be considered for heat-generating materials and pilot plants with large heat sources.

4.73. Related functions of the ventilation system should be considered in the safety analysis, such as the maintenance of cooling to prevent operator heat stress or the control of humidity in materials handling. These can have an indirect effect on the safety of operations.

Dropped Loads

4.74. Requirement 10 of Ref. [8] requires an assessment that structures, systems and components are sufficiently robust, including lifting equipment. The frequency of potentially damaging, dropped loads should be avoided by qualification of cranes, avoidance of clashes, provision of appropriate slings and grabs, handling at a low elevation and the training and qualification of relevant operators.

4.75. Mechanical or human failures during the handling of radioactive material may result in degradation of criticality control, confinement or shielding. Dropped loads are recognized as postulated initiating events and their possible consequences should be minimized (see paragraph IV.42 and Annex I of Ref. [1]). Mechanical or human failures during the handling of non-radioactive loads may cause a degradation of R&D facilities safety functions. Safe travel paths should be provided and floors designed to withstand a dropped load. Hoisting

devices should be designed in such a way that a load drop becomes extremely unlikely to occur with a high level of confidence. Containers should be designed and qualified to maintain containment and protect their contents wherever appropriate.

Mechanical failure

4.76. Measures for the safety of commercially supplied equipment (e.g. mechanical guards) installed in nuclear facilities should be retained. If there is a need for adaption to their nuclear environment, this should be justified.

4.77. Mechanical failures could result in damage (e.g. missiles, crushing, bending, breakage), which may result in degradation of criticality control, confinement or shielding. For complex or critical systems (e.g. rod handling systems designed to avoid the risk of breaking the rod), a systematic failure analysis method should be applied.

Radiolysis hazard

4.78. A number of chemical processes can be affected by radiolysis potentially generating secondary hazards. Irradiation of organic or hydrated substances by radioactive materials can lead to gas generation, especially hydrogen. Radiolysis risks should be taken into account in the safety analysis for:

- Liquid effluents and organic solvents used in the laboratory;
- Contaminated oil and inflammable waste;
- Process scraps enclosing hydrogenated additives;

Where necessary, the design should prevent or mitigate radiolysis hazards.

External hazards

4.79. As stated in Paragraph 6.21 of Ref. [1], "SSCs important to safety shall be designed to withstand the effects of extreme loadings and environmental conditions (e.g. extremes of temperature, humidity, pressure) arising in operational states and in relevant design basis accident (or equivalent) conditions". The R&D facility design should take account of operational experience regarding the effects of extreme loadings due to these events individually and in combination, e.g. earthquake and tsunami.

Earthquake

4.80. R&D facilities should be designed for the design basis earthquake so as to ensure that an earthquake does not induce failures that result in a loss of containment or a criticality accident. Seismically induced failures of containment or criticality safety parameters (such as

geometry and moderation) could have significant consequences to other personnel on the site, or members of the public.

4.81. To determine the design basis earthquake, the main characteristics of the disturbance (e.g. intensity, magnitude, and focal distance), based on historic data and the distinctive geological features of the area, should be determined. The approach should ideally evaluate the seismological factors on the basis of historical data for the site. Where historical data are inadequate or yield large uncertainties, an attempt should be made to gather paleoseismic data to facilitate determination of the most intense earthquake for the R&D facility location. These different approaches can be combined since the regulatory body generally takes both into account in the approval of the design.

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

4.83. An adequately conservative spectrum should be used for calculating the structural response to guarantee the stability of buildings and to assure the integrity of the ultimate means of confinement in case of earthquake. Certain structures, systems and components important to safety will require seismic qualification. This will apply mainly to equipment used for storage and vessels that contain materials necessary for safety and hazardous chemical materials. Design calculations for the buildings and equipment should be made to verify that, in the event of an earthquake, no unacceptable release of radioactive material to the environment would occur and the risk of a criticality accident would be very low.

External fire and explosions

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

4.85. To demonstrate that the risks associated with such external hazards are within acceptable levels, the operating organization should first identify all potential sources of hazards and then estimate the associated event sequences affecting the R&D facility. The radiological and associated chemical consequences of any damage should be evaluated and it should be verified that they are within acceptance criteria. The operating organization should carry out a survey of potentially hazardous installations and transport operations for

hazardous material in the vicinity of the R&D facility. In the case of explosions, risks should be assessed for compliance with overpressure criteria.

4.86. To evaluate the possible effects of flammable liquids, falling objects (such as chimneys) and missiles resulting from explosions, their possible distance from the R&D facility and hence their potential for causing physical damage should be assessed. Toxic hazards should be assessed to verify that specific gas concentrations to meet the acceptance criteria and do not affect the controllability of the R&D facility.

Extreme weather conditions

4.87. Typically, the extreme weather conditions used to design and/or evaluate the response of a R&D facility are wind loading, tornadoes, rainfall, snowfall, ice storm and extreme temperatures.

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

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

4.90. A R&D facility should be protected against extreme weather conditions by means of appropriate design provisions. These should generally include:

– The ability of structures important to safety to withstand extreme weather loads;

– Prevention of flooding of the R&D facility;

– The safe shutdown of experiments in the R&D facility in accordance with the operational limits and conditions.

Tornadoes

4.91. Measures for protection against tornadoes will depend on the meteorological conditions for the area where the R&D facility is located. The design of buildings and ventilation systems should comply with specific regulations relating to hazards from tornadoes.

4.92. High winds are capable of lifting and propelling objects such as automobiles or telephone poles. The possibility of impacts by missiles such as these should be considered in the design stage for the R&D facility; by their initial impacts and by possible secondary fragments arising from collisions with, and spallation from, concrete walls or by other momentum transfer mechanisms.

Extreme temperatures

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

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

4.95. Human access may be essential for safety and under such circumstances the combined effects of low temperatures and ventilation on operators should be considered.

Snow and Ice

4.96. The occurrence of snowfall and its effects should be taken into account in the design of the R&D facility and its safety analysis. Snow is generally taken into account as an additional load on the roofs of buildings. Snow can also block the inlets of ventilation systems and outlets of drains. The neutron reflecting effect or the interspersed moderation effect of the snow should be considered if relevant. The effect of ice on wall loadings should also be considered where this is a possibility.

External Flooding

4.97. Flooding should be taken into account in the design of a R&D facility. Two approaches to cope with flooding hazards are:

– In some States the highest flood levels historically recorded are taken into account and the nuclear facilities are sited at specific locations above the flood level, or at sufficient elevation to avoid major damage from flooding.

– In other States, in which the use of dams is widespread and where a dam has been built upstream of a potential or existing site of a nuclear facility, the hazard posed by a breach of the dam is taken into account. The buildings of the facility are designed to withstand the water wave arising from the breach of the dam. In such cases the equipment - especially that used for the storage of fissile material - should be designed to prevent any criticality accident.

Accidental aircraft crash hazards

4.98. The likelihood and possible consequences of impacts onto the R&D facility should be calculated by assessing the number of aircraft that come close to the R&D facility and their flight paths, and by evaluating the areas vulnerable to impacts, i.e. areas where hazardous material is processed or stored. If the risk is acceptably low no further evaluations are necessary. Further guidance is provided in Section 5 of Ref. [21] and in paragraph 5.5 of Ref. [1].

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

INSTRUMENTATION AND CONTROL

Instrumentation

4.100. Instrumentation should be provided to monitor facility parameters and systems over their respective ranges for: (1) normal operation; (2) anticipated operational occurrences; (3) design basis accidents (or their equivalents); and (4) design extension conditions[6]. The information obtained on the status of the facility and experiments should allow any necessary actions to be undertaken in accordance with operating procedures or in support of automatic systems.

4.101. Instrumentation should be provided for measuring all the main variables that may affect the processes and for monitoring the general safety conditions of the R&D facility (such as radiation doses due to internal and external exposure, releases of effluents and ventilation conditions) and for obtaining any information on the facility necessary for its reliable and safe operation. Provision should be made for automatic measurement and recording of parameters that are important to safety, allowing remote viewing if necessary.

Control systems

4.102. Passive and active engineering controls are more reliable than administrative controls, and should be preferred for control in normal operational states and in accident conditions.

[6] Postulated accident conditions that are not considered for design basis accidents, but that are considered in accordance with best estimate methodology to avoid large or early releases.

When used, automatic systems should be designed to maintain process parameters of the R&D facility or experimental apparatus within operational limits and conditions or to bring the process to its safe stable state, which is generally the shutdown state.

4.103. Appropriate information should be available to the R&D facility operators for monitoring the effects of automatic actions. The layout of the instrumentation and the mode of presentation of information should provide the operating personnel with an adequate overall picture of the status and performance of the R&D facility. Devices should be installed that provide in an efficient manner visual and, as appropriate, audible indications of operational states that have deviated from normal conditions and that could affect safety. Control systems should be provided to ensure compliance with regulatory limits e.g. on discharges.

Control rooms

4.104. Control rooms should be provided to centralize the main (e.g. surveillance and overview monitoring) data displays, controls and alarms for general conditions at the R&D facility. For specific experiments, it may be useful to have local control areas where relevant information can be gathered together and monitored. These controls should be located in parts of the R&D facility where risks to operators and occupational exposure can be minimized. Special attention should be given to identifying events, both internal and external to the control rooms, which may pose a direct threat to the operators and to the operation of control rooms. Ergonomic factors should be taken into account in the design of the control room.

Safety related instrumentation and control systems (I&C) for normal operations

4.105. During normal operation, the safety related I&C systems should be separated from the experimental instrumentation and should include where appropriate:

(a) Criticality control

Where there is a risk of criticality and depending on the method of criticality control, monitoring and control parameters should include mass, density, moisture content, isotopic content, fissile content, reflection and moderation by additives and the location of materials.

(b) Monitor and control of equipment and supplies

For the safety of R&D equipment, it may be necessary to monitor and control a number of safety parameters; e.g. temperature, gas flow, compositions/flow rates, pressure. A key safety control measure is the means of confirming correct concentrations of reactive media in supplies to hot equipment.

