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Standard Guide for
Design of Equipment for Processing Nuclear and Radioactive Materials[1]

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1. Scope

1.1 *Intent*:

1.1.1 This guide covers equipment used in shielded cell or canyon facilities for the processing of nuclear and radioactive materials. It is the intent of this guide to set down the conditions and practices that have been found necessary to ensure against or to minimize the failures and outages of equipment used under the subject circumstances.

1.1.2 It is intended that this guide record the principles and caveats that experience has shown to be essential to the design, fabrication, and installation of equipment capable of meeting the stringent demands of operating, dependably and safely, in a nuclear processing environment that operators can neither see nor reach directly.

1.1.3 This guide sets forth generalized criteria and guidelines for the design, fabrication, and installation of equipment used in this service. *This service* includes the processing of radioactive wastes. Equipment is placed behind radiation shield walls and cannot be directly accessed by the operators or by maintenance personnel because of the radiation exposure hazards. In the type of shielded cell or canyon facility of interest to users of this guide, either the background radiation level remains high at all times or it is impractical to remove the process sources of radiation to facilitate in situ repairs or carry out maintenance procedures on equipment. The equipment is operated remotely, either with or without visual access to the equipment.

1.2 *Applicability*:

1.2.1 This guide is intended to be applicable to equipment used under one or more of the following conditions:

1.2.1.1 The materials handled or processed constitute a significant radiation hazard to man or to the environment.

1.2.1.2 The equipment will generally be used over a long–term life cycle (for example, in excess of two years), but equipment intended for use over a shorter life cycle is not excluded.

1.2.1.3 The material handled or processed must be retained, contained, and confined within known bounds for reasons of accountability or to minimize the spread of radioactive contamination.

1.2.1.4 The materials handled or processed must be kept and maintained within one or more of the following conditions:

(1) In a specific geometric array or configuration, and

(2) Within a range of conditions that have been determined to be a critically safe set of conditions for that piece of equipment, that is, *1*) in a given and specified operational position where adjacent nuclear criticality interaction conditions are known and unchanging, *2*) for a given and specified set or range of operating conditions, and *3*) for a given and specified process.

1.2.1.5 The equipment can neither be accessed directly for purposes of operation or maintenance, nor can the equipment be viewed directly, for example, without intervening shielded viewing windows, periscopes, or a television monitoring system.

1.2.2 This guide is intended to be applicable to the design of equipment for the processing of materials containing uranium and transuranium elements in any physical form under the following conditions:

1.2.2.1 Such materials constitute an unacceptable radiation hazard to the operators and maintenance personnel,

1.2.2.2 The need exists for the confinement of the in-process material, of dusts and particulates, or of vapors and gases arising or resulting from the handling and processing of such materials, and

1.2.2.3 Any of the conditions cited in 1.2.1 apply.

1.2.3 This guide is intended to apply to the design, fabrication, and installation of ancillary and support services equipment under the following conditions:

1.2.3.1 Such equipment is installed in shielded cell or canyon environments, or

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1.2.3.2 Such equipment is an integral part of an in-cell processing equipment configuration, or an auxiliary component or system thereof, even though an equipment item or system may not directly hold or contain nuclear or radioactive materials under normal processing conditions.

NOTE 1—Upsets, accidents, or certain emergency conditions may be specified (and thus required) design considerations, but not necessarily acceptable or normal operating circumstances under this definition.

1.2.4 This guide is intended to apply to the design and fabrication of any and all types of equipment for radioactive wastes processing when any of the conditions cited in 1.2.1 apply. This would include equipment for waste concentration; for incorporation of wastes in selected host materials or matrices; and for the fixation, encapsulation, or canning of such wastes. It is intended to apply to all such wastes, regardless of the product waste composition or form. The product radioactive waste may have a glass, ceramic, metallic, concrete, bituminous, or other type of host material or matrices (composition), and may be in pelletized, solid, or granular form.

1.3 *User Caveats*:

1.3.1 *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.*

NOTE 2—**Warning:** This standard pertains to equipment used in and for the handling and processing of nuclear and radioactive materials. These operations are known to be hazardous for a variety of reasons, one being chemical toxicity.

1.3.2 This standard is not a substitute for applied engineering skills. Its purpose is to provide guidance.

1.3.2.1 The guidance set forth in this standard relating to design of equipment is intended only to alert designers and engineers to those features, conditions, and procedures that have been found necessary or highly desirable to the acquisition of reliable equipment for the subject service conditions.

1.3.2.2 The guidance set forth results from discoveries of conditions, practices, features, or lack of features that were found to be sources of operational or maintenance trouble, or causes of failure.

1.3.3 It is often necessary to maintain the materials being processed within specific chemical composition or concentration ranges, or both. When such constraints apply, it may also be necessary to create and maintain a specific geometric array to minimize the chances of a nuclear criticality incident. Designers and engineers are referred to other standards for additional guidance when such requirements apply.

1.3.4 Equipment usage intent, service conditions, size and configuration, plus the configuration and features of the operating and maintenance environments have an influence on equipment design. Therefore, not all of the criteria, conditions, caveats, or features would be applicable to every equipment item.

1.3.5 It is intended that equipment designed, fabricated, procured, or obtained by transfer or adaptation and re-use of existing equipment, and installed in accord with the standard meet or exceed statutory, regulatory, and safety requirements for that equipment under the applicable operating and service conditions.

1.3.6 This standard does not supersede federal or state regulations, or both, and codes applicable to equipment under any conditions.

2. Referenced Documents

2.1 *Industry and National Consensus Standards*—Nationally recognized industry and consensus standards applicable in whole or in part to the design, fabrication, and installation of equipment are referenced throughout this guide and include the following:

2.2 *ASTM Standards:*[2]

C 859 Terminology Relating to Nuclear Materials[3]
D 5144 Guide for Use of Protective Coating Standards in Nuclear Power Plants

2.3 *ANSI Standards:*[4]

ANSI/ANS 8.1 Nuclear Criticality Safety in Operations with Fissile Materials Outside Reactors
ANS Glossary of Terms in Nuclear Science and Technology (ANS Glossary)
ANSI A14.3 Ladders, Fixed Safety Requirements

2.4 *ASME Standard:*[5]

Boiler and Pressure Vessel Code, Section VIII
ASME NQA 1 Quality Assurance Requirements for Nuclear Facility Applications
ASME NOG-1, Rules for Construction of Overhead Gantry Cranes (Top-Running Bridge, Multiple Girder)

2.5 *Federal Regulations:*[6]

10CFR50, Appendix B, Quality Assurance
29CFR1910, Occupational Safety and Health Standards

2.6 *National Electrical Manufacturers Association (NEMA) Standards:*[7]

NEMA 250 Enclosures for Electrical Equipment 1000 Volts Maximum (Type 4)

2.7 *National Fire Protection Association (NFPA) Standards:*[8]

NFPA 70, National Electric Code

3. Terminology

3.1 *Definitions:*

3.1.1 The terminology employed in this guide conforms with industry practice insofar as practicable.

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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] Withdrawn.

