Designation: C 1062 – 00

Standard Guide for Design, Fabrication, and Installation of Nuclear Fuel Dissolution Facilities[1]

1. Scope

1.1 It is the intent of this guide to set forth criteria and procedures for the design, fabrication and installation of nuclear fuel dissolution facilities. This guide applies to and encompasses all processing steps or operations beyond the fuel shearing operation (not covered), up to and including the dissolving accountability vessel.

1.2 *Applicability and Exclusions*:

1.2.1 *Operations*—This guide does not cover the operation of nuclear fuel dissolution facilities. Some operating considerations are noted to the extent that these impact upon or influence design.

1.2.1.1 *Dissolution Procedures*—Fuel compositions, fuel element geometry, and fuel manufacturing methods are subject to continuous change in response to the demands of new reactor designs and requirements. These changes preclude the inclusion of design considerations for dissolvers suitable for the processing of all possible fuel types. This guide will only address equipment associated with dissolution cycles for those fuels that have been used most extensively in reactors as of the time of issue (or revision) of this guide. (See Appendix X1.)

1.2.2 *Processes*—This guide covers the design, fabrication and installation of nuclear fuel dissolution facilities for fuels of the type currently used in Pressurized Water Reactors (PWR). Boiling Water Reactors (BWR), Pressurized Heavy Water Reactors (PHWR) and Heavy Water Reactors (HWR) and the fuel dissolution processing technologies discussed herein. However, much of the information and criteria presented may be applicable to the equipment for other dissolution processes such as for enriched uranium-aluminum fuels from typical research reactors, as well as for dissolution processes for some thorium and plutonium-containing fuels and others. The guide does not address equipment design for the dissolution of high burn-up or mixed oxide fuels.

1.2.2.1 This guide does not address special dissolution processes that may require substantially different equipment or pose different hazards than those associated with the fuel types noted above. Examples of precluded cases are electrolytic dissolution and sodium-bonded fuels processing. The guide does not address the design and fabrication of continuous dissolvers.

1.2.3 Ancillary or auxiliary facilities (for example, steam, cooling water, electrical services) are not covered. Cold chemical feed considerations are addressed briefly.

1.2.4 *Dissolution Pretreatment*—Fuel pretreatment steps incidental to the preparation of spent fuel assemblies for dissolution reprocessing are not covered by this guide. This exclusion applies to thermal treatment steps such as "Voloxidation" to drive off gases prior to dissolution, to mechanical decladding operations or process steps associated with fuel elements disassembly and removal of end fittings, to chopping and shearing operations, and to any other pretreatment operations judged essential to an efficient nuclear fuels dissolution step.

1.2.5 *Fundamentals*—This guide does not address specific chemical, physical or mechanical technology, fluid mechanics, stress analysis or other engineering fundamentals that are also applied in the creation of a safe design for nuclear fuel dissolution facilities.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *Industry and National Consensus Standards*—Industry and national consensus standards applicable in whole or in part to the design, fabrication, and installation of nuclear fuel dissolution facilities are referenced throughout this guide and include the following:

2.2 *ASTM Standards:*[2]

C 1010 Guide for Acceptance, Checkout, and Pre-Operational Testing of a Nuclear Fuels Reprocessing Facility

C 1217 Guide for Design of Equipment for Processing Nuclear and Radioactive Materials

2.3 *ASME Standards:*[3]

ASME Boiler and Pressure Vessel Code, Sections II, V, VIII, and IX

---

[1] This guide is under the jurisdiction of ASTM Committee C26 on Nuclear Fuel Cycle and is the direct responsibility of Subcommittee C26.09 on Nuclear Processing.

Current edition approved June 10, 2000. Published August 2000.

[2] *Annual Book of ASTM Standards*, Vol 12.01.

[3] Available from American Society of Mechanical Engineers, 3 Park Ave., New York, NY 10016.

ASME NQA-1 Quality Assurance Requirements for Nuclear Facility Applications

2.4 *ANS Standard:*[4]

ANS Glossary of Terms in Nuclear Science and Technology (ANS Glossary)

ANS 8.1 Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors

ANS 8.3 Criticality Accident Alarm System

ANS 8.9 Nuclear Criticality Safety Criteria for Steel-Pipe Intersections Containing Aqueous Solutions of Fissile Materials

ANS 57.8 Fuel Assembly Identification

2.5 *Federal Regulations*[5]—Federal Regulations that are specifically applicable in whole or in part to the design, fabrication, and installation of nuclear fuel dissolution facilities include the following:

10CFR50 Licensing of Production and Utilization Facilities

10CFR50, App B Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants

2.6 This guide does not purport to list all standards, codes, and/or federal regulations that may apply to nuclear fuel dissolution facilities design.

3. Terminology

3.1 *General*:

3.1.1 The terminology used in this guide is intended to conform with industry practice insofar as is practicable, but the following terms are of a restricted nature, specifically applicable to this guide. Other terms and their definitions are contained in the ANS Glossary.

3.1.2 *shall, should, and may*—The word “shall” denotes a requirement, the word “should” denotes a recommendation and the word “may” indicates permission, neither a requirement nor a recommendation. In order to conform with this guide, all actions or conditions shall be in accordance with its requirements but they need not conform with its recommendations.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *accident*—an unplanned event that could result in unacceptable levels of any of the following:

3.2.1.1 equipment damage,

3.2.1.2 injury to personnel,

3.2.1.3 downtime or outage,

3.2.1.4 release of hazardous materials (radioactive or non-radioactive).

3.2.1.5 radiation exposure to personnel, and

3.2.1.6 criticality.

3.2.2 *accountability*—the keeping of records on and the responsibility associated with being accountable for the amount of fissile materials entering and leaving a plant, a location, or a processing step.

3.2.3 *basic data*—the fundamental chemical, physical, and mathematical values, formulas, and principles, and the definitive criteria that have been documented and accepted as the basis for facilities design.

3.2.4 *double contingency principle*—the use of methods, measures, or factors of safety in the design of nuclear facilities such that at least two unlikely, independent, and concurrent changes in process or operating conditions are required before a criticality accident is possible.

3.2.5 *eructation*—a surface eruption in a tank, vessel, or liquefied pool caused by the spontaneous release of gas or vapor, or both, from within the liquid. An eructation may bear some resemblance to the flashing of superheated water; but it best resembles a burping action that may or may not be accompanied by dispersion of liquid droplets or particulates, or both, and by a variable degree of liquid splashing. The potential for eructation is most often caused by an excessive heating rate combined with an inadequate agitation condition.

3.2.6 *geometrically favorable*—a term applied to a vessel or system having dimensions and a shape or configuration that provides assurance that a criticality incident cannot occur in the vessel or system under a given set of conditions. The given conditions require that the isotopic composition, form, concentration, and density of fissile materials in the system will duplicate those used in preparation of the criticality analysis. These variables will remain within conservatively chosen limits, and moderator and reflector conditions will be within some permitted range.

3.2.7 *poison or poisoned*—any material used to minimize the potential for criticality, usually containing quantities of one of the chemical elements having a high neutron absorption cross-section, for example, boron, cadmium, gadolinium, etc.

4. Significance and Use

4.1 The purpose of this guide is to provide information that will help to ensure that nuclear fuel dissolution facilities are conceived, designed, fabricated, constructed, and installed in an economic and efficient manner. This guide will help facilities meet the intended performance functions, eliminate or minimize the possibility of nuclear criticality and provide for the protection of both the operator personnel and the public at large under normal and abnormal (emergency) operating conditions as well as under credible failure or accident conditions.

5. General Requirements

5.1 *Basic Data and Design Criteria*—The fundamental data and design criteria that form the basis for facilities design shall be documented in an early stage such that evolving plant concepts and engineering calculations have a solid and traceable origin or foundation. Design criteria can be included in an owner/client prepared data document or, when the owner/client so instructs, they may be selected or developed by the responsible design, organization. Values, formulas, equations, and other data should derive from proven and scientifically and technically sound sources. Any and all changes to the basic data shall be documented and dated. Procedural requirements associated with the authentication, documentation, and retention of the data base should be essentially equivalent to, and meet the intent of, ASME NQA-1.

5.2 *Responsibility for Basic Data*—The production, authentication, and issue of the basic data document should be the responsibility of the owner/client. However, this responsibility may be delegated.

---

[4] Available from American Nuclear Society, 555f N. Kensington Ave., La Grange Park, IL 60526.