(c) Glovebox control

For gloveboxes under inert atmosphere, the gas concentration should be monitored and controlled for safety and possibly product quality purposes. Temperatures should also be monitored. Instrumentation and controls for fulfilling requirements for negative pressure and requirements for fire control should be in place, in accordance with paragraphs 9.60 and II.25 of Ref. [1].

(d) Monitoring of external occupational radiation exposure

Sensitive dosimeters with real-time display and/or alarm should be used to monitor and control occupational radiation exposures, especially in areas with inspection equipment like X-rays and sealed radiation sources. Installed equipment should be used where possible to control gamma and neutron whole body exposures.

(e) Monitoring of internal occupational radiation exposure

In R&D facilities with the potential for airborne contamination, the following provisions should be considered in order to ensure early detection of radioactive particulate:

- Installation of continuous air monitors to detect contamination as close as possible of the working areas;

- Installation of detectors for surface contamination (beta, gamma or alpha) close to working areas and self-monitoring at the exits of rooms.

(f) Monitoring and control of liquid discharges

The liquid discharges of R&D facilities should be appropriately monitored and controlled. This can be done by sampling and analysis; and measuring the volume of discharge.

(g) Control of gaseous effluents:

Generic requirements for control of atmospheres and pressures are given in paragraphs 6.37 to 6.39 of Ref. [1], which state that “the nature and number of the barriers and their performance, as well as the performance of the air purification systems, shall be commensurate with the degree of the potential hazards with special attention paid to the potential dispersion of alpha emitters means of monitoring and appropriate alarm systems for atmospheric contamination shall be installed”. These should include measurements such as differential pressure to

confirm that the filtration systems are working effectively, and continuous monitoring of discharges.

Monitoring and control is needed to ensure that the airflows in all areas of the R&D facilities are flowing in the correct directions i.e., from less to more active areas. In work areas, the temperature, humidity and pollutants should be controlled to ensure worker comfort and hygiene. In some cases local ventilation should be used e.g., in rooms housing back up batteries.

Safety related instrumentation and control systems for operational occurrences

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

- Fire detection and extinguishing systems and building evacuation systems;
- Radiation, airborne activity detection and alarm systems;
- Gas detectors and alarm systems, where leakage of gases such as hydrogen could produce an explosive atmosphere.
- Diluting gas flows for vessels where hydrogen accumulation could be an issue

Safety related instrumentation and control systems for design basis accidents

4.107. In addition to the previous listings, the safety related I&C systems for design basis accident conditions (or equivalent) should include:

– Where there is potential for criticality; criticality detection systems, alarm systems and building evacuation systems;
– Detection and alarm systems for abnormal releases of effluents.

HUMAN FACTOR CONSIDERATIONS

4.108. The requirements relating to consideration of human factors are established in paragraphs 6.15 and 6.16 of Ref. [1].

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

– Possible effects on safety of human errors (with account taken of ease of intervention by the operator and tolerance of human error);

– The potential for occupational exposure.

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

(a) Design of working conditions to ergonomic requirements:

- The operator–process interface, e.g. electronic control panels displaying all the necessary information and no more;
- The working environment, e.g. good accessibility to, adequate space around, equipment and suitable finishes to surfaces for ease of cleaning;
- Commercial equipment that has been adapted for nuclear use (e.g. in a glovebox) should maintain original safety functions;

(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 personal radiation protection (such as tabards).

4.111. In the design and operation of fume-hoods, gloveboxes and (where appropriate) hot cells, the following specific considerations should be taken into account:

(a) The design of equipment to avoid conventional laboratory hazards that may result in worker injuries, including internal radiation exposure through cuts in the gloves and/or wounds on the operator's skin and/or the possible failure of confinement;

(b) Ease of physical access, work space and visibility in and around these installations;

(c) The potential for loss of containment, including glove damage;

(d) Training of operators on procedures to be followed in normal and abnormal situations.

SAFETY ANALYSIS

4.112. The safety analysis for a R&D facility should be performed in two major steps:

- The assessment of occupational exposure and public exposure for operational states of the R&D facility and comparison with authorized limits for operational states;

- Determination of the radiological and associated chemical consequences of design basis accidents (or the equivalent) and design extension conditions for the public and verification that they are within the acceptable limits specified for accident conditions.

4.113. The results of these two steps should be reviewed for identification of the possible need for engineered safety features and/or additional operational limits and conditions.

Safety analysis for operational states

Occupational radiation exposure and exposure of the public

4.114. At the design stage of a new R&D facility, an assessment should be made of the radiation exposure to the workers in all workplaces, on the basis of conservative assumptions for factors including the following:

- Licensed inventories of radioactive materials in each part of the R&D facility;
- Calculated radiation levels should use the enveloping R&D facility source term wherever located;
- The maximum cumulative annual working time at each workplace for both normal operation and anticipated maintenance work;
- Calculations of the efficiency of shielding during normal operation based on conservative assumptions regarding its performance.

4.115. The design of equipment, layout of equipment in the R&D facility, shielding, etc., should be based on adequate interaction and feedback between process and mechanical designs, safety assessment, operational experience from similar and/or upstream facilities.

4.116. Cleaning operations (e.g. dust elimination from hoods, gloveboxes and hot cells) should be given special consideration in the design.

4.117. The calculated exposure should be compared with actual exposure during subsequent R&D facility operation. If considered necessary, maximum permissible annual working times for specific workplaces may be included in the operational limits and conditions.

4.118. Calculations of estimated public doses should be made on the basis of maximum estimated releases of radioactive material and maximum deposition on the ground. Conservative models and parameters should be used to calculate the estimated doses to the public.

Release of non-radioactive hazardous materials

4.119. This Safety Guide deals principally with those material hazards that can give rise to radiological hazards (see paragraph 2.2 of Ref. [1]). Realistic and robust[7] estimations of material toxicity to R&D facility personnel should be made. Releases of hazardous radioactive chemicals or biological materials affecting the public or the environment should be evaluated using conservative models and parameters, no lower than the standards used in equivalent non-nuclear industries, see Ref. [19].

Safety analysis for accident conditions

Methods and assumptions for safety analysis for accident conditions

4.120. For R&D facilities, the consequences of accidents are not necessarily limited to individuals located on site and in close proximity to the location of the accident. The consequences depend on various factors such as the release rate and quantity, distance between receptor and source of release, material transport to the receptor and exposure time.

4.121. The acceptance criteria associated with the accident analysis should be defined in accordance with paragraph 6.5 of Ref. [1] and with respect to any national regulations and risk criteria. To estimate the on-site and off-site consequences of an accident, the wide range of physical processes that could lead to a release of radioactive material to the environment should be modelled in the accident analysis and the enveloping cases encompassing the worst consequences should be determined (see paragraphs 2.6, 2.10-2.12 and 4.24 of Ref. [1]).

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

1) An approach using the bounding case (worst case approach) 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 and some non-safety features beyond their originally intended range of functions to reduce the consequences of accidents (the best estimate approach).

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

[7] i.e. conservative

The second case is generally used when the first one cannot be applied to justify the safety of an accident condition.

Assessment of possible accident consequences

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

(a) Analysis of the actual site conditions and conditions expected in the future;

(b) Identification of workers and members of the public (i.e. the representative person living in the vicinity of the R&D facility) who could possibly be affected by accidents, allowing for demographic variations;

(c) Specification of the accident configurations, with the corresponding operating procedures and administrative controls for operations;

(d) Identification and analysis of R&D facility conditions, including internal and external initiating events that could lead to a release of material or of energy with the potential for adverse effects, the time frame of emission and the exposure time, in accordance with reasonable scenarios;

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

(f) Characterization of the source term (material, mass, release rate, temperature, etc.);

(g) Identification and analysis of transport pathways for released material within the facility;

(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 representative person identified in the safety assessment.

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

4.125. Environmental transport of material should be calculated with qualified models/codes or using data derived from qualified codes, with account taken of the meteorological and hydrological conditions at the site that would result in the highest exposure of the public.

EMERGENCY PREPAREDNESS AND RESPONSE

4.126. The hazards associated with a R&D facility and potential consequences should an emergency occur should be assessed to provide a basis for adequate emergency arrangements in accordance with Refs. [10], [11] and paragraph 9.62 of Ref. [1]. The on-site and off-site emergency arrangements, including emergency plan(s) and procedures, that take into account the potential hazards (plant and experimental) analysed for the facility, should be developed for a range of postulated emergencies irrespective of the cause. Such emergencies include, but are not limited to, criticality accidents and, nuclear or radiological emergencies coincident with external hazards affecting the infrastructure in the vicinity of the R&D facility (e.g. widespread fires, earthquakes and tsunamis).

4.127. The R&D staff running experiments should inform management of the hazards and shutdown arrangements for all experiments in the facility, for both Case 1 and Case 2 facilities.

4.128. For R&D facilities belonging to Case 2, an expanded list of hazards is defined in the IAEA Safety Guides related to the corresponding type of nuclear fuel cycle facilities e.g. Refs. [5], [15] and [16]. These should be considered in the hazard assessment used for developing the emergency arrangements.