[4] Available from American National Standards Institute, 11 W. 42nd St., 13th Fl., New York, NY 10036.

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

[6] Available from U.S. Government Printing Office, Superintendent of Documents, Mail Stop SSOP, Washington, DC 20402-9328.

[7] Available from Global Engineering Co., 15 Inverness Way, Englewood, CO 80112.

[8] Available from National Fire Protection Agency (NFPA), One Batterymarch Park, Quincy, MA 02269.

3.1.2 For definitions of terms used in this guide, refer to Terminology C 859 and ANS Glossary.

3.2 *Descriptions of Terms Specific to This Standard*—The terms defined below are of a restricted nature, specifically applicable to this guide.

3.2.1 *accident*—an unplanned event that could result in unacceptable levels of any of the following: (*1*) equipment damage, (*2*) injury to personnel, (*3*) downtime or outage, (*4*) release of hazardous materials (radioactive or non-radioactive), (*5*) radiation exposure to personnel, or (*6*) criticality.

3.2.2 *accountability*—the keeping of detailed records on, and the responsibility—on the part of operations personnel and plant management—of being accountable for the amounts of special nuclear materials entering and leaving a plant, a vessel, or a defined processing step.

3.2.3 *datum connection points*—those locations on equipment where separate auxiliary equipment items such as pumps, agitators, columns, condensers, and other separately removable equipment pieces are mounted, or where process, service, instrumentation, or electrical jumper connections are made.

3.2.3.1 *Discussion*—These datum connection points are positioned by dimensioning from (theoretically) perfectly placed base *X, Y* and *Z* datum planes; for example, such points or locations are dimensionally located by three-plane coordinate dimensions. Datum connection points are the loci of positioning elements such as dowels, trunnions, trunnion guides, and such other devices or elements that serve to align, position, or locate equipment in a precise position or array, or which serve as a point for the connection or placement of other components.

3.2.4 *engineering responsibility*—an obligation to perform engineering design activities assigned to a specified organization.

3.2.5 *geometrically favorable*—equipment having set dimensions, and a shape or a layout configuration, that provides assurance that a criticality incident cannot occur in the equipment or system under a given set of circumstances or conditions.

3.2.5.1 *Discussion*—The given set of conditions or circumstances requires that the isotopic composition, form, concentration, and density of fissile materials in the equipment or system will not violate those assumed and used for the preparation of the criticality analysis, and that those variables will remain within conservatively chosen limits, and that nuclear criticality interaction conditions will be within some permitted, pre-set range.

3.2.6 *jumpers*—the pipe line, electrical service, or instrumentation service connector assemblies that span the gap between nozzles or connection points on the canyon or cell-mounted equipment and (*1*) nozzles or connection points on adjacent or nearby vessels, or (*2*) service nozzles or connector points on the interior sides of the cell or shield walls.

3.2.7 *owner-operator*—the firm having either legal ownership responsibilities and rights for the nuclear and radioactive materials handling/processing facility where subject equipment is to be installed and/or used, *or* the firm that has accepted all management, engineering, operation, and maintenance responsibilities and rights (or specified portions thereof) by way of contractual arrangement(s) with the legal owner of the facilities.

4. Significance and Use

4.1 Equipment operability and long-term integrity are concerns that originate during the design and fabrication sequences. Such concerns can only be addressed or are most efficiently addressed during one or the other of these stages. Equipment operability and integrity can be compromised during handling and installation sequences. For this reason, the subject equipment should be handled and installed under closely controlled and supervised conditions.

4.2 This guide is intended as a supplement to other standards, and to federal and state regulations, codes, and criteria applicable to the design of equipment intended for this use.

4.3 This guide is intended to be generic and to apply to a wide range of equipment types and configurations.

4.4 The term *equipment* is used herein in a generic sense. See 3.2.5 for the definition.

4.5 This service imposes stringent requirements on the quality and the integrity of the equipment, as follows:

4.5.1 Leak tightness is required. This implies containment of liquids at all times, and retention of vapors and gases by means of vessel design, or through means of engineered provisions or operational procedures, or both, that ensure the retention, collection, and treatment of vapors and off-gases when the vessel cannot be fabricated or operated with an air-tight vessel configuration. Radioactive materials must be contained.

4.5.2 Equipment must be capable of withstanding rigorous chemical cleaning and decontamination procedures.

4.5.3 Equipment must be designed and fabricated to remain dimensionally stable throughout its life cycle.

4.5.4 Close fabrication tolerances are required to set nozzles and other datum points in known positions.

4.5.5 Fabrication materials must be resistant to radiation damage, or materials subject to such damage must be shielded or placed so as to be readily replaceable.

4.5.6 Smooth surface finishes are required. Irregularities that hide and retain radioactive particulates or other adherent contamination must be eliminated.

4.5.7 Equipment must be capable of being operated virtually unattended, unseen, and trouble-free over long periods.

4.6 It is assumed that the radiation hazards, combined with the need for confinement and containment, will necessitate a shielded enclosure cell equipped for some degree of remote handling and processing capability in the transuranic materials handling, processing, or machining operations (see 1.2.2).

4.7 Equipment intended for use in the processing and incorporation of radioactive wastes in host composites or matrices may operate at high temperatures and pressures and may require engineered provisions for the removal of large heat loads under normal and emergency conditions. The chemical corrosion and erosion conditions encountered in these processes tend to be extremely severe, placing emphasis on design for containment integrity.

4.8 Maintenance records from the plant or from a plant having a similar processing mission may be available for reference. If available and accessible, these records may offer valuable insight with regard to the causes, frequency, and type of failure experienced for the type and class of equipment being designed and engineered.