[5] Available from U.S. Government Printing Office, Washington, DC 20402.

5.2.1 The Architect-Engineering (AE) organization charged with design and engineering responsibility for the nuclear fuel dissolution facilities is generally held responsible for the adequacy, appropriateness, and completeness of the basic data. The AE shall indicate the acceptance of this responsibility by a signed client/AE acceptance document in testimony thereof. Such an acceptance document should be executed within 90 days after receipt of the basic data document.

5.3 *Quality Assurance*—A formalized quality assurance program shall be conducted as required by 10 CFR 50, App B. This program shall be in general accordance with ASME NQA-1.

5.4 *Personnel*—Personnel associated with facility design and construction should collectively have the training, experience, and competence to understand, analyze, engineer, and resolve questions or problems associated with their assigned tasks.

5.4.1 Records shall be kept showing names and responsibilities of personnel involved with and responsible for the design, fabrication, inspection, and installation of nuclear fuel dissolving facilities for purposes of auditing quality assurance (QA) records.

5.5 *Degree of Quality*—The quality and integrity of materials and workmanship associated with the design, fabrication, and installation of nuclear fuels dissolution facilities shall be commensurate with calculated, demonstrable needs. Such needs arise from known and perceived risks, given physical and chemical principles, and applicable codes and regulations.

5.5.1 In setting forth the need for any given level of quality or integrity, the organization or individual responsible for making any such determination shall document the tests and acceptance criteria by which attainment or conformity is to be judged. Attainment or conformity verification requirements should be written into the Quality Assurance Inspection procedures.

5.6 *Records Retention*—All records pertaining to the basic data, design calculations, computer analysis, quality, quality assurance, chemical or physical test results, inspections, and other records that bear on the condition, safety, or integrity of the dissolution system facilities shall be available for audit purposes at any time subsequent to their creation.

6. Equipment

6.1 *Design Considerations*—The general principles used to design dissolvers for nuclear fuels are essentially the same as those widely employed in the design of processing equipment in the chemical industry. Design of nuclear processing facilities presents three additional considerations: the possibility of nuclear criticality, the dissipation of heat created by radioactive decay, and the provision for the adequate containment of radioactive contaminants under both normal and abnormal conditions. The latter consideration demands a degree of quality and the application of quality assurance procedures that are in excess of those that are normally required in the chemical industry.

6.1.1 General considerations and accepted good practice in regard to the design of dissolvers and other processing vessels for nuclear and radioactive materials is contained in guide C 1217.

6.1.2 Design of dissolution equipment and facilities shall include provisions to minimize the release of radioactive material from process vessels and equipment (including pipes or lines connecting to vessels or areas that are not normally contaminated with radioactive material, such as cold reagent and instrument air) or confinement (e.g. shielding cell walls) during normal and foreseeable abnormal conditions of operation, maintenance, and decontamination.

6.1.3 Offgas, vapor, droplet, and foaming disengagement space, equivalent to approximately 100 % freeboard should be included in sizing the dissolver. The dissolver fuel baskets should be sized so that the fuel charge occupies no more than 75 % of the basket depth. This will help to ensure confinement of hulls and metal fragments during the dissolution cycle. Fuel basket perforations (openings) should be limited in size to retain metal fragments and yet allow free flow of dissolvent solutions.

6.1.4 Design should specify the controls and checks that are required to ensure that vessel design dimensions are achieved and maintained during fabrication and construction sequences. This is a requirement for vessels designed to provide geometrically favorable handling conditions for fissile materials.

6.1.5 Criticality assessment calculations (see 8.1) shall include an allowance to compensate for vessel fabrication inaccuracies and corrosion. This compensatory calculation allowance is not to be construed as establishing or altering given dimensions or tolerances on design drawings.

6.1.6 The layout and installation of equipment and piping for the processing and transfer of aqueous solutions of enriched uranyl nitrate should be in accordance with the requirements and constraints set forth in ANSI/ANS 8.9.

6.1.7 A gas sparge connection should be included in the dissolver. Gas sparging serves as an aid to dissolution, agitation, and the removal of fission product gases such as iodine, krypton, and xenon.

6.1.8 The layout of dissolver internals, vessel shape and profiles, and the placement of sparger nozzles should accommodate thorough hydraulic flushing of the bottom of the dissolver in order to facilitate the removal of sludges and metallic fines.

6.1.9 The dissolution cycle vessels should contain provisions for sampling liquid contents.

7. Fuel Types

7.1 *Cladding and Core Combinations*—Nuclear fuels are invariably fabricated with a corrosion resistant metal cladding material covering the nuclear material in the core. The core material is exposed for dissolution by either chemical removal of the cladding or by mechanical chopping to expose the core.

7.1.1 Some of the methods that have been used for cladding removal or core exposure treatment, or both, are listed in Table 1.

7.1.2 Core dissolution has been achieved almost exclusively with hot nitric acid except for some very special fuels (see Appendix X1).

8. Criticality

8.1 *General Considerations*—Candidate dissolver (and dissolver solutions hold/transfer vessel) concepts shall undergo a

TABLE 1 Core Exposure Methods Cladding Material

Core	Aluminum	Zircaloy[A]	Stainless Steel
Oxide	. . .	Chop/Chemical	Chop/Chemical
Metal	Chemical	Chemical	. . .
Alloy	. . .	Chop	. . .

[A] Zircaloy is a registered trademark of Westinghouse Electric Corporation, Blairsville, PA.

criticality assessment analysis prepared by a qualified engineer or physicist, and the analysis shall be subject to a QA verification audit to ensure procedural and computational accuracy. The calculational method and audit should satisfy the conditions of ANS 8.1. The analysis and audit should be repeated at intervals during the design and operating sequences as changes occur and as necessary to ensure that safe conditions will prevail throughout the equipment's life cycle.

8.1.1 The need for and the extent of criticality control in the processing of irradiated nuclear fuel is governed by the isotopic composition of the fuel and by many other factors. In the dissolution of nuclear fuels that are more enriched than natural uranium (for example, that have a ^{235}U content in excess of approximately 0.72 %), precautions must be taken to prevent formation of a critical configuration. In designing a safe dissolver system capable of holding more than one critical mass, the following three methods, either alone or in combination, are generally used and recommended for ensuring nuclear safety:

8.1.1.1 Using subcritical geometry (for example, geometrically favorable vessel dimensions).

8.1.1.2 Adding soluble neutron absorbers (poisons) with the dissolver solvent and other influent streams.

8.1.1.3 Controlling fissile material concentrations below safe concentration limits.

8.2 *Design Considerations*:

8.2.1 *Geometry*—In the development of the design for a geometrically favorable nuclear fuel dissolving system, many precautions must be taken. Some of these special design considerations are as follows:

8.2.1.1 The system shall be designed for the most reactive fuel configuration likely to be encountered during the operating life of the dissolver. Both expected variations in operating conditions and credible off-standard and accident conditions should be considered.

8.2.1.2 Suitable allowances shall be made in selecting geometrically favorable slab thicknesses and cylinder diameters to allow for fabrication tolerances and for expected corrosion over the design lifetime of the vessels (see 6.1.5). It may also be necessary to provide an allowance for slab distortion under maximum fill level and design pressure load conditions, or to provide stays or reinforcement such as to prevent distortion or variations in slab thickness under design and operational load conditions.

8.2.1.3 Fissile material fines or precipitates may be intentionally or accidentally generated during the dissolution process. The dissolver design must include provisions for safely accommodating them to a noncritical array. They can either be removed from the system as generated, or provisions must be included in the design of the dissolver for their safe accumulation and later removal (for example, in slabs or cylinders of geometrically favorable dimensions for these more nuclear-reactive materials). Special precautions and design provisions are necessary in order to ensure that during removal operations, the solids are not redisbursed into an unsafe geometry at another location.

8.2.1.4 If heating or cooling jackets, or both, are included on geometrically favorable cylinders or slabs, the geometrically favorable dimension should include the thickness of the jacket, or special provisions should be included to prevent leakage of dissolver solution into the jacket. (See 8.1.)

8.2.1.5 Dissolver dimensions should be fixed in such a manner as to prevent the introduction or charging of fuel in amounts in excess of those provided for in the criticality analysis. This assumes that administrative controls will prevent the charging of fuels having a higher fissile element content than that for which the dissolver was designed.