MANAGEMENT OF RADIOACTIVE WASTE

General

4.129. Requirements for managing radioactive waste from R&D facilities are established in paragraphs 9.54 to 9.57 in Ref. [1]. General requirements on predisposal management of radioactive waste are established in Ref. [22] and further information on the optimization of protection for radioactive waste is provided in Refs. [23] and [24]. Specific guidance on predisposal management of radioactive waste from nuclear fuel cycle laboratories is provided in Ref. [25], while guidance which may relevant to pilot plants can be found in Ref. [26]. IAEA standards require the generation of radioactive waste to be minimized in volume and activity, as far as practicable. The following aspects should be considered in design:

a) Generation:

Requirement 8 of Ref. [22] establishes general design requirements for radioactive waste generation and control. At the generation step, waste should be properly characterized in in terms of total activity, concentrations of relevant radionuclides and other hazards. A record keeping system should be implemented to ensure the proper identification, traceability and accounting for the radioactive waste generated, and the avoidance of criticality conditions when fissile material becomes waste and during its subsequent processing. In fume-hoods, gloveboxes and hot cells it is possible to reduce waste by reducing the materials introduced into these installations;

b) Handling:

Requirement 10 in Ref. [22] states that adequate containers should be provided for radioactive waste removed from R&D facilities. It is good practice to minimize contamination spread by control at the point of origin. Guidance on the handling of fissile waste is provided in Ref. [9] including mass control. Special requirements apply to fissile waste, as stated in V.15 of Ref. [1]. The engineered features should provide containment and control of geometry. Examples include; filters from hoods, gloveboxes, hot cells and ventilation systems;

c) Collection:

Design features should reduce the risk of damage to waste containers that can potentially lead to loss of containment. For the assessment and the management of radioactive waste, consideration should be given to a central waste management area. In this central area, radionuclides in the waste should characterized and quantified (including any fissile content) and may be treated and placed in containers for interim storage. The mixing of wastes that are chemically or radiologically incompatible in the same containers or storage areas should be avoided by design where possible;

d) Storage:

The design of storage should take account of the radioactivity and other hazards of the waste, even if the storage is intended to be short-term. Requirement 11 of Ref. [22] states that “Waste shall be stored in such a manner that it can be inspected, monitored, retrieved and preserved in a condition suitable for its subsequent management”. Measures to guarantee the integrity of the facility and the waste containers considering low probability events should be taken even for interim storage.

e) Processing:

Subsequent processing outside R&D facilities can include pretreatment (i.e. segregation, chemical adjustment and decontamination), treatment (i.e. volume reduction, removal of radionuclides from the waste, and change of composition) and conditioning, (i.e. immobilization and packaging) before longer term storage. Techniques and procedures for treatment and conditioning are preferred that provide waste forms and/or waste packages in line with the established or anticipated waste acceptance requirements for storage and eventual disposal.

Management of Gaseous and Liquid Discharges

4.130. The gaseous effluent discharge from a R&D facility should be controlled by an air purification system, which normally consists of a number of high efficiency particulate air (HEPA) filters in series. Performance standards should be set for the air purification system, in accordance with an appropriate safety assessment.

4.131. Monitoring equipment such as the following should be installed and used:

(1) Differential pressure gauges to identify the requirement for filter changes;

(2) Activity or gas concentration measurement devices and discharge flow measuring devices with continuous sampling; and

(3) Injection and sampling equipment to test filter performance.

4.132. Liquid effluents to the environment should be treated to reduce the discharge of radioactive materials and hazardous chemicals to levels authorized by regulatory authorities. The use of filters, ion-exchange beds or other technology should be considered where appropriate.

OTHER DESIGN CONSIDERATIONS

Gloveboxes and hot cells

4.133. Fume-hoods, gloveboxes and hot cells should be designed to facilitate the use of dry cleaning methods (e.g. criticality safe filtered vacuum cleaners). Features such as easily cleaned surfaces, strippable coatings, rounded corners etc. should be considered.

Radiation protection shielding

4.134. The materials handled in a R&D facility can generate significant dose rates (neutron, beta/gamma) depending on the isotopic composition of the material processed. Therefore consideration should be given at the design stage for the need for neutron and gamma shielding.

4.135. Effective gamma and neutron shielding can be applied to hot cell and glovebox faces but this can restrict visibility and increase occupancy. The choice and type of shielding should therefore be based on a prediction of the total occupational exposure during normal operation and maintenance.

Design for fresh fuel storage

4.136. Stores for fresh fuel should be designed with fixed, dry and marked locations for the fuel, in accordance with the conclusions of the criticality safety analysis. Racks, fixings and handling arrangements should be capable of accommodating fuel of the required dimensions whilst maintaining the required stability. Fuels should be clearly identifiable. Necessary provisions for physical protection should be included in the design.

4.137. In designing stores for fresh fuel, consideration should also be given to provisions for:

- Weighing items for inventory control and verification without the need to transfers to and from storage;
- Space and facilities for packaging, with inert atmosphere if appropriate.

Design for maintenance

4.138. Design for maintenance should include following aspects:

(a) Consideration of whether maintenance can be carried out remotely if possible or carried out using personal protective equipment.

(b) Criticality safety conditions such as limiting the introduction of liquids, solvents, plastics and other moderators;

(c) Prevention of contamination spread when maintaining or replacing equipment (e.g. motors, drives can be located outside gloveboxes);

(d) The R&D facility design should aid good-housekeeping. Gloveboxes and hot cells can become dusty unless cleaned regularly. Tools should be stored in designated locations. Waste accumulation should be avoided;

(e) Removal of shielding material. Shielding on gloveboxes is often provided for normal process operations and may need to be removed for maintenance access. Consideration should be given to the removing all radioactive sources before removing any shielding;

(f) The facility design should minimize sharp edges and the need for sharp equipment in gloveboxes to minimize the potential for contaminated wounds.

(g) The design should include segregation and handling of mixed and hazardous waste.

Decontamination and dismantling

4.139. Floor, wall and ceiling surfaces should be chosen, particularly in wet chemical areas, to facilitate decontamination and future decommissioning. Surfaces in areas where contamination may exist should be made nonporous and easy to clean, particularly in rooms containing hot-cells and gloveboxes, as well as within containment. Appropriate methods include the application of coverings or coatings to such surfaces, for instance by using paint, resins or stainless steel liners. They should be designed without corners or crevices that may be difficult to access. In addition, all potentially contaminated surfaces should be made readily accessible for allow for periodic and eventual decontamination (e.g. by stripping of paint or coating).

5. CONSTRUCTION

5.1. Para 7.1 of Ref. [1] states "Before the construction of a fuel cycle facility begins, the operating organization shall satisfy the regulatory requirements regarding the safety of the facility design" and the construction of a R&D facility will require authorization from the regulatory body.

5.2. For a complex R&D facility, authorization should be sought in several stages. Each stage may conclude with a hold point at which approval by the regulatory body is required before the subsequent stage may commence. The extent of regulatory involvement during construction should be commensurate with the potential hazards posed by the R&D facility during its expected life cycle.

5.3. Current good practices should be used for building construction, fabrication and installation of facility equipment. Effective means should be in place to prevent the installation of counterfeit, fraudulent or suspect items, as well as non-conforming or sub-standard components, because such items or components could impair safety even after commissioning of the R&D facility

5.4. Modularized components (e.g., gloveboxes, hot cells, hoods, monitoring systems) should be used in the construction of complex R&D facilities of Case 1. This enables equipment to be tested and proven at manufacturers' premises before installation in the R&D facility. In addition, this approach also aids commissioning, maintenance and decommissioning.

5.5. The construction of parts of the R&D facility and commissioning or operation of other parts of the R&D facility can overlap. Construction in a radioactive environment can be

significantly more difficult and time consuming than when no active material is present. When this occurs, the R&D facility organization should take measures to prevent:

- Construction personnel from receiving unnecessary exposure to radiation;
- Damage to structures, systems and components necessary for operating the R&D facility by construction activities;
- Transfer of radioactive materials to the part of the facility under construction;
- Potential harm to personnel in the operating part of the facility.

5.6. These preventative measures should include training of construction personnel for their own safety and the safety of others, on simulated installations prior to performing actual construction.

5.7. Consideration should be given to the quality assurance programme during construction of a R&D facility. The programme should be prepared early in the construction stage and include:

- Applicable codes and standards;
- Organizational structure;
- Design change programme (configuration control);
- Procurement control;
- Records maintenance;
- Equipment testing;
- Coding and labelling of safety relevant components, cables, piping, and other pieces of equipment.

5.8. Further guidance on safety in construction of nuclear installations can be found in Ref. [27].

6. COMMISSIONING

6.1. Section 8 of Ref. [1] sets out the requirements applicable to commissioning of a R&D facility. A commissioning programme should be prepared and implemented to demonstrate that the R&D facility conforms to its designed objectives and safety performance criteria as well as to familiarize the operating personnel with particular characteristics of the facility. The establishment of a good safety culture should start at earliest possible stage in commissioning.

6.2. Paragraph 8.9 of Ref. [1] establishes the requirement for commissioning to be divided into three stages, which is also applicable to a R&D facility at the plant or experimental level;

Inactive or 'cold' commissioning

6.3. In this phase, the facility's systems are systematically tested, both individual items of equipment and the systems in their entirety. The emergency arrangements for the facility should be in place prior to the next phase of commissioning, in accordance with Ref. [10].As it is relatively easy to take corrective actions, as much verification and testing as possible should be carried out in this phase. Operators should take the opportunity to prepare the set of operational documents and to learn the details of systems. Leak-tightness and the stability of control systems are best tested at this stage;

Uranium or 'warm' commissioning

6.4. Natural or depleted uranium should be used in this phase as necessary; to avoid criticality risks, to minimize occupational radiation exposure and to limit possible needs for decontamination. This phase also provides the opportunity to initiate the control regimes that will be necessary when higher activity materials are introduced, such as plutonium, other actinides or fission products.

6.5. Safety tests performed during this commissioning stage should mainly be devoted to confinement checking. These should include (i) checking for airborne radioactive material; (ii) smear checks on surfaces; and (iii) checking for gaseous discharges and liquid releases. There should also be checks for unexpected accumulations of hazardous material;

Active or 'hot' commissioning

6.6. This stage enables administrative and engineered systems to be progressively and cautiously brought into full operation. Paragraphs 8.5 and 8.10 in Ref. [1] establish requirements to fully exercise radioactive systems and reinforce safety culture ensuring that operating personnel are fully trained in handling radioactive materials and associated emergency arrangements.

6.7. The license to operate the R&D facility is generally issued to the operating organization just before this third phase. The regulatory body should define hold points and/or witness points as license obligations, coordinated with the proposed commissioning programme. At this stage, 'hot' commissioning will be performed under the responsibility, safety procedures and organization of the licensed operator. The 'hot' commissioning may be considered part of operational stage of the R&D facility.

6.8. The Safety Committee (or an equivalent review body) should be established before active commissioning commences, if one has not been established already. Lessons learned from similar facilities should be implemented especially for the commissioning of a new R&D facility.

6.9. During commissioning and later during operation of the R&D facility, predicted estimates of worker doses should be assessed against actual dose rates. If in operations, the actual doses are higher than the predicted doses, corrective actions should be implemented including making any changes to the licensing documentation (e.g. the safety case) or adding or changing safety features or work practices (see also Sections 6 and 7). The fundamental principles 4, 5 and 6 of Ref. [28] apply.