4.9 The constraints cited herein are intended to help the engineer establish conditions aimed toward the following:

4.9.1 Enhancing radioactive materials containment integrity,

4.9.2 Minimizing the loss of in-process materials or the spread of hazardous radioactive contaminants,

4.9.3 Minimizing equipment blemishes or faults that promote the adherence or retention of radiation sources,

4.9.4 Facilitating the ease and safety of decontamination and maintenance sequences, and

4.9.5 Reducing the failure frequency rate for all types and classes of equipment used in this service.

4.10 *Exclusions*:

4.10.1 In general, this guide is not intended to apply when the conditions set forth in 1.2.1 are irrelevant to the design of equipment or systems.

4.10.2 Given the conditioned exceptions set forth in 4.10.3, this guide is not intended to apply to the following:

4.10.2.1 *Operations*—Operation of equipment or facilities.

4.10.2.2 *Uranium Ore Mining*—Equipment or facilities associated with the mining of uranium ore.

4.10.2.3 *Uranium/Plutonium/Heavy or Reactive Metals Processing Equipment*—Equipment for the processing, machining and handling of uranium, plutonium, or other transuranic materials in metallic or other forms such as solutions, slurries, powders, or pellets when the radiation exposure levels are minimal, or when such operations are carried out in hoods or glove boxes and do not require massive radiation shield walls or enclosures (see 1.2.2).

4.10.2.4 *Laboratory/Research and Development/Semiworks Equipment*—Equipment for the above named facilities. The use of this guide in an unrestricted manner would result in equipment that is over-designed and costly for the above service conditions. (See qualification in 4.10.3.)

4.10.2.5 *Ancillary and Support Services*—Equipment and facilities designed for ancillary and service facilities that are located and installed outside shield walls, in spaces that are directly accessible for purposes of operation, maintenance and repair. (Note, however, the exception stated in 1.2.3.)

4.10.2.6 *Nuclear (Fission) Reactors and Auxiliaries Thereof*—Design of nuclear fission reactor vessels and auxiliary components and systems used in, or associated with, power reactor facilities or to nuclear reactors and auxiliaries intended for any other use or purpose. This guide does not apply to any equipment item or complex where the primary equipment design considerations include the dissipation of fission heat, or where the removal of radioactive decay heat loads resulting from reactor shutdown is a necessity, or both. (See qualification in 4.10.3.)

4.10.2.7 *Decommissioning*— Decommissioning of equipment. (See qualification in 4.10.3.)

4.10.2.8 *Nuclear Criticality Safety*—Design for nuclear criticality safety. (See qualification in 4.10.3.)

4.10.3 Given the foregoing non-applicability statement, this guide may be selectively applied to laboratory, research and development, and semi-works equipment when equipment integrity, materials containment, and the need for ease of cleaning are prime design considerations, where it is deemed essential to safety, or when it is otherwise justifiable. Also, many of the design criteria, guidelines, and caveats set forth herein will have applicability to certain equipment items and auxiliaries to be found in a reactor facility environment. Guidance provided herein relative to equipment features and provisions that minimize the retention of radioactive contamination in any form, and that facilitate cleanup and decontamination, will generally satisfy the potential need for equipment cleanup associated with the eventual decommissioning and disposal of the equipment. Specific guidance is provided in instances where design, fabrication, or integrity considerations are essential to the preservation of conditions or dimensions necessary to meet pre-determined and specified nuclear safety requirements.

5. Quality Assurance and Quality Requirements

5.1 *Quality Assurance (QA)*:

5.1.1 The owner-operator should have an approved QA program that is traceable to the criteria cited in applicable portions of 10CFR50, Appendix B. The QA program should also meet the requirements of and be in accordance with ASME NQA-1.

NOTE 3—The above-referenced documents are general in format and do not serve as a procedure, instruction, or QA plan or program specific to any one piece or class of equipment, or to any one task associated with equipment design, fabrication, and installation.

5.1.2 Each sub-contractor engineering firm and each vendor involved in equipment design, fabrication, inspection, testing, and installation should have a QA program traceable to both the criteria of 10CFR50, Appendix B and the requirements of the owner-operator's QA program.

5.1.2.1 The vendors or sub-contractor firms should be required to submit their QA programs to the owner-operator client for review and acceptance prior to initiating firm design and engineering work, and before materials procurement and fabrication commences.

5.1.3 An individual QA plan, specifically applicable to the subject equipment (or service), should be prepared early in the conceptual design stage, and implemented throughout the design, fabrication, inspection, and installation phases for the equipment. Complete, definitive, and specific quality assurance methods and procedures should be delineated in this QA plan. The document should be controlled, numbered, or otherwise identifiable to facilitate its being referenced in other documents. Where appropriate, reference to the QA Plan should: (*1*) appear on vessel or equipment drawings or documents, or both; (*2*) be included in applicable fabrication specifications; (*3*) be included in applicable purchase order or procurement documents; (*4*) be included in specifications and procedures covering equipment inspection and testing; (*5*) be included in procedures for the preparation and packaging of equipment for shipment; and (*6*) be included in specifications and procedures covering equipment installation. This should apply regardless of the origins of the drawings or documents.

5.1.3.1 All specific QA instructions contained in the QA plan should indicate the tasks and responsibilities for which any and all individuals, functions, or groups are to be held accountable.

5.1.4 The individual QA Plan should be written and applied in such a manner as to assign responsibilities both for performing tasks, and for verifying adherence to QA Plan requirements. If the responsibility for verifying specified QA inspections, examinations, analyses, and tests is wholly or partially delegated to equipment vendor or fabricator organizations, rigid back-up verification procedures should be carried out.

5.1.5 The owner-operator or responsible design and engineering organization should reserve the right to visit suppliers' and fabricators' facilities to (1) perform audits or surveillance activities; (2) witness specified operations; or (3) examine pertinent records. It may also propose changes to the QA Plan and relevant procedures.

5.2 *Quality Requirements*:

5.2.1 The quality and integrity of methods, workmanship, and materials associated with the design and fabrication, testing, and inspection of equipment or systems intended for service under the subject conditions must be commensurate with calculated, known, or demonstrable needs. Such needs arise from: (1) stated risks and hazards, whether known or perceived, associated with the handling and processing of nuclear and radioactive materials; (2) basic physical and chemical principles; and (3) applicable codes and regulations. The originating organization for the design and engineering of the equipment should determine such needs, and should then document the calculations or rationale, or both, by which such needs were determined.

5.2.2 The owner-operator, or alternatively the individual or organization defining the service conditions and performance requirements for a piece of equipment or for a system should specify any and all conditions to be met. The individual or group should specify material requirements and determine the need for and specify the tests and inspection requirements, and should establish or state the acceptance criteria by which compliance is to be judged and recognized, and should state what records are required.