8.2.1.6 Dissolver instrumentation shall be capable of providing an accurate assessment of vessel contents to the extent that this is practicable and possible. Consideration may be given to the installation of duplicate instruments when such instrumentation is critical to safe operation and control of the dissolver.

8.2.1.7 The dissolution system shall be designed consistent with the double contingency principle.

8.2.1.8 Nuclear interaction between the dissolver contents and the immediate environment at the installation location of the dissolver shall be evaluated in developing its design.

8.2.1.9 Nuclear interaction between the contents of nearby or adjacent vessels in the vicinity of the dissolver shall be evaluated when either of the volumes under consideration contains fissile materials. Neutron reflection from cell walls, floors and ceilings, and from other nearby objects (for example, equipment, piping, personnel) for a specific installation location shall also be considered. The geometrically favorable dimension(s) shall be reduced appropriately to take into account any interaction between vessels' contents and to account for the presence of interconnecting piping and appurtenances. In some instances, such as that in the NFS dissolver design discussed in 8.2.3, interaction between geometrically favorable component shapes can be minimized or essentially eliminated by interposing moderating materials (for example, concrete) and neutron capture materials (for example, gadolinium, cadmium, boron) between the geometrically favorable compartments of a vessel.

8.2.1.10 For dissolver systems designed for less than full neutron reflection (for example, dissolvers designed as geometrically favorable configurations for mounting or placement in air cells), special precautions must be taken and operational constraints invoked to ensure that excessive cell flooding is precluded and that significant amounts of neutron reflecting and moderating materials are not brought into the immediate vicinity of the dissolver. This would include prohibitions against the placement of another vessel in near proximity to the dissolver in the cell, unless the criticality analysis is recalculated and appropriate design changes are made.

8.2.1.11 Sumps designed to collect solutions that leak out of, or overflow from, dissolvers shall also be of safe design;

that is, they shall have geometrically favorable dimensions or other provisions such as poisoned raschig rings. Sumps should be designed to collect safely the maximum amount of liquid likely to come out of any one process vessel in a" worst case" design basis accident (DBA) scenario. The sumps shall be equipped with instrumentation and alarms that notify operating personnel of abnormal sump accumulations. Pumps, eductors, or jets should be installed for moving solutions containing fissile materials out of the sumps into a vessel having a geometrically favorable shape and which is positioned in a manner such that the addition of sump contents will not initiate a criticality incident due to interaction with adjacent vessels or masses.

8.2.1.12 When fuel reprocessing operations involve handling of fissile materials in amounts sufficient to create a potential criticality hazard, the load conditions established for vessel design shall include the potential shock loads and lateral forces that may result from a design basis seismic event. The forces developed by the design basis earthquake (DBE) shall be accommodated by the vessel design without vessel collapse or distortion that would render a geometrically favorable shape or dimension to be altered in such a manner as to allow a criticality incident to occur in the vessel.

8.2.2 *Soluble Poisons*—The use of soluble poisons, for example, chemical elements having high neutron absorption cross-sections, in an alternative or supplementary method of reducing the potential for a criticality incident.

8.2.3 *Nuclear Fuel Services, Inc. (NFS) Design*—For the dissolution of power reactor fuels, dissolver designs have been developed that use thin slabs (straight slabs or annular cylinders) or long cylinders of subcritical dimensions. A typical example of subcritical geometry, used in combination with concentration control, was the batch dissolver designed for use in the West Valley plant of Nuclear Fuel Services, Inc. (NFS). The design employed six fuel baskets that were 8 ft (244 cm) high, and were 8 in. (20 cm) or less in diameter. One basket (with the enclosed fuel charge) was loaded into each of the six 10-in. (25 cm) diameter cylindrical ports. The basket diameter and the fuel loading selected for a particular fuel was one that limited the fissile materials concentration in the 3-in. (8 cm) wide peripheral annulus and the 10-in. cylindrical areas to 60 % of the calculated critical concentration value when the fuel was dissolved. Nuclear interaction between the six cylindrical sections was minimized by addition of 0.5 wt % natural boron to the concrete core section of the dissolver that was positioned and sized so as to provide for a minimum of 30-in. (76 cm) separation between the 10-in. (25 cm) diameter cylindrical areas.

8.2.4 *Allied-General Nuclear Services (AGNS) Design*—Although the plant was not operated using irradiated fuels, the Allied-General Nuclear Services (AGNS) Barnwell plant dissolver illustrated a design using a soluble neutron poison in the dissolver. It was intended that sufficient natural gadolinium (as gadolinium nitrate) be added to the nitric acid dissolvent such that no criticality would occur based on the fissile concentration of the unirradiated fuel (initial enrichment) to be dissolved.

8.2.5 Mention of specific dissolver designs does not constitute an endorsement of one concept versus another. Other critically safe dissolver designs are equally acceptable.

8.3 *Operating Considerations*:

8.3.1 *Soluble Poisons*—If soluble poisons are used to provide nuclear safety, the nuclear poison concentration selected shall be capable of ensuring dissolver nuclear safety for the most reactive fuel mixture to be processed.

8.3.1.1 The dissolver and associated dissolution system equipment shall be operated under conditions that ensure that the poison concentration in the systems remains within the prescribed range and that the nuclear poison remains in solution during normal operating conditions under predictable abnormal operating conditions and under credible accident conditions. Cold feed solutions that have the capability for precipitation of either the soluble poison or the fissile materials should not be directly connected to (piped into) the dissolver. If such piping connections are employed, the lines shall contain lockable valving under supervisory control or other flow blockage provisions.

8.3.1.2 When cooling jackets or heating jackets, or both, are provided on a poisoned dissolver, the effects of coil or jacket heat transfer media leakage into the dissolver shall be considered since dilution of the poison could produce a more reactive condition. Inclusion of poison in the cooling or heating media should be considered. Design must also consider the potential for leakage of fissile material solutions into heating and cooling circuits and provide protection against conveyance of such materials into areas occupied by operator personnel or into auxiliary systems equipment where criticality may potentially occur.

8.3.2 *Administrative Control of Charge Mass*—Operational control over the accumulation of a critical mass in the dissolver vessel is an active means of preventing a criticality incident but one which provides an added measure of protection. As inferred, this is primarily an operational procedure, but facilities design shall provide the informational feedback, through instrumentation to enhance operational control.

9. Dissolution

9.1 *Design Considerations*—Dissolution processes are outlined in Appendix X1. Operating considerations incidental to the use of each of the processes are discussed therein. Design shall anticipate operation over a wide range of temperature, pressure, and reaction rate conditions and use adequate margins of safety in the design. Some of the safety considerations, and the sources of hazards and their mitigation or control, are discussed in Appendix X3.

9.1.1 *Chemical Reactivity*—The dissolver and the dissolver offgas handling and treatment equipment shall be designed as a complete entity, sized to handle the offgas load from the most reactive dissolution chemistry that can be predicted for the dissolver design and potential fuel charges being considered. Typically, the offgas system capacity should be capable of accommodating offgas surge rates or burps in the range of five to eight times the normal (production) processing rate over a one to three minute time period. *However, if the chemical reactivity is controlled through solvent (acid) availability, the offgas system should be capable of accommodating offgas surge rates of 1.3 to 1.5 times the normal processing rate.*

9.1.1.1 Nuclear fuel dissolution sequences have many similarities, but the sequential steps for any one process may not be fully applicable to other nuclear fuel dissolution cycles.

9.1.1.2 The metal charge, in the form of chopped/sheared fuel pins one to three inches long, is frequently added in perforated metal baskets. For these cases, the dissolver design may incorporate remotely operable provisions to raise the charge basket above the solution level. This provides an alternative means of reaction rate control for emergency use in the event that the reaction rate becomes excessive, to the extent that the offgas evolution rate threatens to overtax the capacity of the offgas treatment system.

9.1.2 *Corrosion*—A variety of chemicals can be used to dissolve particular fuels and residue sludges that may remain in the dissolver at the conclusion of the dissolution cycle. The designer must anticipate these, select appropriate materials of construction, and provide a corrosion allowance that tends to ensure contents confinement integrity over the design life of the vessel. Organic acids and other chemicals used in decontamination sequences need consideration, and the corrosive effects of ions released during the chemical dissolution cycle should also be considered. Accelerated corrosion tests on candidate materials of construction are recommended.