6.10. For R&D facilities of Case 1, the review of worker doses starts during the commissioning phase but continues throughout the lifetime of the facility as new experiments and materials are introduced or parts of the facility are brought into operation.

7. OPERATION

CHARACTERISTICS OF A R&D FACILITY

7.1. Ref. [1] states “The operating organization shall have the overall responsibility for the safety of the facility during operation. The operating organization shall establish an appropriate management structure for the facility and shall provide the necessary infrastructure for operations to be conducted safely”. Subsequent paragraphs in Ref. [1] detail responsibilities for operations, maintenance and control of modifications. These requirements and the general guidance in Ref. [3] are relevant to R&D facilities. This section provides specific guidance on good practices and additional considerations in meeting the safety requirements for a R&D facility, including operations and experiments that may be undertaken by different teams, or by different organizations. Paragraph 1.2 of this guide outlines some distinctive hazards for an R&D facility that should be taken into account in meeting the safety requirements.

7.2. Safety should be coordinated between operational functions and the research function. This coordination should be very clear and the responsibilities of personnel in both functions should be well defined. Responsibilities that should be coordinated carefully include radioactive material management, waste management and experiment monitoring. The R&D facility Safety Committee (or equivalent body) should comprise representatives of both

operations and research functions. Specific documents should be written and interfaces defined for everyday use and not only through the Safety Committee.

7.3. Research programmes should be compliant with the existing safety case or considered as a modification. Research implicitly requires flexibility in the materials and processes used and the safety case should anticipate a variety of research needs, see paragraph 2.7. The domain of safe operation defined through the operating limits and conditions should be large enough to avoid frequent modifications of the safety case or of the regulatory authorization. The modification should be reviewed and approved by the appropriate authority, in accordance with regulatory requirements.

7.4. Some of the operational activities performed in a R&D facility are more appropriate for facilities of Case 1 and others more appropriate to facilities of Case 2 in Annex I. Some paragraphs in this section make reference to these cases and the Annex.

QUALIFICATION AND TRAINING OF PERSONNEL

7.5. The general safety requirements related to qualification and training of R&D facility personnel are defined in the paragraphs 4.10, 4.24, 8.4 and 9.8 to 9.13 of Ref. [1].

7.6. The diversity of R&D facility personnel should be accommodated by the training programmes for safety. All training programmes linked with the R&D facility should aim to establish a common safety culture.

7.7. In these training courses, emphasis should be given to individual responsibility for safe operation, organization, human factors, lessons learned from events (both inside and outside the facility), defence in depth and assessment of the safety of specific R&D facility programmes or operations.

7.8. The operating organization should consider the effect of changes in research and operating personnel and work programmes when planning training programmes.

7.9. Many processes related to glovebox and hot cell operations involve manual intervention. Therefore, special attention should be paid to training R&D facility personnel operating gloveboxes and hot cells, including reaction to anticipated operational occurrences (e.g., punctured glove in glovebox and loss of ventilation in hot cell).

FACILITY OPERATION

7.10. Just as Para 9.6 of Ref. [1] contains requirements related to interdependencies and communication between facilities on the same site, different organizational units within a R&D facility should hold regular work planning meetings to achieve a common work plan

and to coordinate activities. Clear definitions of individual assignments should be documented and approved at a suitable level of authorization.

7.11. To ensure that the R&D facility operates well within the operating limits and conditions under normal circumstances, a set of lower level sub-limits and conditions should be defined. Such sub-limits and conditions should be clear and should be made available to and well understood by personnel operating the facility. Where there is flexibility for different groups to set their own sub-limits the management system should ensure that these are notified to all relevant personnel.

7.12. Operating documents should be prepared that list all the limits and conditions under which the R&D facility is operated. Annex III gives examples of operational limits and conditions applicable to facilities in Case 1 and Case 2, which can be used for defining operating limits and conditions in the various R&D facility areas.

7.13. Generic limits should also be set for the facility. Examples are:

(1) Ranges of mass control of fissile material, during operation, transfer, and storage to avoid criticality, e.g., inventory limit of fissile material in gloveboxes;
(2) Limits on concentrations, geometry and moderators in solutions containing fissile materials;
(3) Inventory limits of radioactive materials and isotopic compositions in gloveboxes or interim storage areas.
(4) The maximum specific heat loads in locations such as hot cells or gloveboxes;
(5) The maximum quantity of additives at different steps in R&D facility processes;
(6) Combustible material limits, types and inventory, in gloves boxes and hot cells;
(7) Limits of flammable atmospheres in enclosed equipment, e.g., hydrogen in a furnace.

7.14. Programmes should be prepared for the routine surveillance of airborne and surface contamination, radiological protection and, more generally, for ensuring an adequate level of housekeeping.

7.15. The values of the key safety variables in operating limits and conditions should be recorded at all times for auditing purposes and to support periodic safety reviews. There should be an investigation and learning process triggered by non-compliances with the operating limits and conditions. The findings of such investigation should be recorded and learning disseminated (operational experience feedback).

7.16. The operating organization should define procedures to assure a proper level of safety when phases of R&D facility operation are limited and are followed by long periods of

shutdown. Training programmes should cope with these situations and reflect these procedures.

7.17. Procedures should also include actions required to ensure criticality safety, chemical safety, fire safety, emergency response[8], and environmental protection. Operating procedures should be defined for the ventilation system in fire conditions. Periodic testing and drills should be performed. Operating instructions and procedures should be reviewed periodically and updated and authorized as appropriate.

7.18. In a R&D facility measures should be taken to ensure that experiments and processes can be placed in a safe shutdown condition. However, some systems, such as ventilation used for confinement, continue to operate. Specific operating procedures should be used for the shutdown of particular processes to prevent for example, exothermic reactions, hydrogen explosion, criticality, etc. Formal systems of communication should be established to ensure that the facility configuration, including the status of items important to safety, the OLCs and other key safety information, is known, recorded and accessible at all times.

7.19. An inspection programme for the facility should be established, the purpose of which is to periodically confirm that the R&D facility is operating in accordance with prescribed operating limits and conditions.

7.20. The R&D facility management should organize pre-job "tool-box" and risk-assessment briefings at the start of each day and before undertaking new operations or experiments, to identify potential safety issues and define the best options for safety, as well as to review and assess procedures. See paragraph 2.37 in Ref. [3]. All R&D facility personnel should participate in such meetings, as far as possible.

MAINTENANCE AND PERIODIC TESTING

7.21. The safety requirements related to maintenance, calibration, periodic testing and inspection of nuclear fuel cycle facilities are defined in Ref. [1], para 9.28 to 9.34.

7.22. When carrying out maintenance in a R&D facility, particular consideration should be given to the potential for surface contamination or airborne radioactive material, as well as to any chemical or biological exposure. The R&D facility should not be placed in an unsafe or unanalyzed condition in order to perform periodic testing or routine maintenance.

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

[8] Emergency procedures are part of overall emergency arrangements to be established in accordance with the section EMERGENCY PREPAREDNESS in Chapter 4.

(1) A suitable maintenance programme should be developed and implemented for all equipment and devices used in work control: e.g. handover and handing back of approved documents, means of communication and visits to job sites, changes to the planned scope of work, suspension of work and ensuring safe access;

(2) Equipment isolation: de-energizing and disconnecting electrical cabling, hot or pressurized piping and draining, venting and purging of equipment;

(3) Testing and monitoring: checks of workplace and tools before commencing work (see para 5.67 in Ref. [3]), monitoring during maintenance and checks for re-commissioning, and communications as above;

(4) Safety precautions during work, e.g. specification of safety precautions, ensuring the availability of personal protective equipment and ensuring its use;

(5) Continued monitoring systems for control of criticality and radiation protection;

(6) Reinstallation of equipment, e.g. reassembly, reconnection of pipes and cables, testing, cleaning the job site and monitoring should be performed after maintenance and before re-commissioning.

7.24. A programme of periodic inspections of the R&D facility should be established, as a minimum at fume-hoods, hot cells, gloveboxes, and entrances to containment areas. The pressure drop across filter banks should be checked on a regular basis. There should be routine programmes of inspection and maintenance to avoid the spread of contamination or release:

- To detect glove material degradation and prevent glove failures;
- Maintenance of master slave manipulators and their sleeves in hot cells;

7.25. Periodic testing of fire detection and suppression systems for the R&D facility should be carried out. The operational compliance of ventilation systems with fire protection requirements should also be verified on a regular basis.

7.26. Regular verification of the availability of materials needed for maintenance should be conducted. For continuity of safe operations of the R&D facility, a programme for provision of spare parts for safety features including radiation monitoring equipment should be established and implemented.

MODIFICATION CONTROL

7.27. R&D facilities are normally established for a variety of different R&D programmes. It may nevertheless be necessary to modify the facility and its safety case if a new programme

of work or item of equipment is not covered by the existing license. As part of the management system, a standard process for any modification should be applied in a R&D facility, in accordance with Para 9.35 of Ref. [1].

7.28. According to the safety significance of the modification and in agreement with the national regulatory authority, modifications should be verified, registered or licensed by the regulatory authority before implementation. The reassessment of the facility safety and the formal authorization by the national regulatory authority identified in paragraph 3.10 of Ref. [1] should consider, in particular, the need to assess human factors, e.g., the man/machine interface, alarm systems, procedures, and qualification or requalification of personnel.

7.29. The assessment, authorisation and implementation of modifications should be managed in accordance a control programme for modifications established by the operating organization. A modification control form, which may be an electronic record, should be used as an overall means of monitoring the progress of modifications through the system and as a format / check sheet to ensure that all modification proposals receive an equivalent and sufficient level of scrutiny. The modification control form should contain a description of the change, why it is being made and describe its potential impact on safety. All aspects of safety that may be affected by the modification should be described, with a demonstration that adequate and sufficient safety provisions are in place to control the potential hazards. For example, changes to the materials and thickness of shielding, quantities of hydrogenated and non-hydrogenated materials, and locations of equipment that may affect criticality safety analyses or radiation safety should be described.