5.2.3 The design and engineering records, including calculations, mathematical modeling, stress analysis, test results, and other engineering documents for equipment or systems intended for critical equipment or systems, as may be adjudged by the owner-operator because of service conditions should be cross-checked, verified, and authenticated by an independent analysis. Such analysis should be in accordance with the applicable or specified portions of ASME NQA-1.

5.2.4 Modification of equipment, in any way and at any stage of its life, might contribute to a subsequent failure if the design intent or capabilities of the equipment, or both, are unknown or misunderstood. If any deviations from the original or presently applicable and specified design conditions, configuration, quality requirements, integrity, and other conditions or requirements established for the equipment are contemplated, a documented effort should be made to review and clear changes through the individuals or group having original or equivalent design and engineering responsibility. All such changes themselves should be well documented as to the reasons and the authorizations for making the changes.

5.2.5 Handling, packing, protection, shipping, storage, and installation of equipment destined for service under the subject service conditions should be accomplished with and through the use of procedures and controls that have been included in either the QA program or the individual QA plan specific to the equipment, and which ensure that the quality and integrity of the equipment is not compromised or diminished.

5.3 *Records Retention*—All records of design, fabrication, inspection, and testing should be passed into the custody of the owner-operator. The records should be retained for the useful life of the equipment or system.

5.3.1 All such records generated by sub-contractor design and engineering firms and by equipment vendors or fabricators, or both, on and for the equipment should be furnished, for audit, to the organization having overall primary design and engineering responsibility. The retention requirements for such records should be specified in writing.

5.3.2 Such records should be available for audit purposes at any time during the period of their retention.

5.3.3 Vendors are cautioned to duplicate such records as may be prudent or necessary for their retention, and to protect and preserve such records with the utmost care until they are passed into the custody of the owner-operator.

6. General Requirements

6.1 *Design Caveat*—:

6.1.1 No equipment or components having a set performance function should be located in a nuclear and radioactive materials handling and processing environment unless there are no safe, practicable, and/or cost effective alternatives. If the in-cell placement is not necessary, the subsequent decontamination and maintenance need is made much more difficult when operating equipment or functional components are placed in a remote-operated canyon or cell.

6.1.2 The design of nuclear processing equipment 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 tanks and instrument air) during normal and foreseeable abnormal conditions of operation, maintenance, and decontamination.

6.2 *Design Features and Constraints for Vessels*:

6.2.1 All equipment fabricated of stainless steel and alloy materials and intended for use in this service should have a very smooth surface finish, one equivalent or superior to a No. 2B bright mill finish as commercially supplied on high quality rolled sheet products. This applies to all surfaces, inside and out, regardless of the location or orientation, or both, of the surfaces. The intent is to discourage the retention of radioactive contaminants and to facilitate ease of decontamination. This provision is also applicable to cast and forged items to the extent that smooth surface finishes can be achieved at an acceptable cost level.

6.2.1.1 The surfaces should be free of gouges, scratches, crevices, cracks (regardless of their origins, causes, or character), voids, weld ripples or overlap, inaccessible surfaces and pits that can capture and retain dirt, moisture, and particulate or deposited radioactive contaminants.

6.2.1.2 Equipment vendors and fabricators should be requested to submit weld samples and surface finish samples typical of those finishes they propose to supply for each piece of equipment on which they are bidding. The purchase order specification should state surface finish requirements in terms of the samples submitted, or in terms that are readily identifiable, achievable, and verifiable.

6.2.2 The inclusion of weep holes or vents in reinforcing pads and collars around flanged openings, nozzles, support trunnions, or lift eyes is not permitted on equipment in this service, irrespective of code fabrication procedural requirements. All such special reinforcement pads or collars should be seal welded around the entire perimeter of the pads or collars. This provision requires that the metal surfaces enclosed be absolutely clean and dry during fabrication.

6.2.3 Impact nut retention provisions such as collars are generally required around bolt holes on the top flange face of flanged joints, when such connections are part of the equipment design configuration. Such nut retention collars must have drain holes or slots that permit run-off and draining of liquids used during decontamination sequences.

6.2.4 The thickness of material used for equipment is critical to its ability to resist bending, flexing, and distortion. The dimensions of plate, structural members, pipe schedule or thickness, positioning members such as dowels, trunnions and guides, and other elements of the equipment should be set at levels that will resist damage once the equipment has been fabricated. A generous metal thickness allowance may often be justified on the basis of preventing distortion and damage to the equipment while it is being transferred and handled during shipment, or during installation in a remote-operated facility. Adherence to this caution can result in a metal thickness over and above that required to meet design basis and operational temperature and pressure conditions. Costs of the extra metal are of minimal concern compared with the assurance of having a dimensionally stable piece of equipment.

6.2.4.1 The prime objective of the caution statement in 6.2.4 is to preserve the accuracy of placement of the nozzles, the positioning dowels and trunnions, the guides and the datum base plates or support points, and such other elements of the equipment as may be necessary in order that when the equipment is placed in its service position the connection points will be at known locations. This contributes to the attainment of leak-tight hookup of pipe jumpers for process and service connections, and secure connection of instrumentation and electrical power supply jumpers. It also assures that flange faces and positioning dowels and guides for the mounting of auxiliaries such as agitators, pumps, condensers, columns, and other components on the base equipment configuration will be at known positions. The service connections for a condenser, an agitator, or a pump may be six to fifteen feet above its mounting flange on the base vessel. Any tilt or distortion of the mounting flange can tilt, throw off, or misposition the datum connection points on the auxiliary equipment item so that the service jumpers cannot be attached. Equipment design based on a minimum adequate metal thickness for given design or operating temperature and pressure conditions is not always acceptable for these reasons.

6.2.5 An as-built record of the precise position of each of the connection and positioning elements, for example, the *X, Y* and *Z* position coordinates for each nozzle, flange, dowel, bolt, and dowel hole, should be taken and documented prior to the time the equipment is placed in its service location. The measurements recorded should include nozzle, flange, and dowel tilt or cant, including degree and direction with respect to the nominal vessel centerlines and the vessel's support base or legs. The placement accuracy and the alignment of dowels, flanges, and guides with regard to verticality, flatness, tilt, cant, direction of tilt, or cant, should be within required and specified tolerances. If the equipment is destined to operate at temperatures in excess of approximately 150°C the measurements should be checked after the equipment has been cycled between ambient room temperature and the operating temperature two or three times so that any residual thermal distortion will be accommodated.