9.1.3 *Residues*—The accumulation of metal fines and undissolved fission products as a sludge in the dissolver will require the capability for flush-out and removal of this material to a sludge tank. Extended leaching and rinse operations are carried out in order to reduce the fissile material content to specification levels prior to removal and disposal of the sludge as waste.

9.1.3.1 Zircaloy[6] fines and small pieces constitute a spontaneous fire hazard. Zircaloy[6] hulls that have been fully stripped of heavy metal values are rinsed and passivated with a caustic solution. It is recommended that the passivation step be carried out in an inert (argon) atmosphere to prevent fires.

9.1.4 *Decay and Reaction Heat Control*—It is recommended that the dissolver incorporate separate heating and cooling provisions (for example, coils) to allow close control over dissolution solution temperatures and reaction rates during both the cladding and the fuel dissolution steps, and to provide for temperature control in instances where exothermal reactions occur. Heat removal capacity (coils or jacket heat transfer area or temperature differences) shall be sufficient to remove the radioactive decay heat load as well as the reaction heat.

9.1.4.1 For those dissolvers employing heating jackets or coils, and where control of the final concentration of the dissolver solution is important, the heat transfer area should be positioned somewhat above the bottom of the dissolver at a level that prevents over-concentration (by boil-up) of fissile material solutions. Concentration, except for that which might occur as a result of self-heating, would cease when heat transfer surfaces are no longer submerged.

9.1.4.2 Cooling coils or jackets should be positioned in processing vessels in such a way as to be fully submerged when vessels are filled to their normal operating levels. The heat transfer surface for cooling shall extend near to the bottom of the vessels in order to provide the means for removal of decay heat from residual amounts of process solutions left in the vessels.

9.1.4.3 Dissolver steam and cooling water supplies should have temperature-activated interlocks. Settings of the interlocks should be fixed at points that will prevent overheating and excessive boil-up of process solutions and at points that will automatically introduce cooling water flow to cooling coils in the event that set points for the vessel temperature are exceeded.

9.2 *Operating Considerations*—Fuels in particulate form are highly reactive in acid solutions. It is recommended that dissolution cycles anticipate the presence of significant quantities of fines. Assuming that such a condition exists, operators should start each dissolution cycle with the use of dilute acid and chemical inhibitors that modify, and have a controlling effect on, the dissolution reaction chemistry.

9.2.1 The administrative and technical practices for criticality safety and control should conform with or meet the intent of those practices set forth in ANS 8.1.

10. Dissolver Vapors and Offgas

10.1 *Design Considerations for Offgas Treatment*—Dissolver offgases generally pass through several sequential treatment steps. The offgas treatment requirements depend on the dissolution chemistry, the composition of the spent fuel being dissolved, the gaseous and volatile radionuclides, other contaminants in the offgas stream, and other factors. Treatment of dissolver vapors and offgas ensures that valuable process materials are recovered, and both radioactive materials and any noxious or undesirable gas/vapor stream constituents are removed to the extent practicable or required. Treatment methods for the removal of any particular offgas constituent may vary. Typical offgas treatment steps are briefly described in the following paragraphs. Mention of a particular offgas treatment process is for purpose of illustration and does not constitute an endorsement of the procedure as the best or only method for removal of contaminants from the offgas stream.

10.1.1 The treated offgas stream shall meet release criteria for toxic and radioactive contaminants as established by law and by basic data specifications.

10.1.2 The offgas systems for dissolvers are generally designed to handle vapors or condensates, or both, that contain very low concentrations of fissile materials and are generally not designed as a geometrically favorable system configuration. If foaming were to be encountered or excessive entrainment were experienced, dissolver solution or fissile fines could be carried into the offgas handling system. Special design provisions to prevent or to mitigate dissolver foaming conditions shall be considered. As a minimum, dissolver system design should include provisions and operating procedures, or both, to return such carry-over materials to the dissolver and to prevent their accumulation in the offgas system (for example, vapor and offgas decontamination devices). Design provisions (for example, overflows, instrumentation, and alarms) and operating precautions shall prevent flooding of the offgas handling system with dissolver solution.

---

[6] Zircaloy is a registered trademark of Westinghouse Electric Corporation, Blairsville, PA.

10.1.3 Specific design features shall be considered to ensure an adequate offgas flow control capability during all phases of the dissolver operation (for example, charging, dissolution, solutions transfer, reaction surges, standby, etc). A means of vacuum regulation (such as a vacuum breaker) shall be included in the dissolver system design to avoid an excessive vacuum on the dissolver, or one that could breach liquid seals or upset weight factor instrumentation.

10.1.4 Designs based on low air in-leakage rates to the dissolver offgas system should ensure that the low design basis rates can be maintained during the entire life cycle for the facilities. The integrity and characteristics of closures design would be a prime consideration here.

10.1.5 Design of the offgas system shall include a pressure relief system or component to limit the maximum dissolver system pressure to 3 to 5 psig, or to the design pressure limits for the vent system. The relief system shall reset automatically.

10.1.6 Provisions should be included to permit periodic flushing of all offgas lines and equipment. Provisions to collect the flush water, together with any accumulated solids or deposited fission products, or both, that are flushed out, are necessary as part of the flush system.

10.2 *Moisture and NO_x Removal*—The removal of dusts, excess moisture and NO_x(oxides of nitrogen) gases may be affected by scrubbing, condensation, and adsorption techniques. Oxygen addition may be employed to enhance NO_x recovery. The offgas scrubber step is intended to remove solid particulates carried off in the offgas stream and prevent the accumulation of these solids in the offgas equipment train. The design of the scrubber shall accommodate recovery and recycling of the solids and fines and shall prevent a criticality incident that might potentially occur through inadvertent accumulation of fissile material fines.

10.2.1 The condenser section of the dissolver should be designed as a total reflux condenser, to return condensed liquids to the dissolver, and to promote acid economy. Typically, gases are passed downwards through the condenser. The condenser capacity should be sufficient to cope with peak boil-up and offgas loads without excessive pressure drop and consequent pressurization of the dissolver assembly. The condenser should be equipped with an acid spray connection to permit wash-down and decontamination of the coil assembly. The design of the condenser and scrubber should provide for reducing the temperature of the offgas stream to the ambient cell or canyon temperature, or lower if practicable.

10.2.2 The removal of NO_x gases may require the inclusion of a multi-tray absorption column, or other NO_x removal methods such as the use of synthetic mordents in a packed column to catalyze selectively the ammonia reduction of NO_x gases.

10.2.3 An atomized steam-driven or pumped solution jet scrubber provides a means of solids removal, as well as means of cooling the offgas stream and assisting in the removal of NO_x gases. The scrubber jet(s) may also serve as part of the vacuum system. When such a treatment step is included in the offgas system, the motive system for maintaining a vacuum condition in the dissolver should be backed by an installed spare (alternative) vacuum-producing component or system that will prevent over-pressurizing the dissolver in the event of steam or pump failure.

10.3 *Ruthenium (Ru) Removal*—The use of a silica gel bed is one of a number of accepted and effective processes for the removal of particulate or volatile Ru from the scrubbed offgas stream.

10.4 *Iodine Removal*—Silver-exchanged mordenite beds in series is one accepted and effective process for the removal of iodine. The beds operate at a temperature of 150°C. Silver-exchanged mordenite beds loaded with iodine are regenerated with hydrogen. Iodine produced in the regeneration cycle is collected on lead-based absorption beds.

10.5 *Krypton-85 Removal*—One suggested process for the removal of ^{85}Kr from an offgas stream features a selective absorption step using refrigerant R-12 (dichlorodifluoromethane) as the absorption medium.

10.6 *Tritium Removal*—Tritium may be recovered by oxidation and sorption techniques. One process is based on the addition of excess hydrogen to the offgas stream that then passes through a Ni-Cr-Pd ribbon catalyst bed to oxidize the hydrogen isotopes to HTO. The unit operates at 400°C. The HTO is then preferentially sorbed on molecular sieves (zeolite).

10.7 *Carbon-14 Removal*—Carbon-14 may be removed as CO_2 gas by adsorption on zeolite molecular sieve beds. The CO_2 gas is driven off the sorbent bed during periodic regeneration cycles and is adsorbed on a BaOH bed.