7.30. Modification control forms should be scrutinized, and be subject to approval, by qualified and experienced persons to verify that the arguments used to demonstrate safety are suitably robust and meet the requirements of the regulatory body. The depth of the safety arguments and the degree of scrutiny to which they are subjected should be commensurate with the safety significance of the modification.

7.31. The modification control form should also specify which documentation will need to be updated as a result of the modification. Procedures for the control of documentation should be put in place to ensure that documents are changed and distributed within a reasonable time, allowing operating personnel to review, adopt and implement modified procedures when modifications are commissioned. The modification control form should also specify the functional checks that are required before the modified system may be declared fully operational again.

7.32. The modifications made in a R&D facility should be reviewed by the operating organization on a regular basis. This is to ensure that the combined effect of a number of minor modifications do not have hitherto unforeseen effects on the overall safety of the facility. Depending upon the national regulatory practices, the assessment may also be reported to the regulatory authority. See section 2 of this publication.

CRITICALITY SAFETY

7.33. Where there is fissile material in a R&D facility, it is particularly important that procedures for controlling criticality hazards are strictly applied (paragraphs 9.49 and 9.50 of Ref. [1]).

7.34. Operational aspects of criticality control in a R&D facility should include:

(1) Consideration of an unexpected change in conditions which could increase the risk of a criticality accident, e.g., unplanned accumulation of fissile material (e.g. in gloveboxes or ventilation ducts) or hydrogenated materials;

(2) Unexpected water accumulation e.g. due to water pipes leaks;

(3) Management of moderating materials, particularly hydrogenated materials such as those used for decontamination of gloveboxes and leakages of oils from gear boxes;

(4) Management of the fissile material transfer (procedures, mass measurement, systems and records) where mass control is used;

(5) Reliable methods for detecting the onset of unsafe conditions with respect to criticality control;

(6) Evacuation drills and/or exercises assuming that a criticality occurs and/or alarm is activated (see section in this publication covering emergency preparedness);

(7) Periodic calibration or testing of criticality control and monitoring systems (e.g., material movement control, balances, scales, etc.).

7.35. The tools used for purposes of nuclear material control and accountability, like mass, volume or isotope measurements and accounting software may also have some use in the field of criticality safety. However, where there is any uncertainty about the characteristics of fissile material, conservative values should be used for parameters such as fissile material content and isotopic composition. This arises particularly when handling cell floor or glovebox sweepings and similar waste material.

7.36. Additional criticality hazards may be encountered when carrying out maintenance work. For example, “if fissile material has to be removed from equipment only approved

containers approved for criticality purposes shall be used", see paragraph V.14 in Ref. [1]. Also, wastes and residues arising from experiments or pilot processes, decontamination, and maintenance activities should be collected in containers with a favorable geometry approved for the work, and stored in dedicated criticality safe areas.

RADIATION PROTECTION

7.37. Paras 9.36 and 9.37 of Ref. [1] state "The measures for protection against radiation exposure of operating personnel, including contractors, and members of the public shall comply with the requirements of the regulatory body and with the requirements established in Ref. [6]. For all operational states the radiation protection measures should be such as:

(a) To ensure that exposures are kept below regulatory limits;

(b) To optimize radiation protection."

In a R&D facility, the radiological hazards to both workers and members of the public include intakes (inhalation/ingestion of particulates, aerosols and gases) and external exposure.

7.38. Paragraphs 9.38 to 9.43 of Ref. [1] require the establishment of an appropriate radiation protection programme. For a R&D facility, account should be taken of its complexity and size, as well as the diversity of inventories. In addition, the physical and chemical properties of the inventory may change inadvertently and result in unforeseen consequences.

7.39. Equipment outside of gloveboxes and hot cells, the rooms in the facility and the surrounding environment should be monitored systematically and regularly. Any deviation of the radiation levels above the normal ranges (e.g. hot spots or slow incremental increases of radiation level) for should be detected, have its origin identified, and result in prompt corrective and/or mitigating actions.

7.40. Radiation protection personnel should be part of the decision-making process in an operating R&D facility so that dose minimization requirements can be applied. These requirements include the early detection of problems and proper housekeeping for material storage and waste segregation. Any zones of high contamination or dose should be recorded and marked.

7.41. Intrusive maintenance and modifications should be major activities requiring 'justification' and 'optimization of protective actions' specified in Ref. [6]. The procedures for intervention should include:

(1) Estimation of doses (external doses) prior to the intervention;

(2) Preparatory activities to minimize the dose, including:

(a) Identification of specific risks to the workers and caused by the activities;

(b) Requirement for use of additional shielding, remote devices or mock-ups;

(c) Definition of specific procedures within the work permit (individual and collective protections requirements such as masks, clothing, gloves and time limitation);

(3) Measurement of the doses during the activities;

(4) Implementation of feedback to derive possible improvements.

Control of internal dose

7.42. During R&D facility operation (including maintenance and modifications) the prevention of internal dose should be controlled by ensuring that:

(a) Performance standards are set for all parameters potentially affecting internal doses, e.g. contamination levels;

(b) Regular contamination surveys of facility areas and equipment are carried out to confirm the adequacy of cleaning programmes;

(c) To aid personnel in considering the level of risk involved in any task and assigning Radiological Protection personnel to routine surveys (rounds), the facility areas are assigned a radiological and contamination classification. These boundaries between the areas are regularly checked and adjusted to match current conditions;

(d) Contamination and radiation zones are delineated with proper signage;

(e) Continuous air monitoring is carried out to alert facility operators if airborne contamination is present;

(f) Contamination levels do not exceed predetermined action levels;

(g) Mobile air samplers are used at contamination sources, as necessary;

(h) Prompt investigation is carried out following high airborne contamination readings;

(i) Personnel are trained in dressing, using, and undressing from personal protective equipment with the assistance of Radiological Protection personnel;

(j) Radiation in air monitors are installed for airborne contamination (i.e., permanent or mobile);

(k) Personal protective equipment is maintained in good condition and is regularly inspected;

(l) A high standard of housekeeping is maintained within the facility. Cleaning techniques are used which do not give rise to airborne contamination;

(m) The effectiveness of the ventilation system should be checked regularly and rebalanced if necessary, following the isolation or de-isolation of boxes and hoods.

(n) Waste arising from maintenance or similar interventions are segregated by type (i.e. by treatment and disposal route), collected, and directed to the appropriate waste route;

(o) Careful consideration is given to the combination of radiological and industrial hazards (e.g., oxygen deficiency, heat stress) with particular attention paid to the risk/benefit analysis of the use of personnel protective equipment especially for air-fed systems;

(p) Personnel and equipment are checked for contamination and decontaminated, if necessary, prior to crossing contamination area boundaries.

7.43. The methodology for assessing internal exposure may be based on collection of air sampling data. The in-vivo (whole-body) monitoring and biological sampling (for example, nose-blow, faecal and periodic urine samples) should also be available, as necessary for normal and accident conditions, as complementary measures to monitor workers' exposure.

7.44. Monitoring efforts should be commensurate with the objective of having no airborne activity or contamination of work places.

7.45. Entry into and exit from the work area should be controlled to prevent the spread of contamination. In particular, clothing changing and decontamination stations should be available.

7.46. During periodic testing, inspections and maintenance of R&D facilities, precautions should be taken to limit the spread of radioactive contamination by means of temporary enclosures and additional ventilation systems.

7.47. On completion of maintenance work, areas should be decontaminated and air sample and smear checks carried out to confirm that the area can be returned to normal use. Consideration should be given to grouping similar activities between work periods, in order to optimize protection and ensure that temporary area categorizations are maintained.

7.48. There should be careful preparation before entry into hot cells or gloveboxes that have contained radioactive materials (such as maintenance gloveboxes), in addition to industrial safety requirements for confined space entries. Radiation exposure rates and non-fixed contamination levels should be measured inside the hot cell or glovebox to choose personal protective equipment and to determine if working time restrictions are required before entry. These operations need appropriate authorizations, depending on local rules.

7.49. Access to areas designated ‘controlled areas’ should be avoided for R&D facility personnel with skin wounds.

7.50. On the basis of effluent monitoring data, regular estimates of exposure to the public (representative person) living in the vicinity of the facility should be made.

Control of external radiation exposure

7.51. There are dedicated areas in a R&D facility where specific arrangements are required to control external radiation exposure. Typically these will be areas in pilot processing facilities where bulk quantities of radioactive materials and source materials are stored and handled.

7.52. Radiation levels should be controlled at the worksite by:

– Ensuring areas of high occupancy are remote or appropriately shielded from significant quantities of radioactive materials;

– Removing radioactive materials from areas adjacent to the work area for extended maintenance work;

– Handling and operating instrumentation with enclosed radiation sources only by suitably qualified and experienced persons;

– Performing routine radiation dose rate surveys.

7.53. External radiation exposure should be controlled or limited by:

– Training of personnel about radiation hazards and use of dose measuring equipment;

– Avoiding unnecessary occupation of controlled radiation zones, e.g. limiting working-time near radiation sources;

– Using individual and temporary shielding;

7.54. Because of the proximity of hands to radioactive materials when doing work in gloveboxes, hands are susceptible to receiving a higher exposure than other parts of the body. Therefore, exposure to extremities should be monitored closely (e.g. use of finger films).

7.55. Additional controls may be needed if higher specific activity materials are used. This could also introduce additional radionuclides into waste streams. A comprehensive assessment of occupational and public exposure should be carried out before the introduction of this type of material.

7.56. Paragraph 6.54 of Ref. [1] lists conventional hazards considered in the design of a facility. The conventional chemical hazards found in R&D facilities and experiments that should be considered include;

– Chemical hazards from compounds, such as acids, bases, toxic organic or metallic compounds;

– Explosion and fire hazards from flammable organics, pyrophoric metals, hydrogen, ammonium nitrate, and ammonia;

– Asphyxiation hazard from the presence of nitrogen, carbon dioxide, noble gases;

Requirements and guidance for these are contained in international and national standards on chemical safety.