6.2.6 All flanged openings and nozzles on equipment intended for liquids handling and processing should be placed at the extreme top of the vessel, or alternately, at a level above the maximum liquid fill level likely to be experienced during the operational cycles for the vessel.

6.2.6.1 A freeboard in the range of 15 to 20 % should be provided for equipment used in non-boiling liquids processing service. The freeboard may need to be increased beyond the suggested level if the equipment has a tall, thin configuration. If the equipment has an overflow nozzle, the overflow nozzle should be placed opposite the vent nozzle location to provide for a vent air sweep across the vessel. The overflow nozzle should turn down and extend to within three inches of the base of the equipment to minimize splashing.

6.2.6.2 The objective of high openings placement is to create a vessel configuration that will minimize chances of accidental overflow and drainage or leakage of radioactive liquids, solutions, or slurries into the processing cell or canyon in the event of gasket, seal, or jumper pipe failure. Accidental overfill of vessels is not common, but it has been known to happen.

6.2.6.3 Anti-siphon protection should be incorporated into the design of the vessel or its jumper, or both, or connecting lines. Such protection is required to prevent accidental transfer of liquids from the vessel to an unintended location. Such siphoning transfers can be caused by variable liquid levels in vessels, due to condensation and collapse of steam pressure in the lines of transfer jet or sparger connections, or from other causes. Equipment and facilities design must provide protection against transfer or suck-back of radioactive materials into occupied operating areas.

6.2.7 Gusseting and reinforcement for the support or stiffening of flanged openings and nozzles, and for stiffening the heads or shells of vessels, should be placed on the external sides of the vessel to facilitate ease of cleanup and decontamination. Placement and configuration of the reinforcement gussets should not create liquid entrapment points. Placement of reinforcement gusseting on the external side benefits calibration accuracy for the vessel.

6.2.8 Lift eyes or trunnions on vessels should be positioned so as to be visible to the operator of the lifting equipment and so as to be clear of all nozzles and openings on the vessel. The lift points must be readily accessible to the hoist hook used to lift and transport the vessel. If equipment design is such that a lift yoke or lift bail suspended from the hoist hook is intended or required to lift and transport the vessel, the placement of the lift points on the vessel shall be such as to allow the yoke or bail to be moved into the lift position with a minimum of interference.

6.2.8.1 Lift eyes, lift bails, or trunnions should be attached to the main shell of the equipment, as opposed to being attached to a heat transfer or insulation cover jacket.

6.2.9 Equipment must be configured and balanced so as to hang vertically and in a stable position when it is suspended from the hoist hook or lift bail or yoke. The constraints with regard to surface finish (see 6.2.1) apply to any ballast added for balancing cell or canyon equipment.

6.2.10 Vessels designed to have a heat transfer jacket or those requiring insulation and an insulation jacket should be subjected to a thorough inspection and to leak tightness and weld integrity tests before the jackets are added. Leak tightness and weld integrity tests for the jacket should be conducted separately.

6.2.11 The insulation (and the insulation jackets) on canyon and cell equipment generally does not abut or cover nozzles, openings, and lift eyes or trunnions, and does not extend to cover the top and bottom of the vessels. The insulation on canyon or cell equipment is most often provided to keep surface temperatures low and thus minimize thermal air currents in the cell environment. The thermal efficiency of the equipment is a secondary consideration. This latter generalization does not apply in the case of furnaces, melters, and other equipment operating at temperatures in excess of 125°C, or where surfaces must be insulated for process reasons.

6.2.12 Insulation cover jackets should be configured to allow for the free draining of decontamination liquids. The jackets should have a short tube connection or an alternative provision to accommodate vacuum leak testing of the enclosed volume.

6.2.13 Equipment design should be standardized to the extent practicable so that common auxiliaries such as agitators, pumps, condensers, lift bails, lift yokes, and jumpers may also be standardized. In the context used here, standardized means having common dimensions and configurations rather than having duplicate performance characteristics, although those too may be desirable. The purpose is to decrease design costs and minimize maintenance problems and the need to store spare equipment items.

6.3 *Design Constraints for Jumpers, Lift Bails, and Yokes*:

6.3.1 Jumpers should be configured to drain towards the vessel on the receiving end of the connection insofar as is practicable.

6.3.2 Jumpers and lift bails or lift yokes should be configured and balanced so as to hang in a vertical and stable position when suspended from the hook on a lift hoist.

6.3.2.1 Lift bails and lift yokes are low maintenance components that are seldom transferred into areas where adhering surface contamination is a threat to personnel. The materials of construction (Section 7) and the surface finish constraints (6.2) are much less stringent for such components. Two sets of lift bails and lift yokes should be provided, one set being used and stored in the contaminated environment, and the other set used to transfer equipment into and out of the contaminated environment.

6.4 *Equipment Installation—General*:

6.4.1 Equipment received on-site and stored while awaiting installation in the cell or canyon environment should be stored under conditions that preserve the dimensional and operational integrity of the equipment. The equipment should be protected from damage due to heat, moisture, sunlight, or corrosive fumes or materials. The equipment should also be stored under conditions that protect it from damage caused by transfer handling, dropped loads, flying debris, or vandalism.

6.4.2 All precautions should be taken to ensure that marking crayons, inks, paints, and labels having an unacceptable chloride content are not used on stainless steel equipment components during storage or during test, transfer, handling, and installation sequences. See 7.4 regarding chlorides and fluorides as causes of stress corrosion cracking.

6.4.3 Equipment test, inspection, calibration, and checkout sequences should be completed prior to equipment installation in the cell or canyon environment to the extent that this is practicable. Equipment should be immaculately clean and empty when it is installed in place. To the extent required, equipment openings should be sealed to exclude dusts and moisture (and the introduction of apple cores, cigarette butts, and other debris by vandals) during the interval between the final cleaning of the equipment and the installation in place. Precautions should be included in the installation specifications that call for the removal of all such temporary seals as a near-final installation step.

6.4.4 All equipment should be handled with extreme care during transfer handling and installation sequences to ensure against collision damage and dimensional changes damage. Pumps, mixers, agitators, centrifuges, and other rotating equipment should be handled in such a manner as to preserve shaft straightness and rotational balance. Equipment should be handled and moved in an upright position using the same type of handling hooks, lift bails, and yokes as are to be employed in the canyon or cell maintenance procedures to the extent this is practicable.