11. Dissolver Product Handling

11.1 *Design Considerations*—Metal solution from the fuel dissolution step undergoes several treatments and measurements before being chemically adjusted so as to be suitable for feed to solvent extraction. The dissolver solution may be processed through a feed clarification step such as centrifugation. The accountability datum is established in a dedicated accountability tank. Nuclear fuel dissolution systems design shall consider the potential for criticality in dissolver solutions hold and transfer tankage as well as in the dissolver vessel (see Section 8). The use of a dilution eductor for solutions transfer from the dissolver may be included by design as one means of minimizing chances of a criticality incident resulting from fissile materials solutions transfer.

11.1.1 The final dimensions and the volume of the accountability vessel shall be accurately determined. The vessel capacity, as determined by the liquid level, temperature, and specific gravity instrumentation, should be calibrated prior to and after installation in order that the calibration data may serve as the basis for accountability determinations. Some types of accountability liquid level instrumentation require placement in a dry, air-conditioned environment to ensure continuing reliable operation. The capability for recalibration of the tank should be incorporated into the design.

11.2 *Operating Considerations*—Analytical, mass, and volume measurements made in the accountability tank are the basis for measuring losses or yield in all successive reprocessing steps.

11.2.1 Chemical and physical analysis of samples taken from the dedicated accountability tank, along with the tank liquid level measurements, provides a starting accountability basis, documenting the initial quantities of fissile, fertile, and fission product elements present in the dissolved heavy metal solutions. Finally, the dissolver solution is transferred to a suitably configured hold tank where the solution can be adjusted through changing of the nitric acid concentration. In this tank the valence conditions of the actinides can be altered or maintained so as to make the solution a suitable feed to solvent extraction.

12. Fuel Transfer (Charging)

12.1 *Design Considerations*—Transfer handling of fuel should be accomplished with minimal or no spillage or loss. The charging equipment or components should be designed for the retention and confinement of particulate contamination, gases, and vapors to the extent practicable.

12.1.1 For dissolvers intermittently charged by batch additions of fuel (for example, sheared pieces or canned metal slugs), the use of bucket-type containers, as opposed to containers with swing or sliding bottom trap door openings, is recommended by reason of simplicity and less susceptibility to accidental discharge or malfunction during the transfer handling of nuclear fuel to the dissolver.

12.1.2 When dissolvers are to be charged in a semi-continuous mode or by methods that employ gravity transfer from a shearing or chopping operation through an enclosed tube or chute, the transfer mechanisms should be designed to prevent unintentional holdup or blockage of the transfer chute.

12.1.3 The design of fuel transfer tubes or chutes with valves or diversion gates to permit the intermittent addition of sheared fuel to the dissolver shall be accomplished in a manner that ensures mechanical failures will not create a hazardous condition. The design shall also ensure that maintenance (or removal and replacement) can be accomplished by remote handling techniques or other safe (low exposure) maintenance procedures. The charge tube design shall effect control over the escape of vapors or gases from closed systems.

12.1.4 The charging transfer operations equipment shall be designed and installed in a manner such as to permit avoidance of or recovery from known and predictable hazard, failure, and accident scenarios. The charging transfer operations shall be designed, equipped, and installed in a manner such as to provide the capability for the removal of excessive decay heat loads under both normal and emergency (failure) conditions. The addition of fuel to the dissolver at temperatures in excess of 100°C can place excessive loads on the offgas system due to steam evolution and an increased reaction rate caused by a rise in the solution temperature.

12.1.5 In the event that charging operations are halted by processing stoppages, by accident or by equipment failure, the design shall ensure that a critical array cannot accumulate. The design should accommodate manual intervention and diversion of the charge batch or stream to a critically safe location or array, should this be judged necessary by Operations or Health Protection personnel.

12.2 *Operating Considerations*—Dissolver charges should be traceable to fuel element identification codes. (See ANS 57.8 Fuel Assembly Identification.) Based upon the dry weight of the spent elements and known weight of end fittings and other nonfuel hardware, the quantity of heavy metal and fission fragments can be calculated from the irradiation history, cool-down time, and other data available. Based on the most reactive charge composition for which the dissolver is to be certified, the design of the dissolver should preclude or prevent overcharging of the dissolver to the extent that this is practicable.

13. Cold Feed Addition

13.1 *Design Considerations*—The design, fabrication, and installation of cold feed chemical addition facilities should meet safety requirements and be in general accordance with recommendations of the Manufacturing Chemists' Association[7] or the suppliers, or both, for each of the reagent chemicals used in the reprocessing facility.

13.1.1 Pipe line connections between nuclear fuel dissolution facilities located inside a shielded cell or canyon facility should be separated from the occupied cold feeds makeup area or facilities by means of an isolation valve on the cold side of the shield wall or (minimal) a static seal leg placed inside the cell.

13.2 *Soluble Poisons*—All liquid streams introduced to a nongeometrically favorable dissolver should contain the specified nuclear poison concentration. Administrative operating controls shall provide for the analysis of poisoned reagent batches, before they are added to the process, to ensure that the required poison concentration is present.

13.2.1 Reliable fail-safe instrumentation shall be provided on poison stream additions equipment or piping such as to provide a capability to alarm and stop cold feeds addition when poison is absent or below specification concentrations levels.

14. Instrumentation

14.1 *Design Considerations*—Dissolution processing equipment should be equipped with instrument censor components, circuitry, readout, and control elements that allow continuous and precise monitoring and control of the process. Consideration shall be given to prevent the backflow of contamination into instrument air lines. Safeguards against the loss or diversion of fissionable nuclear material during the reprocessing stages is dependent on a highly accurate accounting step that includes representative sampling and volume measurement. A precise calibration curve for the accountability vessel is required. Instrumentation to achieve the required accountability is delineated below. Requirements for control of the following operational parameters (14.2-14.7) are applicable to each of the processing vessels or subelements thereof:

14.2 *Volume*:

14.2.1 *Measurement:*

14.2.1.1 Liquid level in vessel.

14.2.1.2 Foam level in dissolver.

14.2.1.3 Coolant volume in closed loop coolant systems.

14.2.1.4 Specific gravity of vessel contents.

14.2.1.5 Solids heel.

14.2.2 *Control or Alarm, or Both:*

---

[7] A typical MCA source text is "Guide For Safety in the Chemical Laboratory," 2nd ed., Manufacturing Chemists' Association, Van Nostrand Reinhold Company, New York, NY, 1972.

14.2.2.1 Excessive high or low liquid levels in vessel. Also, changes in the liquid level that occur without concurrent execution of a command signal.

14.2.2.2 Volume changes that alter criticality potential unfavorably.

14.2.2.3 Foaming conditions/quantities at inlet to the dissolver offgas system.

14.2.2.4 Out-of-range changes in the volume of coolant in closed loop systems.

14.3 *Temperature*:

14.3.1 *Measurement:*

14.3.1.1 Vessel contents temperature.

14.3.1.2 Coolant temperatures in/out.

14.3.1.3 Heating medium temperature (or steam pressure).

14.3.2 *Dissolver Control or Alarm, or Both:*

14.3.2.1 Heating rate, *Temperature.*

14.3.2.2 Coolant flow rate.

14.3.2.3 Offgas system temperature conditions.

14.3.2.4 Temperature extremes, high and low.

14.4 *Pressure/Vacuum*:

14.4.1 *Measurement:*

14.4.1.1 Vessel pressure.

14.4.1.2 Pressure differentials across each component vessel in the offgas system.

14.4.1.3 Pressure difference, vessel-to-cell.

14.4.2 *Control and/or Alarm:*

14.4.2.1 Vessel pressure.

14.4.2.2 Dissolver offgas system pressure differentials.

14.4.2.3 Vacuum suck-back/siphoning conditions.

14.5 *Flow*:

14.5.1 *Measurement:*

14.5.1.1 Quantities of solutions transferred.

14.5.1.2 Dissolver coolant flow rates.

14.5.1.3 Dissolver heating medium or steam flow rates.

14.5.1.4 Quantities and rates of cold feed chemical additions to dissolver.

14.5.2 *Control or Alarm, or Both:*

14.5.2.1 Valve openings/closures.

14.5.2.2 Pumping/transfer rates.

14.5.2.3 Cold feed addition rates.

14.5.2.4 Pump motor monitors.

14.6 *Neutron and Gamma Field (Flux)*:

14.6.1 *Measurement:*

14.6.1.1 Flux intensity.

14.6.1.2 Gross gamma (for short-cooled fuel).

14.6.2 *Control or Alarm, or Both:*

14.6.2.1 Excessive flux levels.

14.6.2.2 Out-of-range changes in flux level.

14.6.2.3 Criticality condition/occurrence, for example, nuclear incident monitor (NIM).

14.7 *Composition*:

14.7.1 *Measurement:*

14.7.1.1 Vessel contents, composition.

14.7.1.2 Cold chemical feed compositions.

14.7.1.3 Fissile materials content.

14.7.1.4 Form of materials (precipitate/solute).

14.7.1.5 Specific gravity of vessel contents.

14.7.2 *Control or Alarm, or Both:*

14.7.2.1 High/low concentration of soluble poison.

14.7.2.2 Fissile materials content.

14.7.2.3 Acidity (pH level).

14.7.2.4 Offgas composition at various points in the system.

14.7.2.5 Humidity level of offgas at various points in the system.

14.8 Instrumentation should include installed spare instruments and circuits (as well as prime elements) for any element or system whose failure can directly cause a major incident. A major incident would include such events as criticality, the release of radioactive contamination in quantities or at rates in excess of allowable limits, a fire, an explosion or other accident that could potentially injure plant personnel, or cause damage to plant or equipment.