7.57. During a fire, dynamic confinement systems should continue operation (including filtration) to remove smoke, heat, and particulates and to compensate for potential over-pressure if appropriate. This operation is maintained so long as temperatures at filters do not exceed the threshold at which containment would be lost, as determined by the safety analysis. Fire hazards analysis should be conducted at periodic intervals to incorporate changes that may affect the fire potential. Sometimes computer fire modelling is used to support the fire hazards analysis.

7.58. An operational radiological protection programme will be provided for exposure to the radioactive properties of any chemicals used in the facility (see section on RADIATION PROTECTION in this publication). As required by the national regulations, a health surveillance programme should be set up which routinely monitors the health of R&D facility workers, see paragraph 3.76(f) in Ref. [6]. Both the radiological and chemical effects of chemicals and materials used and produced should be considered as part of the surveillance programme as necessary.

7.59. The national and international standards that apply to non-nuclear chemical laboratories also apply to nuclear chemical laboratories. Guidelines should be developed for scientific staff, covering the types of chemical hazards to be expected and their prevention. Much of the guidance may overlap with standard practice for radiological protection and there will be areas where there should be guidance specific to chemical hazards. These may cover topics such as; eye protection, reaction hazards and toxicity and may refer to documentation

provided by chemical and equipment suppliers or contained in the relevant international and national standards.

MANAGEMENT OF RADIOACTIVE WASTE

7.60. The requirements related to the management of radioactive waste and effluent during operation are defined in paragraphs 9.54 to 9.57 of Ref. [1]. General requirements on predisposal management of radioactive waste are established in Ref [22]. Specific guidance on predisposal management of radioactive waste from nuclear fuel cycle laboratories is provided in Ref. [25], while guidance which may relevant to pilot plants can be found in Refs. [26] and [29].

7.61. Performance standards set for air purification systems should specify the levels at which filter or scrubber medium changes are required. Following filter changes, tests should be carried out to ensure that filters are not damaged and correctly seated, particulate efficiency tests may be used.

7.62. The generation of solid radioactive waste can be reduced by removing unnecessary packaging from articles before transfer into contamination areas. Processes like incineration, metal melting, and compaction can also be used to reduce the volume of waste, Ref. [26]. Such processes should be selected on the basis of the characteristics of the waste concerned after segregation. According to the national regulations and as far as reasonably practicable, waste material resulting from processing should be recycled or re-used or cleared from regulatory control where possible. Facility cleaning methods should be adopted which reduce and/or minimize waste generation, for instance reuse of washings from clean areas for more contaminated areas.

7.63. As part of the management system, measures for quality assurance and control should be implemented for the processing of all waste streams to ensure, as far as achievable, compliance with the waste acceptance criteria for the selected or anticipated disposal option.

7.64. Mixing waste streams should be limited to those streams that are radiologically and chemically compatible. If the mixing of chemically different waste streams is considered, the chemical reactions that could occur should be evaluated in order to avoid uncontrolled or unexpected reactions.

7.65. The operating organization should characterize radioactive waste as it is produced. Relevant records and reports should be created and managed according to the proper management system, Refs. [26] and [29].

7.66. When legacy materials exist without chemical and radiological analyses, reports on the research and development programmes that produced these wastes should be collected or prepared and stored, to be used in subsequent safety assessments. Where necessary to fill gaps in historical information, former employees should be interviewed and published scientific and annual reports on legacy materials should be evaluated.

7.67. Before clearance of equipment for recycling or release for disposal, it should be decontaminated to the level required by the regulatory authority. Levels for clearance applicable to many R&D facilities are defined in Schedule 1 of Ref. [6].

EMERGENCY PREPAREDNESS AND RESPONSE

7.68. This subsection provides guidance on the requirements and supporting recommendations on emergency preparedness and response contained in Ref. [10], [11] and [30] (as appropriate) and those defined in Paras 9.62 to 9.67, V.17 and V.18 of Ref. [1] , as they apply to R&D facilities.

7.69. The emergency arrangements established in accordance with Chapter 4 should consider the layout of the R&D facility site (i.e., the site may be composed of a great number of buildings and facilities).

7.70. The operating organization should carry out regular emergency exercises, some of which should involve off-site resources, to check the adequacy of the emergency arrangements, including the training and preparedness of on- and off-site personnel and services including communications.

7.71. The emergency arrangements should be periodically reviewed and updated taking account of any lessons learned from facility operating experience, emergency exercises, modifications, periodic safety reviews and from emergencies that have occurred with similar facilities, emerging knowledge and changes to regulatory requirements.

8. PREPARATION FOR DECOMMISSIONING

8.1. Decommissioning activities are performed with an optimized approach to achieving a progressive and systematic reduction in radiological hazards, and are undertaken on the basis of planning and assessment to ensure the safety of workers and the public and protection of the environment, both during and after decommissioning operations, see Ref. [31] which establishes general safety requirements for the decommissioning of facilities.

8.2. The following measures should be taken during the design, construction and operational stages of R&D facility life to facilitate eventual decommissioning:

(1) Design measures to minimize contamination penetrating structures;

(2) Physical and procedural methods to prevent the spread of contamination;

(3) Design features to facilitate decommissioning;

(4) Consideration of the implications for decommissioning resulting from modifications and experiments in the facility, when they are proposed;

(5) Identification of reasonably practicable changes to the facility design to facilitate or accelerate decommissioning;

(6) Comprehensive record preparation for all significant activities and events at all stages of the facility's life, archived in a secure and readily retrievable form, indexed in a documented, logical and consistent manner;

(7) Minimizing the eventual generation of radioactive waste during decommissioning.

8.3. The radiological hazard associated with decommissioning R&D facilities depends upon the type of work performed: Either the decommissioning work should fall inside the existing decommissioning plan or be subject to an appropriate modification before the decommissioning begins. It should normally be expected that any temporary experimental apparatus inside Case 1 facilities would be dismantled and removed before operations cease.

– In High Activity cells/units, deposits of gamma-beta activity exist and may require prior decontamination by chemical or mechanical means (such as chemical rinses, sand-blasting or specialized tools). The objective is to remove contamination where possible in order to reduce dose levels to as low as possible in order to allow direct access to the equipment. If after decontamination dose rates remain high, remote handling should be used.

– In alpha liquid units, deposits of alpha activity may exist and require adequate rinsing with chemical materials other than those used during operation.

– In alpha powder units deposits of alpha activity may exist and can be managed with appropriate personal protective equipment.

8.4. Where fissile material could be present, the requirements on criticality safety in paragraphs V.19 and V.20 of Ref. [1] should be applied.

PREPARATORY STEPS

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

(1) Post-operational clean-out to remove all bulk quantities of radioactive and other hazardous materials;

(2) Identification of contaminated parts of buildings and equipment and radionuclides;

(3) Characterization of the types and levels of contamination;

(4) Decontamination of the facility to reach the required regulatory clean-up levels, or lowest reasonably achievable level of residual contamination;

(5) Preparation of risk assessments and method statements for the licensing of the decommissioning process, see Ref. [32] which contains guidance on safety assessment for decommissioning.

8.6. In the event of decommissioning being significantly delayed after a R&D facility has permanently shut down, safety measures should be implemented to maintain the R&D facility in safe and stable state, including measures to prevent criticality, spread of contamination, fire, and to maintain appropriate radiological monitoring. Consideration should be given for the need for a revised safety assessment for the 'shut down' facility state and to using 'knowledge management' methods to retain the knowledge and experience of operators in a durable and retrievable form. Effort should be made to remove as much radioactive or hazardous material from the facility as is possible, before it is permanently shut down.

DECOMMISSIONING PROCESS

8.7. Specific guidance on the decommissioning process for nuclear fuel cycle R&D facilities is provided in Ref. [33], guidance which may relevant to pilot plants can be found in Ref. [34]. It should be ensured that personnel deployed for R&D facility (plant or experimental equipment) decommissioning are suitably experienced and qualified for such work. They should clearly understand the control regime under which they are working in order to maintain acceptable environmental conditions and to implement applicable health and safety standards.

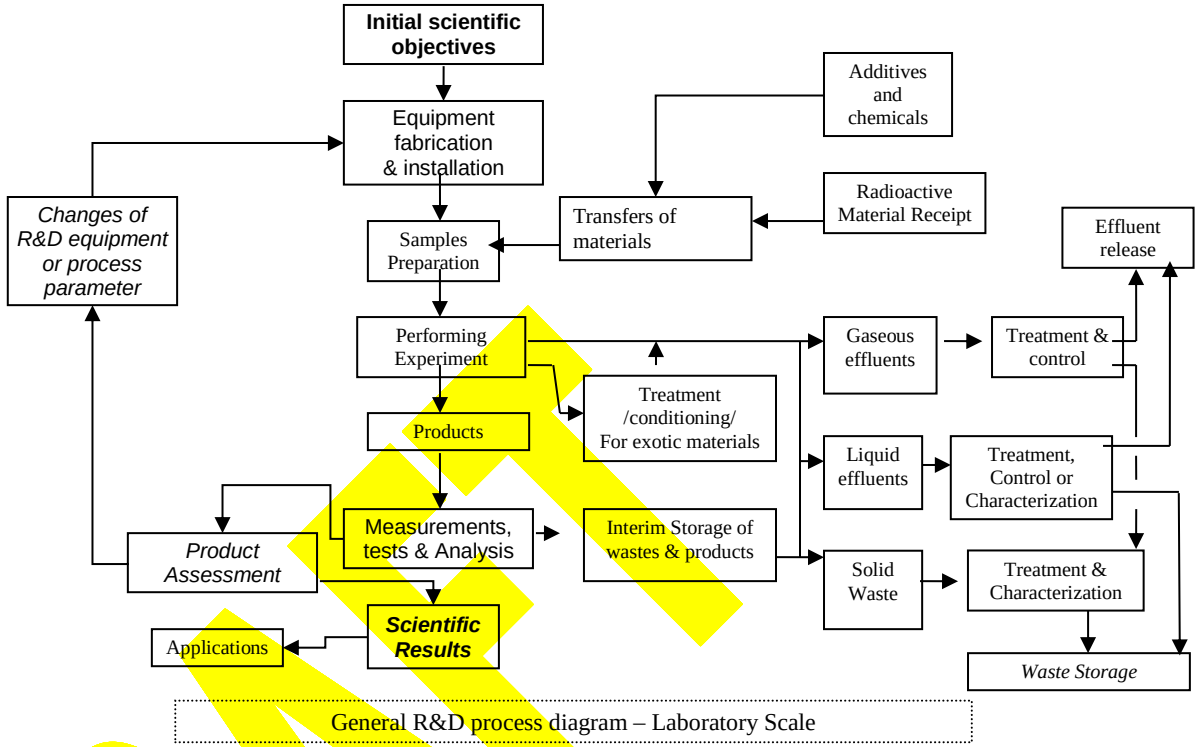
8.8. During the decommissioning of radioactive areas, particular attention should be paid to:

- Avoiding the spread of contamination through the use of appropriate techniques and procedures. In particular, the amounts of liquids (such as water and chemicals) used for decontamination should be minimized in order to reduce the generation of secondary radioactive waste.