6.4.5 Installation sequences should be planned and sequenced so that other equipment is not handled above and around previously installed components to the extent practicable. Personnel access to equipment previously installed should be sharply limited and constantly supervised. Equipment previously installed should not be used to rest, support, or otherwise come into contact with other equipment or components being installed. Equipment should not be walked on or used as an access platform.

7. Materials of Construction

7.1 *General Considerations for Metals and Alloys*:

7.1.1 It is highly desirable that corrosion resistant alloys or metals be used for all equipment in this service. Carbon steels, copper, aluminum, and other readily oxidized materials capture and retain radioactive contaminants in the rust and corrosion layers. The use of a Type 300 Series stainless steel such as corrosion released 304-L stainless is suggested as a minimum. The constraint applies to all elements and components of the equipment, even those not exposed to the process.

7.1.1.1 The objective of this constraint is to facilitate ease of cleanup and decontamination. Rust and oxidation complicate the decontamination effort, making it a difficult and time-consuming task. The radiation exposures of maintenance personnel are needlessly increased. The quantities of contaminated wastes, both liquid and solid, generated by the equipment cleanup and decontamination sequences are significantly greater when corrosion products must be removed as part of the decontamination operations.

7.1.2 Materials selection, given the above constraint and those set forth in 6.2.4, should be based on the worst case chemical and physical exposure conditions likely to be encountered in service. The metal thickness added when necessary as design allowance for corrosion and erosion should be on the generous side. A better type or grade of material may also be warranted to guarantee the retention of nuclear and radioactive materials within the system under all predictable or "what if" accident scenarios. The use of materials such as titanium, tantalum, zirconium alloys, platinum, and even depleted uranium metal may be the most economic choice. The cost of the material itself is generally a minor fraction of the equipment cost for these service conditions.

7.1.2.1 Alloy materials to be used in the fabrication of equipment destined for use under these service conditions should be subjected to accelerated corrosion evaluation tests, and to other chemical or physical tests, or both, as may be required or recommended by the design engineer. All such tests shall be completed prior to bulk procurement of materials, and prior to the initiation of equipment fabrication. Generic test data in open literature may be used if appropriate.

7.2 *General Considerations for Nonmetallic Materials*:

7.2.1 The recommended constraint cited in 6.1 applies to plastics, elastomers, resins, bonding agents, solid state devices, wire insulation, thermal insulation materials, paints, coatings, and other materials subject to radiation degradation damage and possible abrupt failure. Not all such materials and components can be excluded from service in the subject environment. Compromises must be made, with the justification documented.

7.2.2 Information on the resistance to radiation damage, and the effects of such damage, is thoroughly documented in the literature. The data available covers the type of failure and damage sustained under various radiation exposure levels for all materials in common use. This information covers materials for gasketing, sealing, lubrication, thermal insulation cements, wire insulation, coatings, adsorption (ion exchange) resins, materials, and other materials or components commonly used in this service and susceptible to radiation degradation damage. Using this information as a guide, the performance of these same materials under given radiation exposure conditions is generally predictable within an acceptable margin for error. References on sources of radiation degradation damage are provided in Appendix X2.

7.2.3 Materials subject to radiation degradation and related damage effects should be configured and placed so as to be readily and separately removable. When this is not practicable, these materials should be placed on removable components or sub-assemblies rather than on the larger or main equipment item to facilitate removal and replacement.

7.2.4 When the use of materials and components susceptible to radiation damage degradation and failure is unavoidable, the provision of a shield or placement of such materials or devices in a shielded site or position will extend the service life of the susceptible materials or components.

7.2.5 The use of solid state circuitry in a radiation environment should be kept to an absolute minimum even though selected types of such devices are highly resistant to failure under such use conditions. Solid state devices that perform a switching or counting function can be switched or activated by exposure to the types of radiation encountered in this service. Whenever such components or circuitry are used, the design must accommodate device failures in such a manner that hazards are not created in the equipment or systems, for example, the processing operations are left in a safe condition.

7.3 *General Considerations for Paint and Coatings*:

7.3.1 Paint and strippable coatings used as surface finishes on equipment are conditionally acceptable for service on equipment in a contaminated environment. Paint and strippable coatings should comply with Guide D 5144. Exceptions exist where components are readily removable, serve no containment function, and are discardable. This would apply to equipment such as carbon steel lift bails or yokes and special jumpers.

7.3.1.1 Commercially produced equipment such as motors, gear reducers, and like components having baked enamel finishes are acceptable when used in applications and placed in locations where they are readily, and preferably separately, removable from the processing cell or canyon environment. This facilitates decontamination, maintenance renewal, or discarding of the item when servicing is required.

7.4 *Materials: Stress Corrosion Crack Prevention*—Stainless alloys, as well as some other metals used for equipment in this service, are highly susceptible to stress corrosion cracking. The chloride content of all materials that become an integral part of the finished equipment and all those materials that are associated with or enter into the fabrication, testing, handling, and installation sequences for the equipment should be maintained as low as possible when the equipment is to be used under these service conditions. An absolute maximum of 200 parts per million of chloride is suggested as the limit for meeting this constraint. This constraint has been proven to be achievable. Procurement of the required materials from commercial sources is possible. It is also imperative that all materials used in, and coming in contact with, the equipment during the fabrication, testing, shipping, handling, and installation sequences be tested for their chloride content before being used, and the documentation of actual chlorides content should be effected. The constraints against the presence of chloride cited here also apply to other halides such as fluorides and bromides.

7.4.1 The recommended constraint on chloride content limits (200 ppm chlorides, max) should be rigidly applied to: (*1*) materials such as sheet, plate, nozzles, fittings, weld rod, gaskets, seals, insulation, and all other materials entering into the fabrication of the equipment, (*2*) to the equipment parts and components, and (*3*) to all materials that will be in contact with the equipment during its fabrication sequences, for example, cleaners, marking inks, cutting oils, paints, plastic covers, temporary plugs or seals and other applied or used materials. Part (*3*) of the constraint applies to materials in contact with the equipment for periods in excess of approximately 90 days. When materials are in contact with the equipment, or the materials for the equipment, for lesser time periods, a higher but closely controlled chloride content may be acceptable provided the equipment or the fabrication material is thoroughly cleaned to remove all traces of chloride contamination as soon as practicable but within the recommended 90–day time limit.

NOTE 4—The prevalent tendency of attaching marking labels or marking tapes to equipment and components, in particular polyvinylchloride tapes and labels, should be methodically and rigidly controlled, regardless of other codes, standards, or instructions calling for labeling or identification of equipment, components, or piping.