14.8.1 Consideration should be given to the duplication of temperature, specific gravity and volume sensing instrumentation installed on the accountability tank.

14.9 A computer-based distributed control system (DCS) that has the capability (including hardware and software capabilities) for monitoring instruments, and for the diagnosis of instrumentation system faults should be considered for the dissolver system to provide better performance, increased efficiency, and improved safety.

14.9.1 The control system should have the capability for entering laboratory analysis results (data) into the DCS. Lab analysis results should be available for display or for printout from the DCS. Lab analysis results, when input to the DCS, shall not have the capability for independently altering control set points, operating conditions, or other control aspects of the dissolution processing facilities. An acceptance, acknowledgment, or command signal initiated by the supervisor or operator shall be a required input before the DCS manipulates or acts on information or data provided by manual entry or data bus transfer from a source outside the systems controlled by the integrated DCS.

14.10 *Offgas Controls/Monitors*—Adequate instrumentation of the offgas system is essential to safe operation of the dissolver. The offgas system should be equipped with sensors to monitor temperature, pressure, flow conditions, humidity, gas composition, and other parameters necessary to determine the operational efficiency of each of the treatment steps and to determine if the offgas composition meets basic data requirements for discharge to a successive treatment step. The offgas system instrumentation shall show if regulatory requirements for discharge to the environment are being met.

14.11 Instruments shall be provided to detect the occurrence or cause of all credible accidents (see 3.2.1).

14.12 The design, performance requirements, installation, and testing of the nuclear incident monitoring system should meet the intent of or be in accordance with the requirements of ANS 8.3.

14.13 *Operating Considerations*—A maintenance and recalibration/repair schedule should be established to periodically check and reconfirm the accuracy of instruments.

15. Facilities Fabrication and Installation

15.1 *Fabrication*—The fabrication of nuclear fuel reprocessing facilities (equipment, piping, etc.) requires a degree of quality and a measure of quality control that is in excess of that required for ordinary chemical processing facilities. The chemical composition and physical properties of all materials of construction should be known and documented. Identification of each of the materials of construction used should be rigidly monitored and verified throughout the fabrication sequences. Unapproved or extraneous materials of construction should not be accessible to fabrication crafts people and should not be stored in the vicinity where fabrication work on the equipment/facilities is being carried out.

15.1.1 A vessels assembly and inspection sequence should be agreed upon as a contractual obligation established at time of orders placement such as to permit and ensure that required quality assurance (QA) inspections can be performed in the proper sequence.

15.1.2 Equipment orders should be placed with ASME code-qualified shops, and the design and fabrication of vessels should conform with the ASME Boiler and Pressure Vessel Code as a minimum. Code stamping of vessels should be in accordance with statutory requirements. However, it should be recognized that the periodic inspection and renewal of the code stamp status is not always practicable for equipment used in a highly radioactive environment and placed in a remote-operated cell or canyon.

15.1.3 Fabrication of vessels to more exacting tolerances than are customarily applied to ordinary shop work is recommended when remote installation/removal/replacement procedures are to be used, or remote in-situ maintenance techniques are to be employed. Close fit-up is required for remotely installed piping and service jumpers to prevent leakage. Tolerances on the placement of datum points or planes that establish positioning of vessels or components, or that form connection points for the attachment of jumpers or the mounting of agitators, pumps, condensers, or other subassemblies, are usually kept in the range of ±1⁄16 in. (±1.5 mm) from the calculated true (datum) position (assuming no tolerances are allowed). In setting fabrication tolerances, it should be noted that matching flange faces must be machined parallel or perpendicular to the datum support plane (usually the vessel supports or vessel bottom) within 0.002 in./in. in order to ensure that joints can be made up remotely, or that secondary connection points on vessel-mounted components will be kept close to the position tolerance limit established above.

15.2 *Installation*—The dissolver and other dissolution cycle equipment should have all openings sealed in the shop after a QA inspection to ensure vessel interior cleanliness. The seals should be of a type that reveals removal and tampering attempts.

15.2.1 Cleanliness control during the construction installation sequences should follow the practices recommended in Subpart 2.1 of ASME NQA-1 as a minimum. The minimum level of cleanliness to be maintained should correspond to Class C as specified in Subpart 2.1 of ASME NQA-1.

15.2.2 Newly installed dissolution cycle equipment should be subjected to checkout and run-in procedures in general accordance with Guide C 1010.

APPENDIXES

(Nonmandatory Information)

X1. DISSOLUTION PROCESSES FOR SPENT NUCLEAR FUEL

X1.1 General

X1.1.1 Of the many nuclear fuel dissolution processes proposed or developed for various fuel compositions, few have been used extensively. Complete coverage of chemical dissolution processes is impractical for this guide. Among others, methods have been conceived, researched, developed, and demonstrated for the dissolution and processing of the following types of nuclear fuels:

X1.1.1.1 Zircaloy-Clad UO_2 Fuels.

X1.1.1.2 Coprecipitated Mixed Oxide Fuels.

X1.1.1.3 Mechanically Blended, Mixed Oxide Fuels.

X1.1.1.4 Three Component Alloy Fuels.

X1.1.1.5 Zircaloy-Clad Uranium Metal Fuels.

X1.1.1.6 Aluminum-Clad Uranium Metal Fuels.

X1.1.1.7 Aluminum-Clad Al-U Alloy and Al-UO_2 Fuels.

X1.1.2 The sequence of dissolution processing steps and assumed reactions associated with the dissolution of each of the above-listed fuel types is in the following sections.

X1.2 Zircaloy-Clad UO_2 Fuel Dissolution

X1.2.1 This fuel must be sheared into short sections to expose the UO_2 to the dissolvent. Lengths in the range of 1 to 5 in. (about 2.5 to 13 cm) have been considered. A sequential dissolution procedure has been used for the processing of Zircaloy-clad UO_2 fuels. Reaction rate control is established by the following:

X1.2.1.1 Use of a low acid concentration (<3M HNO_3) for the initial batch acid charge.

X1.2.1.2 Controlling the dissolver solution temperature (<50°C).

X1.2.1.3 Adding strong acid (approximately 3M HNO_3) at a controlled rate only as the dissolution reactions proceed.

X1.2.1.4 Increasing the solution temperature gradually to 90°C only after most (>50%) of the fuel has been dissolved.

X1.3 Coprecipitated Mixed Oxides Fuel Dissolution

X1.3.1 The dissolution of mixed oxide fuels containing up to approximately 30 % plutonium proceeds rapidly due to the reactivity of UO_2 fines. Acid strength is varied during the dissolution procedure to maintain effective control over the reaction (and offgas evolution) rates. Reaction rate control is affected by the following:

X1.3.1.1 Use of dilute (approximately 0.5M HNO_3) initial batch acid charge to dissolve loose/dislodged UO_2 powder.

X1.3.1.2 Use of strong acid (approximately 13M HNO_3) metered in at controlled rates to complete the dissolution cycle.

X1.4 Mechanically Blended, Mixed Oxide Fuel Dissolution

X1.4.1 A sequential dissolution procedure is generally necessary for the processing of mechanically blended, mixed oxide fuels. The rate of dissolution is dependent to some extent on the irradiation history of the fuel. A typical dissolution procedure is as follows:

X1.4.1.1 Dissolution is initiated with dilute acid (approximately 0.5M HNO_3) to dissolve loose UO_2 powder.