- Appropriate waste handling and packaging as well as planning for appropriate disposal of radioactive waste.
- The safe processing and storage of contaminated waste material that cannot be disposed of immediately.
- Minimizing the creation of airborne contamination, rather than simply relying on personal protective equipment.

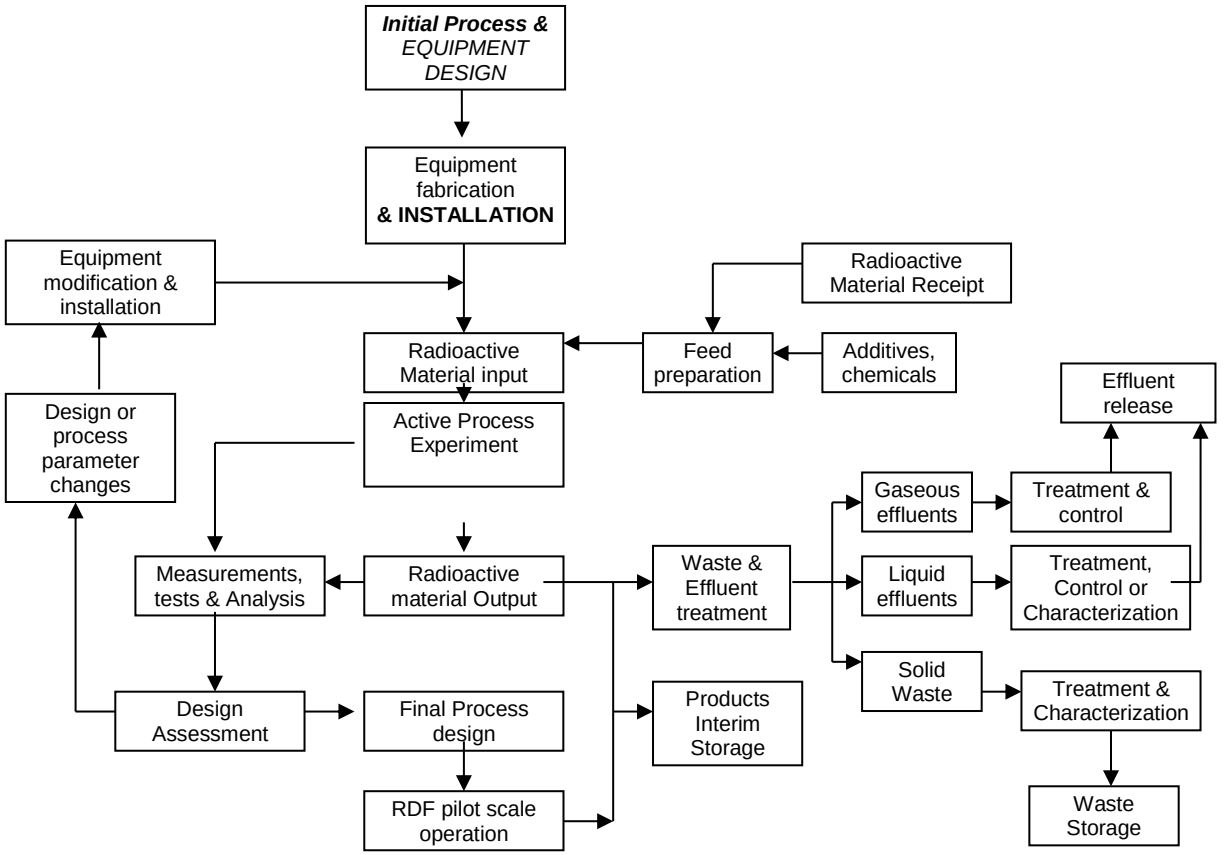
8.9. The level of decontamination required to recycle equipment or release buildings or facilities from regulatory control should be in accordance with the criteria set by the regulatory authority, in accordance with Ref. [31] and Schedule 1 of Ref. [6].

ANNEX I-A: R&D FACILITY PROCESS ROUTE CASE 1 - LABORATORY SCALE



General R&D process diagram – Laboratory Scale

ANNEX I-B: R&D FACILITY PROCESS ROUTE CASE 2 - PILOT SCALE



General R&D process diagram - Pilot Scale

ANNEX II: SAFETY FUNCTION IMPLEMENTATION BY PROCESS AREA

Safety Function (SF):
(1) Prevention of criticality;
(2) Confinement of radioactive material, including the removal of decay heat, for the prevention of potentially harmful releases;
(3) Protection against external radiation exposure;

Examples of R&D facility Structures, Systems and Components (SSCs important to safety) implementing each of the above Safety Functions are listed below by process area, together with corresponding Operating Limits and Conditions, mitigations and other comments.

Process Area	**Example SSC**	**Events**	**Safety Function**	**OLCs/Comments/other mitigation**
Initial scientific objectives			1, 2 and 3	Implementation of IAEA safety principles 4-9, Ref. [28] Safety assessment of programmes and activities
Equipment fabrication & installation	Equipment ensuring geometry & moderation control. Reflectors Neutron absorbers Detection and alarm systems	Criticality accident	1	Quality of the design and construction Installation according to the safety case and set procedures Accessibility/visibility to allow periodic maintenance and checks
	Equipment ensuring mass, and concentration	Criticality accident	1	Quality of the design and construction with diverse and robust control of key parameters Installation according to the safety case and set procedures with realistic commissioning tests
	– Building, hoods, gloveboxes, hot cells and interim storage – Ventilation, filters	Contamination. Loss of integrity	2	Quality of the design and construction Use of fail-safe designs where possible Installation according to safety case and set procedures Realistic commissioning tests. Measurement points for airflow/pressure Accessibility/visibility to allow periodic checks of

Process Area	Example SSC	Events	Safety Function	OLCs/Comments/other mitigation
				structural integrity
	Hot cells or shielded gloveboxes	Insufficient shielding	3	Quality of the design and construction OLCs on radiation protection Validation of the shielding suitability during commissioning
Radioactive material receipt	Transportation means	Degradation of criticality safety margin	1 (fissile only)	Transport rules, regulations and procedures Verification by recipient in accordance with OLCs
	Measurement devices for isotopic and chemical composition	Violation of acceptance criteria Unexpected or exotic material (see paragraph 2.2(5) of this publication)		Transport rules, regulations and procedures Suitably Qualified and Experienced Personnel Non Destructive Analysis or sampling of imported fissile material for isotopic or chemical characterization Calibration of the measurement devices
	Transportation means	Leakage Exposure Overpressure or explosion. For example, hydrogen due to radiolysis effect	2	Transport rules, regulations and procedures On-site transportation rules Suitably Qualified and Experienced Personnel Visual inspection of container and its seals Smear tests, pressure-tests
	Licensed container			Transport rules, regulations and procedures On site transportation rules Suitably Qualified and Experienced Personnel Verification of use of right container Correct labelling
	Shielding	Increase dose to R&D facility personnel	3	Transport rules, regulations and procedures

Process Area	Example SSC	Events	Safety Function	OLCs/Comments/other mitigation
	Licensed container			On-site transportation rules Suitably Qualified and Experienced Personnel Verification of use of right container Verification by recipient Visual inspection and radiation monitoring
Additives , chemicals including gases	Engineering fittings e.g. gas bottles Standardized containers	Fire, explosion and toxicity	2 (industrial safety)	Positive identification of supplies Checks of Material Safety Data Sheets (MSDS) Suitably Qualified and Experienced Personnel for receipt, storage, use and disposal of chemicals
Transfers of nuclear and non-nuclear materials	For nuclear materials; Hoods or coupling device to hot cell or glovebox For chemicals – as defined by the MSDS	Breach of the continuity of containment leading inadvertent release	2 and 3	For nuclear materials – R&D facility safety case limits Operating procedures consistent with safety analysis For chemicals, conformation to MSDS Radiation protection controls Chemical hazard controls
Sample/feed preparation	Chemical analysis, weighing devices	Non acceptable K_{eff}	1	Procedures, criticality control measures, moderator limits etc. Calibration of SSCs
	Criticality accident alarm system	Unavailability of alarm	1	Procedures controlling fissile transfers, personnel access and egress
	Hoods, hot cells or gloveboxes	Breach of containment	2	Maintenance and periodic testing Permissible pressure
	Hoods, hot cells or shielded gloveboxes	Insufficient shielding	3	Maintenance and periodic RP checks
Performing	Calibrated equipment.	Non acceptable K_{eff}	1	OLCs where necessary

Process Area	Example SSC	Events	Safety Function	OLCs/Comments/other mitigation
experiments /Equipment	Diverse equipment ensuring mass, geometry, moderation control. Reflectors Neutron absorbers Detection and alarm systems	Double-batching Inadvertent accumulation of fissile material		Independent double check by suitably qualified and experienced persons especially for mass and concentration of fissile materials Stringent implementation of Quality Assurance (QA) including maintenance and periodic inspection e.g.: of reflectors Questioning attitude
	Hoods, hot cells or gloveboxes Pressure monitoring/recording	Breach of containment	2	Effective isolation procedures Maintenance and periodic testing
	Emergency power supply	Loss of power	2	System dependent procedures e.g. for battery low Volts Maintenance and periodic testing
	Fire protection system	Uncontrolled fire Accumulations of flammable materials, blocked exits	2	Note potential pyrophoric materials Maintenance and periodic testing Good house-keeping
	Hoods, hot cells or shielded gloveboxes	Insufficient shielding Build-up of radioactive materials	3	Maintenance and periodic radiological checks Good house-keeping
Products	Criticality detection and alarm system or neutron measurement device Criticality accident alarm system	Non acceptable K_{eff}	1	Anticipation and verification of characteristics of products in line with OLCs - assessment if significant change in density, chemical and physical form e.g. precipitation Maintenance and periodic testing of the equipment
	Control of discharge of powders or fluids from the equipment to hot cell, glovebox or waste.	Fire and explosion Breach of the containment	2	OLCs. Implementation of conservative procedures RP checks; smear tests, pool water activity etc.