7.4.2 The basis for the constraint in 7.4.1 lies in the fact that thousands of chloride stress corrosion cracking failures have been documented, many catastrophic and within very short time spans, even under use conditions where the temperature and chemical exposures are classed as "mild." Such failures can occur very rapidly at higher temperatures and under severe chemical exposure conditions. Again, the recommendation is based on the need to exercise the greatest care to preserve equipment function.

8. Equipment and Vessel Design

8.1 *Code Design and Fabrication*—It is suggested, as a minimum, that all closed vessels intended for use under these service conditions be designed, fabricated, and inspected in accordance with the requirements of the ASME Boiler and Pressure Vessel Code (ASME Code), Section VIII. Special case rulings and interpretations may be necessary in order to comply. The procedures and methods set forth in various other sections of the given reference code should be reviewed by equipment designers and engineers for applicability under special circumstances, with specific call-out and reference being made to those sections, appendices, or paragraphs that are to apply to each specific vessel. In any event, rigid and precise specifications should be applied to fabrication and inspection sequences for equipment destined for use in this service.

8.1.1 The ASME Code does not normally apply when the equipment operates at ambient or nominal pressure and temperature conditions. To achieve code fabrication integrity, the engineer may wish to consider the substitution of an artificial set of temperature and pressure conditions so that the code will apply. Alternately, the ASME Code sections covering materials selection and specifications, materials identification and control, welding procedures, weld quality control and verification, inspection requirements, inspection and tests procedures documentation, and vendor or fabricator personnel qualifications may be specified.

8.1.2 The above constraints are based on experience that has demonstrated that fabricator shops qualified by the ASME to use and append the ASME Code stamp to their work use personnel who are also qualified by the ASME to actually perform the equipment fabrication work, the tests and the inspections, and their qualifications—when applied to equipment fabrication, testing and inspection sequences—results in a quality vessel or system that has the degree of integrity commensurate with requirements for nuclear and radioactive materials containment and confinement. This does not imply that equipment fabrication, testing, and inspection work must be placed only with vendors or shops that have been qualified by the ASME to do fabrication work or to perform other work under conditions or using methods approved by the ASME.

8.1.3 Several standards applicable to equipment design and fabrication, in whole or in part, are referenced in Section 2. Other useful references have been listed in Appendix X3.

8.2 *Equipment Design Features and Considerations*:

8.2.1 Steam and cooling water coils, regardless of their position in the equipment, should be fabricated from one continuous length of seamless pipe or tubing as opposed to two or more abutting, welded sections, to the extent this constraint is practicable. Alternatively, the seamless pipe or tube lengths shall be selected so as to keep the number of butt welds in the coils to a minimum. The complete elimination of butt welds in heat exchangers should be a design goal. Weld failure along pipe or tubing seams and at butt-joint weld locations is the most prevalent cause of coil failure when the coils are exposed to hot acidic service conditions typically encountered in this (subject) service.

8.2.2 Equipment intended for use under these service conditions and having the potential for the following enumerated uses should be designed to have a freeboard (space above the normal operating fill level) of at least 100 % to allow for adequate vapor and droplets disengagement space within the vessel: (*1*) use as a boiling or reactor vessel, (*2*) use as a vessel which is to be air or gas sparged, (*3*) use as an evaporator, (*4*) use as a vessel that requires vigorous agitation or (*5*) use in an application where vapors, droplets, particulates, or off-gases are evolved.

8.2.3 A remotely removable and replaceable coil or tube bundle design should be considered when the design life of a vessel exceeds two to three years.

8.2.4 Heat exchanger, condenser, and off-gas cooling coils should be fully stress relieved prior to their installation in vessels intended for use in this service. A full stress relief for the entire vessel assembly should be considered if welding operations are performed on coils during assembly sequences.

8.2.5 Vessel cooling coils should be placed in a position that will provide for the removal of radioactive decay heat loads from the" heels" left in vessels after the vessel is emptied or pumped down to the level where pump or siphon jet suction legs start to lose their suction. Cooling coils should be sized and designed to remove both the process heat load and the radioactive decay heat load.

8.2.5.1 Accelerated corrosion rates at the vapor-liquid interface is a dominant failure mode when equipment is exposed to hot acidic processing environments. A longer life expectancy for the vessels may be achieved when coils are either fully submerged in the liquids being processed, or when the coils are positioned entirely in the vapor phase spaces. The constraint applies to either heating or cooling coils and it is recognized that compliance in every instance and in every service application is not possible.

8.2.6 The installation of internal baffles for purposes of enhancing agitation efficiency and thoroughness should be avoided if practicable. Such baffles complicate the decontamination sequences. The use of multi-bladed mixer propellers or agitators is preferred over baffles whenever design calculations for the vessel indicate mixing and slurry suspension can be achieved by use of an agitator alone.

8.2.7 Internal spray decontamination provisions should be included in the design of vessels destined for liquids processing. Precipitation, salting out, or the accumulation of solid particulates, sludges, or coatings on vessel internals occurs accidentally or as the result of process chemistry in every vessel. Fixed internal spray nozzles, if used, should be sized, placed, and aimed to effect 100 % or near 100 % spray coverage of vessel internals. A separate spray lance (not part of the vessel) is sometimes used as an alternative means of decontaminating vessel internals.

8.2.7.1 The layout and positioning of coils, coil supports, dip tubes, agitation baffles, and other internal elements of the equipment should not obstruct decontamination of the internals by means of the spray nozzles or the use of a steam lance or cleaning solutions lance. Such internals should also be kept clear of sparger provisions in the vessels.

8.2.8 All liquids processing equipment designed for use under these service conditions should be equipped with built-in sparger nozzles. The purpose of the sparger nozzles is to facilitate movement of solids, particulates, and sludges to the pumpout point for the equipment. The sparger nozzles should be positioned and aimed to provide for thorough flushing of the bottom of the vessel. The placement of baffles, support lugs for coils or dip tubes and other projections on the interior of the vessel bottom should offer minimal interference to sparger spray patterns.

8.2.9 Canyon or cell vessels intended for use as hold, storage, or accountability tanks must be calibrated. Liquid hold volume per increment of liquid depth at cell/canyon processing and ambient conditions must be documented. Instrumentation used to calibrate the vessels should have an accuracy equivalent to that of the in-service vessel so that readings taken under processing conditions are in keeping with those recorded during vessel calibration sequences.