X1.4.1.2 Strong acid (approximately 13M HNO_3) is metered in at controlled rates to continue the UO_2 dissolution and to initiate dissolution of PuO_2.

X1.4.1.3 Potassium fluoride is added (approximately 1.5M KF) to the dissolvent to approximately 0.1M fluoride ion concentration to catalyze the complete dissolution of the mixed oxide fuel.

X1.5 Three Component Alloy Fuel Dissolution

X1.5.1 Fuels composed of the ternary U-Pu-Mo alloy are less reactive than the oxide form fuels and the dissolvers are usually operated at higher temperatures (approximately 95°C) from the outset to effect dissolution of the fuel.

X1.5.2 A masking ion (Fe^{+3} or Al^{+3}) is generally added to the solvent to prevent post-dissolution precipitation of the molybdenum ion. $Al(NO_3)_3$ or $Fe(NO_3)_3$ solution is added to the dissolvent after the dissolution is essentially complete. The masking ion balance must be maintained at a level sufficient to hold the Mo in solution (as polymolybdic acid) without over-masking the fluoride ion that is added to catalyze dissolution of the plutonium.

X1.6 Zircaloy-Clad Uranium Metal Fuel Dissolution

X1.6.1 The dissolution of this fuel requires shearing into small (¾ to 1 in.) lengths in order to provide access to as much uranium surface area as is practicable.

X1.6.2 A two, or three-step leach dissolution cycle is recommended, with the dissolvent solution being held at near boiling (95°C) temperatures. As the acid is depleted, the uranyl nitrate solution is drawn off and replaced by fresh, strong acid (approximately 13M HNO_3) until solution analysis shows a uranium concentration below set limits. A dissolvent solution showing low uranium content may be recycled for use with a new metal charge when accountability requirements are not disrupted by such a procedure.

X1.6.3 The overall dissolver cycle (assuming a 24-h initial leach procedure) followed by an 8-h secondary leach procedure may extend for 40 or more hours. This (projected) cycle assumes time has been included to accommodate solution sampling and analysis steps and time required to effect solution transfers, and hull rinses and disposition handling operations.

X1.7 Aluminum-Clad Uranium Metal Fuel Dissolution

X1.7.1 The dissolution of aluminum-clad fuels is usually completed in two stages as follows:

X1.7.1.1 The aluminum jacket is dissolved in a caustic solution in the presence of sodium nitrate to suppress hydrogen evolution. Sodium aluminum (jacket) wastes are discarded. The decladding is initiated using a dilute (5–10 %) caustic solution. When the reaction rate subsides, strong caustic (50 % NaOH) is metered in at controlled rates to maintain the Al dissolution reaction at a level within the capacity of the offgas system. The cladding waste solution is removed before the uranium dissolution is started.

X1.7.1.2 Uranium metal dissolution is initiated through the addition of dilute acid. The reaction rate is controlled by metering in strong (50 % HNO_3) acid as the dissolution reactions proceed, and as the capacity of the offgas system allows.

X1.7.2 When criticality considerations permit, a uranium metal heel may be maintained in the dissolver in order to provide more uranium metal surface area for the dissolution reactions. The uranium is not attacked by the caustic solution when the aluminum cladding from the next fuel charge is dissolved. The multi-cut dissolving technique that results from use of a metal heel does not lend itself to accountability on a batch-by-batch basis.

X1.7.3 Accountability, when the dissolution procedure includes use of a metal heel, is based on the processing of one type of fuel, from one source. Accountability records are derived from data collected over several dissolver cycles ending with a complete clean-out of the dissolver.

X1.8 Aluminum-Clad Al-U Alloy and Al-UO_2 Fuels Dissolution

X1.8.1 The dissolution of Al-clad Al-U or Al-UO_2 fuels may be accomplished in a single step by the use of mercury catalyst in nitric acid. The mercury in nitrate solution is reduced on the aluminum surface, amalgamates with the aluminum, and then is dissolved by the nitric acid, thus regenerating the mercury nitrate. Since this type fuel generally is highly enriched, fuel tubes are held in safe slab configuration by a basket or insert in the dissolver.

X1.8.2 Dissolution rates can be controlled by the catalyst concentration. Initially high dissolving rates of the cladding can also be reduced by using dissolver solution from the previous charge, already high in dissolved aluminum concentration. After the more reactive cladding is dissolved, the dissolver solution is removed and replaced by fresh acid. Frequent clean-out of undissolved fuel remnants is accomplished with catalyzed nitric acid to ensure nuclear safety.

X2. INTERACTIVE PROCESSES/DESIGN CONSIDERATIONS

X2.1 Design of radiochemical plants in general, nuclear fuel dissolution facilities in particular, is not an isolatable function. Although general specifications are written and basic data supplied for a process, the actual selection and development of the process and the design of the dissolution equipment or facility is an iterative action. Process development is generally done on a laboratory scale using actual irradiated fuels. Scaling tests, if done at all, are usually with nonradioactive stand-ins. Interpretation and application of this information involves both the researcher and the designer. Frequently, there is no industrial-scale direct analog of the development equipment, and layout, capacity and maintenance access compromises must be struck. Designs are reviewed at early stages for applicability, and many times, either the equipment or the process must be modified for compatibility. Trade-offs between process, equipment, and performance must continually be reviewed in order to achieve a design that meets process, safety, and regulatory requirements, and meets economic and efficiency criteria. Process and equipment alternatives similarly must be reviewed for potentially superior applicability. Areas where such iterative interactions might occur for the dissolver design include the following:

X2.1.1 Type of dissolver (batch, semi-continuous, continuous).

X2.1.2 Method(s) of criticality control.

X2.1.3 Dissolver off-gas treatments.

X2.1.4 Dissolution chemistry.

X3. SAFETY CONSIDERATIONS

X3.1 Safety is the most important area of both design and operation. Safety should be continually reviewed throughout every stage of design, by the designer and by the customer. Hazards analysis is an excellent means of reviewing the safety of the design. The hazards analysis methodology facilitates the identification of incidents that, by themselves or in combination with other incidents, may have significant and adverse consequences on the safety of the operations personnel or the off-site population or both. Some postulated events or causes, after further design and additional analysis, may be found to impact only process operability or efficiency, and can be removed as issues affecting plant or operational safety.

X3.2 Possible causes of incidents are identified in Tables X3.1-X3.4. Note that these tables are not intended or purported to be complete. Some events are treated as causes, while other events are listed both as incidents and causes of incidents. Natural phenomena, such as earthquakes or tornadoes, are treated only as causes, rather than incidents, since these events cannot be prevented by design features of the facility. However, design can mitigate the consequences of incidents caused by these phenomena. By the same reasoning, human failures can be reduced by administrative control, training, and procedural operation. In Tables X3.1-X3.4, it is indicated as to whether design (D), administrative control (A), or a combination (A or D) is required.

TABLE X3.2 Dissolver Solution Transfer/Hull Handling

Safety Considerations	Possible Causes	Control[A]
Self-concentration of solution	Prolonged storage	A
	Inadequate cooling	D or A
Vessel Rupture	Impact by moving equipment or dropped equipment	D or A
Overconcentration	Self-concentration of solution	D or A
	Operator error	A
	High acid concentration	A
Organic material in recycle acid	Transfer error	A
	Decanter leakage	D
	Entertainment	D
Caustic added to feed	Transfer error	A
	Valve error	A
	Operator error	A
	Chemical make-up error	A
Sampler pluggage	Incomplete dissolution	A
	Precipitation	A
Piping plugged with solids	Incomplete dissolution	A
	Operating error	A
	Inadequate procedure	A
Transfer error	Valving error	A
	Piping error	D
	Procedural difficulty	A
Chemical addition error	Chemical make-up error	A
	Valving error	A
	Piping error	D
Loss of purge to feed tank	Blower failure	D
	Line pluggage	D
Fissile residue accumulation in hull rinse tank	Incomplete dissolution	A
	Insoluble fines	A
	Digester sparge air failure	D
Inadequate cladding rinse	Operating error	A
	Pluggage	D
Failure of cladding monitor	Power failure	D
	Short circuit	D
	Improper calibration	D
	Incomplete dissolution	A
High fuel loss to leached cladding	Inadequate cladding rinse	A

[A] Design (D), Administrative (A), or both (D or A).