Process Area	Example SSC	Events	Safety Function	OLCs/Comments/other mitigation
	Containers, cabinet, well, wet storage.			Put the R&D facilities in a safe state Maintenance and periodic testing Potential bio-hazards
Measurements, tests & analysis	Safety-related instruments and controllers	Unexpected outcome. Non-acceptable K_{eff}	1	Criticality assessment defining OLCs Double contingency principle Calibration
	Safety-related instruments and controllers e.g. pressure, radiation	Unexpected outcome.	2	Adequacy of the material with the safety case. Hazard assessment defining OLCs Calibration, regular inspections Maintenance and periodic testing
Application	None	Hazard transferred to a third party (customer of the facility)	1,2 and 3	QA applied to work conducted by the R&D facility with some transfer of knowledge and safety information to the user; – Product identified (labelled) and capable of safe handling – Documentation and training of third parties and customers – Checks on export packages prior to use Responsibility for the subsequent safety of product and its application transferred from the R&D facility to user or third party
Gaseous effluents	Off gas treatment units, iodine filters and HEPA filters Differential pressure measurements and controls	Breach of containment Fan malfunction	2	Periodic monitoring and testing as defined by procedures and regulatory limits

Process Area	Example SSC	Events	Safety Function	OLCs/Comments/other mitigation
	Scrubbers, HEPA filters, connections and casings	Contact dose on filter casing Deposition of radioactive particulate	3	Periodic radiological checks as defined by procedures and regulatory limits
Liquid effluents	Ion exchange resins and extraction	Abnormal presence of fissile material	1	Periodic testing by gamma/neutron counting Accountability. Smear tests Criticality controls
	Connections, equipment for retention of filtering medium or resin e.g. prevention of backflow	Presence of leak	2	Measurements, periodic testing as defined by procedures and regulatory limits Tightness, fail-safe design Radiological checks
	Filters, Ion exchangers resins, extraction evaporation	Build-up of dose on media and increasing risk to R&D facility operators	3	Good planning, periodic radiological checks as defined by procedures and regulatory limits
	Containers	Contact dose on containers Breach of containment	2	Measurements e.g. smear test, periodic testing as defined by procedures and regulatory limits
	Shielding on containers	Build-up of radiation in packaging and increased risk to R&D facility operators	3	Periodic radiological checks as defined by procedures, accountancy and regulatory limits for discharges

ANNEX III: EXAMPLE OPERATING LIMITS AND CONDITIONS

Area or Operation	Example Operating Limit or Condition
Radiation protection in hot cells or shielded gloveboxes	No more than 100 millilitres of radioactive product or 1 TBq iodine-131 equivalent allowed in cell XYZ at any one time.
Verification of receipt for fissile material	The consignment number, weight and isotopic compostion on the label are recorded in the "Samples-In" system and its as-received weight measured and recorded. Enrichments over 4.0% or discrepancies in the weight greater than 100mg should be reported to the supervisor.
Criticality control of process	The H/U atomic ratio should not exceed 8.4 at any time
Criticality control of process product	No more than 10mg/litre solids in daily product sample as measured by analytical service department
Individual experiment	No more than 10 litres of hydrogen shall be used in the glovebox in any one experiment.
X-Ray machines	The X-ray machine shall not be energized unless the door to the x-ray cell is closed and the interlock is functional

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Fuel Cycle Facilities: Safety Standards Series No. NS-R-5 Rev.1, IAEA, Vienna (2014)

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, The Management System for Facilities and Activities, Safety Standards Series No. GS-R-3, IAEA, Vienna (2006) {DS456}

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

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Governmental, Legal and Regulatory Framework for Safety, IAEA Safety Standards Series No. GSR Part 1, IAEA, Vienna (2010)

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Uranium Fuel Fabrication Facilities, Specific Safety Guide No. SSG-6, IAEA, Vienna (2010)

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards - Safety Standards Series No. GSR Part 3, IAEA, Vienna (2014)

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Occupational Radiation Protection: Safety Guide, Safety Standards Series No. RS-G-1.1, IAEA, Vienna (1999) {DS453 Occupational Radiation Protection, IAEA, Vienna (2015)}

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment for Facilities and Activities, General Safety Requirements Part 4, IAEA, Vienna (2009)

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Criticality Safety in the Handling of Fissile Material, Safety Guide No. SSG-27, IAEA, Vienna (2014)

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Preparedness and Response for a Nuclear or Radiological Emergency, General Safety Requirements, Safety Standards Series No. GS-R-2, IAEA, Vienna (2002) {DS457, GSR Part 7 (2015)}

[11] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS OFFICE FOR THE CO-ORDINATION OF HUMANITARIAN AFFAIRS, WORLD HEALTH ORGANIZATION, Arrangements for Preparedness for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GS-G-2.1, IAEA, Vienna (2007)

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Site Evaluation for Nuclear Installations, Safety Standards Series No. NS-R-3, IAEA, Vienna (2003)

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Meteorological And Hydrological Hazards in Site Evaluation of Nuclear Installations, IAEA Safety Standards Series No. SSG-18, IAEA Vienna (2011)

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

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Conversion Facilities and Uranium Enrichment Facilities, Specific Safety Guide No. SSG-5, IAEA, Vienna (2010)

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Safety of Uranium and Plutonium Mixed Oxide Fuel Fabrication Facilities, Specific Safety Guide No. SSG-7, IAEA, Vienna (2010)

[17] All publications in the IAEA Nuclear Security series are available on-line from; http://www-ns.iaea.org/security/nss-publications.asp?s=5

[18] INTERNATIONAL ATOMIC ENERGY AGENCY, Volcanic Hazards in Site Evaluation for Nuclear Installations, Safety Standards Series No. SSG-21, IAEA, Vienna (2012)

[19] INTERNATIONAL ATOMIC ENERGY AGENCY, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, UNITED NATIONS INTERNATIONAL DEVELOPMENT ORGANIZATION, Manual for the classification and prioritisation of risks due to major accidents in process and related industries, IAEA Technical Documents Series No. 727 (Rev. 1), Vienna (1997).

[20] INTERNATIONAL STANDARDS ORGANISATION, Nuclear Energy - Fissile Materials - Principles of criticality safety in storing, handling and processing, ISO-1709 (1995)

[21] INTERNATIONAL ATOMIC ENERGY AGENCY, External Human Induced Events in Site Evaluation for Nuclear Power Plants, Safety Standards Series No. NS-G-3.1, IAEA, Vienna (2002)

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

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

[24] INTERNATIONAL ATOMIC ENERGY AGENCY, Recycle and Reuse of Materials and Components from Waste Streams of Nuclear Fuel Cycle Facilities, TECDOC-1130, IAEA, Vienna (2000).

[25] INTERNATIONAL ATOMIC ENERGY AGENCY, Predisposal Management of Radioactive Waste from the Use of Radioactive Material in Medicine, Industry, Agriculture, Research and Education, IAEA Safety Standards Series No. WS-G-2.7, IAEA, Vienna (2005) {DS454}

[26] INTERNATIONAL ATOMIC ENERGY AGENCY, Predisposal Management of High Level Radioactive Waste, IAEA Safety Standards Series No. WS-G-2.6, IAEA, Vienna (2003) {DS447}

[27] INTERNATIONAL ATOMIC ENERGY AGENCY, Construction of Nuclear Installations, IAEA Safety Standards Series No. DS441 {SSG-38}, IAEA Vienna (2014)

[28] INTERNATIONAL ATOMIC ENERGY AGENCY, Fundamental Safety Principles: Safety Fundamentals No. SF-1 (2006)

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

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

[31] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Facilities Using Radioactive Material, Safety Standards Series No. GS-R Part 6, IAEA, Vienna (2014)

[32] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment for the Decommissioning of Facilities using Radioactive Material, Safety Standards Series No. WS-G-5.2, IAEA, Vienna (2009)

[33] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Medical, Industrial and Research Facilities Safety Standards Series No. WS-G-2.2, IAEA, Vienna (1999)

[34] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Nuclear Fuel Cycle Facilities, Safety Standards Series No. WS-G-2.4, IAEA, Vienna (2001) {DS452}

[35] INTERNATIONAL ATOMIC ENERGY AGENCY, The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste, General Safety Guide No. GSG-3 (2013)

[36] INTERNATIONAL ATOMIC ENERGY AGENCY, Predisposal Management of Low and Intermediate Level Radioactive Waste, IAEA Safety Standards Series No. WS-G-2.5, IAEA Vienna (2003) {when replaced by DS448 this reference should be removed}

CONTRIBUTORS TO THE DRAFTING AND REVIEW

Bardelle, P.	Commissariat à l'énergie atomique et aux énergies alternatives (CEA), Centre de Cadarache , France
Carr, V.M.	International Atomic Energy Agency
Gater, R.	International Atomic Energy Agency
Kotzalas, M.	Nuclear Regulatory Commission, United States of America
Mester, W.	GRS, Köln, Germany
Nocture, P.	International Atomic Energy Agency
Norato, M	Nuclear Regulatory Commission, United States of America
Orabi, G.	National Centre of Nuclear Safety and Radiation Control, Egypt
Sigit, Dr. Ir.	National Nuclear Energy Agency (BATAN), Indonesia
Williamson, R.	National Nuclear Laboratory, Sellafield, United Kingdom
Uchiyama, G.	Japan Atomic Energy Agency (JAEA), Japan