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

This standard is issued under the fixed designation C1062; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

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 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.4 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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

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[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.

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dissolution facilities are referenced throughout this guide and include the following:

2.2 *ASTM Standards:*[2]

C859 Terminology Relating to Nuclear Materials

C1010 Guide for Acceptance, Checkout, and Pre-Operational Testing of a Nuclear Fuels Reprocessing Facility (Withdrawn 2001)[3]

C1217 Guide for Design of Equipment for Processing Nuclear and Radioactive Materials

2.3 *ASME Standards:*[4]

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

ASME NQA-1 Quality Assurance Requirements for Nuclear Facility Applications

2.4 *ANS Standard:*[5]

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*[6]—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:

10 CFR 50 Licensing of Production and Utilization Facilities

10 CFR 50, 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, or federal regulations, or combinations thereof 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 For definitions of general terms used to describe the design, fabrication, and installation of nuclear fuel dissolution facilities refer to terminology in Terminology C859.

3.1.3 *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

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Two Park Ave., New York, NY 10016-5990, http://www.asme.org.

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

[6] Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, http://www.access.gpo.gov.

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.

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 C1217.

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 (for example, 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 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.

TABLE 1 Core Exposure Methods Cladding Material

Core	Aluminum	Zirconium Alloy	Stainless Steel
Oxide	. . .	Chop/Chemical	Chop/Chemical
Metal	Chemical	Chemical	. . .
Alloy	. . .	Chop	. . .

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 cylinder ports with diameters of 10 in. (25 cm). The basket diameter and the fuel loading selected for a particular fuel was one that limited the fissile materials concentration in the peripheral annulus to a width of 3 in. (8 cm) and the 10 in. (25 cm) 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 natural boron with a mass fraction of 0.5 % to the concrete core section of the dissolver that was positioned and sized so as to provide for a minimum separation of 30 in. (76 cm) 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 Zirconium alloy fines and small pieces constitute a spontaneous fire hazard. Zirconium alloy 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.

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.