TABLE X3.4 Waste Handling

Safety Considerations	Possible Causes	Control[A]
Fire in fuel hardware fixation area	Pyrophoric forms of Zr (fines) ignite spontaneously	D or A
	Loss of inert blanket in hulls hopper or feeder	D or A
Drum overflow in fuel hardware fixation area	Instrument failure	D
Airborne cement dust in grout mixer area	Spills of dry powder during transfers	D or A
Radioactive contamination in cement preparation area (cold)	Air flow reversal from hot area system failure	D or A
	Ventilation system failure	D
Excessive fissile	Incomplete removal of fissile from hulls in dissolver	A
Failure of contaminated process components	Mechanical failures	D
	Corrosion, erosion, etc.	D
Waste container failure after filling	Defective drum	D
	Impact with other equipment	D or A
Loss of normal electric power	Power to substation off	D
	Substation failure	D
	Failure in power distribution center	D
	Natural phenomena	D
Failure of emergency power system	Diesel fails to start or fails to run	D
	Generator malfunction	D
	Switchgear failure	D
	System under repair	A
	System turned off (operating error)	A
Fire in process cell	Flammables present in cell	D or A
	Ignition source	D or A
	Spontaneous combustion	A
	Inoperative fire detection circuitry	D
Fire suppression system failure	No electric power or instrument air	D or A
	Valves fail closed	D
	Broken feed pipe	D or A
	Alarm failure	D
Ventilation airborne activity	Cladding failure from dropped fuel assembly	D or A
	Loss of cooling	D or A
	Fuel core exposed	D or A
	Pressurization of:	
	shear	D or A
	dissolver	D or A
	Failure of seals in:	
	dissolver	D or A
	offgas system	D or A
	Leaks	D or A
	Overflows	D or A
	Fire	D or A

[A] Design (D), Administrative (A), or both (D or A).

TABLE X3.1 Dissolution

Safety Considerations	Possible Causes	Control[A]
Inadequate poison in dissolvent	Chemical make-up error:	
	Wrong chemical added	A or D
	Poison concentration too weak	A or D
	Failure of poison addition to add at correct vol ratio	D
	Pluggage	D or A
	Pump failure	A
	Operator error	A
	Valving error	D
	Metering malfunction	A
	Incorrect chemical analysis	A
Hydrogen explosion in tank or vessel vent system	Self-concentration of solution	D or A
	Hydrogen produced by radiolysis of solution	D
	Loss of purge to hold tank	D or A
	Oxygen source	D or A
	Ignition source	D or A
Criticality potential	Inadequate poison in dissolvent (see above)	A
	Overconcentration of solution, followed by precip'n	A
	Accumulation of fissile residue	A
	Caustic added to feed	A or D
	Dissolver blockage in addition to loss of poison	A or D
Inadequately cooled fuel	Wrong fuel from pool	A or D
Dissolver pressurization	Loss of vacuum	D
	Pluggage	D
	Absorber flooded	D or A
	Overheated fuel	D or A
	Overheating (loss of steam controller)	D or A
	High reaction rate	A
Inadequate acid flow or concentration	Chemical make-up error	A

TABLE X3.1 *Continued*

Safety Considerations	Possible Causes	Control[A]
	Valving error	A
	Metering malfunction	D
	Pump malfunction	D
Leaks	Uncomplexed fluoride in dissolver	A
	Corrosion	A
	Weld failure	A
	Valve failure	A
	Pump failure	A
Overflow of hold tank	Operator error	A
	Instrument failure	D or A
	Jet cut-off failure	D or A
	Transfer error	A
Sparge air failure	Pluggage	D
	Blower failure	D
Accumulation of fissile residue	Incomplete dissolution	A
	Insoluble fines	A
	Precipitation	A
	Sparge air failure	D or A
Heating coil leak	Corrosion	D
	Weld failure	D
	Wrong material	D
	Uncomplexed fluoride	A
Eructation	Excessive heatup rate	A
	Foreign matter in feed	A
Heating coils not submerged	Inadequate dissolvent	A
	Loss of cooling water	D or A
	Operator error	A
	Procedure inadequacy	A
Uncomplexed fluoride in dissolvent	Chemical make-up error	A
	Valving error	A
High acid concentration	Chemical make-up error	A
	Valving error	A
Overheated fuel	Wrong fuel processed	A
	Inadequate cooling	D or A
Steam leaks	Valve failure	D
	Weld failure	D
	Seal failure	D
	Corrosion	D
	Erosion	D
Pluggage of steam condensate return	Corrosion products	D
	Leakage of solid from dissolver	D
	Inoperative steam tap	D
Loss of cooling water to condenser	Pump failure	D
	Pluggage	D
	Operator error	A
Overconcentration of solution	Loss of cooling water	D
	Overheating	D
	Fuel overcharged	A
	Inadequate acid volume	A

[A] Design (D), Administrative (A), or both (D or A).

TABLE X3.3 Dissolver Offgass System

Safety Considerations	Possible Causes	Control[A]
Hydrogen explosion in vessel off-gas header	High hydrogen and ignition source present	A
Massive leak into vessel off-gas system	Explosion or uncontrolled reaction in process tank	D or A
	Sudden venting by:	
	impact on line or connector	D or A
	gasket failure	D
	connector failure	D
	vessel failure	D
Vessel off-gas blower failure	Power failure	D
	Motor failure (shorted)	D
	Bearing failure	D
	Broken drive	D
	Missile	D
	Fire in blower room	D
	Operator error	A
	Earthquake	D
	Aircraft crash	D
	Tornado	D
Dissolver off-gas header pluggage	Flow restrictions: solids in off-gas	D
Loss of vessel off-gas header vacuum	Pluggage in header	D
	Process vessel pressured	D
	Valving error	A
	Pluggage of absorber bed	D
	Blower failure	D
Power failure of vessel off-gas blowers	Power to substation off	D
	Substation failure	D
	Failure in power distribution system	D
	Natural phenomena	D
Fissile material in vessel off-gas header	Filter failure in oxide conversion	D
	Pressurization of process vessel	D
Iodine Adsorption		
AgZ bed overloaded	Operator error	A
	Water in bed	D or A
Excessive ammonia in absorber feed gas	Ammonia in off-gas from NO_x destruction reactor	D or A
Explosion in vessel off-gas AgZ absorber	Rapid reaction or decomposition of Ag azide in bed	D or A
	Silver azide formation from hydrazoic acid (from solvex)	A
AgZ bed upset	Overheating	D or A
	Bed flooded with acid	A
Failure of AgZ bed heaters or DOG heater	Corrosion	D
	Mechanical failure	D
	Power failure	D
Temperature instrument failure	Corrosion	D
	Impact	D
	Loss of instrument power	D
	Readout malfunction	D
AgZ bed poisoned or plugged	Feed gas impurities	D or A
Excessive NO_x in AgZ absorber feed gas	Malfunction in DOG NO_x absorber	D or A
Failure of iodine absorption off-gas monitor	Corrosion	D
	Pluggage	D
	Short circuit	D
	Readout failure	D
Failure of AgZ bed heaters	Corrosion	D
	Mechanical failure	D
	Power failure	D
Ruthenium Removal		
High dissolver off-gas pressure	Header pluggage	D
	Ru bed pluggage	D
	Dissolver pressurization	D
	Valving error	A
High Ru bed temperature	Bed overloaded with Ru	D or A
	Cooling inadequate	D or A
Temperature instrument failure	Corrosion	D
	Impact	D or A
	Loss of instrument power	D or A
	Readout malfunction	D or A
	Ru accumulation on sensor	D or A
NOx Destruction		
Flooded NO_x absorber	Pump failure	D
	Pluggage	D
	Startup procedure violation	A

TABLE X3.3 *Continued*

Safety Considerations	Possible Causes	Control[A]
	Instrument failure	D
Compressor or blower failure	Bearing failure	D
	Shorted motor	D
	Corrosion	D
	Loss of lubrication	D
	Broken drive	D
NO_x absorber failure	Operator error	A
	Pluggage of spray nozzle	D
	Absorber flooded	D or A
Heater failure	Corrosion	D
	Mechanical failure	D
Recycle blower failure	Power failure	D
	Shorted motor	D
	Corrosion	D
	Broken drive	D
	Loss of lubrication	D
	Bearing function	D
Formation of ammonia compounds	Reaction of ammonia with acidic vapors	D or A
	Excessive ammonia fed to reactor	A

[A] Design (D), Administration (A), or both (D or A).

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org).