8.2.10 Spare nozzles should be provided on canyon and cell vessels when the placement and addition of such nozzles is practicable. The inclusion of one spare of each type and size that might be required on the vessel in question would be desirable. This allows for greater flexibility of use for the vessel over its useful service life.

8.2.11 The layout, sizing, and positioning of nozzles and flanged openings, and the positioning of dowels, bolts, and positioning trunnions on like-sized and configured vessels should be replicated to the extent that this is practicable.

8.2.11.1 The capability for and freedom to use the vessel in more than one cell or canyon installation position is enhanced when vessels are dimensional duplicates. The need for this interchangeability is contingent on the placement of trunnion guides and service nozzles on the walls of the cells or canyon modules in positions that are replicated from one cell position to another. Replication of datum connection points for both the cell modules and the equipment accommodates multiple usage of process and service jumper connections, and reduces the cost of designing and fabricating both equipment and jumpers.

8.2.12 Thermal insulation on cell or canyon equipment must be totally enclosed in a water and vapor-tight jacket assembly to exclude contaminants from entering inaccessible places, to prevent wetting the insulation, and to permit decontamination of external surfaces. The thermal insulation should be oven dried at a temperature in excess of 150°C for 2 to 8 h, as necessary, to drive off excessive amounts of moisture. Such out-baking should occur immediately prior to its installation in the jacket.

8.2.13 Design of the larger flanged openings, for example, those approximately 60 cm in diameter and larger, should be coordinated with fabrication shops having the tooling and the experience of fabricating and machining such closures. Large flanged openings on vessels are generally machined after they have been mounted and welded to the vessel. The inflexibility of the vessel supporting the flange, and the rigidity of the machining lathe or tool mount, must be such as to ensure that the machining accuracy of flange sealing faces is achieved. Selection of a qualified vendor-fabricator is critical if these constraints are to apply (see 6.2.4 and 6.2.4.1). Flange waviness can be caused by vessel or tool instability. Flange tilt and waviness, coupled with gasket thickness and compressibility, can result in a flange assembly that cannot be sealed. Excessive tilting or canting of flanges on which pumps, agitators, condensers, and other separately mounted components are to be placed is unacceptable for cell or canyon applications. Drawings and specifications should place limits on tilt, cant, and waviness based on those calculated as being acceptable for the maintenance of datum connection points positioning accuracy.

8.3 *Nuclear Safety*:

8.3.1 The handling and processing of special nuclear materials requires the avoidance of criticality incidents. Equipment intended for use in processing materials having a special nuclear material content should undergo a criticality assessment analysis in accordance with the requirements of ANSI/ANS 8.1 and such other standards and regulations as may be applicable.

8.3.2 Equipment fabricated in a geometrically favorable shape or array such as a slab, cylinder, toroidal shape, annular shape, or piping, or shape intersections and any other acceptable shape, should have a material thickness or sufficient external reinforcement by way of gussets, bracing, and stiffening rings or shapes to assure that the specified internal dimensions are maintained during the design life of the vessel. If an internal corrosion and erosion allowance is necessary, the equipment design and fabrication drawings should show dimensions that subtract the corrosion/erosion allowance from those dimensions calculated as being allowable by the criticality analysis. The equipment then corrodes to a condition within the dimensional limits set by the criticality analysis.

NOTE 5—**Caution:** Jacketed equipment needs special attention during the design and criticality safety assessment stages to deal with the potential for leakage and its impact on nuclear criticality safety.

9. Mechanical Equipment

9.1 *General*:

9.1.1 The constraint cited in 6.1 applies in particular to mechanical equipment. When mechanical equipment cannot be excluded from a canyon installation, the focus should be on measures or modifications which will extend the service life of the equipment and the mean time between failures, as well as on maintainability. The installation position, the orientation, and the attachment methods should be such as to simplify removal and replacement of mechanical equipment susceptible to periodic or unpredictable failure or outage.

9.1.1.1 Pedestals welded on equipment for the mounting of motors, gear boxes, pillow blocks, bearings, and like components should not have bolt holes or threaded openings, and should be totally enclosed and seal welded to exclude all moisture and particulate contaminants from the interior of the pedestal in order to minimize cleanup difficulties encountered during decontamination sequences.

9.1.2 Belt drives and chain drives are not suited to use in cell or canyon environments. Gear reducers and direct-drive shafts are preferred, if not mandatory. Gear housings and bearings should be fully enclosed in leak-tight casings to the extent practicable. Gear cases should be split horizontally, with the normal oil fill level located below the lowest shaft so that seal and gaskets are not subjected to a liquid head. Cartridge type mechanical seals are preferred over elastomeric lip seals for shafts penetrating the case.

9.1.3 Permanently lubricated bearings, seals, and gear assemblies will have shortened life expectancy in a cell or canyon processing environment due to radiation damage suffered by the lubricants and seal materials. Equipment having such provisions should be tested under simulated use and radiation exposure conditions in order to make an intelligent selection and to accurately predict their service life expectancy.

9.1.4 Gear reducers and other gear cases not permanently lubricated and sealed should be equipped with overflow lubrication provisions. Provisions to collect the overflow lubricants are necessary.

9.2 *Agitators and Mixing Propellers*:

9.2.1 Agitators and mixing propeller assemblies should be designed and mounted in a configuration that keeps bearings and shaft couplings exterior to the vessel, or as a minimum and much less preferable, above liquid levels in the equipment.

9.2.2 Shaft couplings, and nuts for the attachment of agitator blades to the shaft, must be pinned or clamped together in order to prohibit total and complete separation of the parts. Spot welds intended to lock such parts together are less desirable because of the more complicated maintenance procedures required under radiation exposure conditions. The failure of a shaft coupling on a mixer or an agitator, or the loosening and loss of a retaining nut, must not result in separation of the blade or the shaft from the drive unit.

9.2.3 Long, overhung shaft and agitator blade assemblies should be static and dynamically balanced as an assembly, complete with the motor and any gear reducer included as part of the drive unit. If possible, the agitator should be designed to run at speed below the lowest critical speed for the assembly in order to minimize vibration and shaft or blade whip as the assembly passes through any critical speed ranges while accelerating to operating speed, or coming to rest after the power is turned off.

9.2.3.1 Rotational tests should be run on prototype mixer and agitator assemblies. Such tests should be conducted while the mixers or agitator assemblies are mounted on vessels similar in size and shape to the actual cell or canyon vessel on which the mixer or agitator is to be mounted while in service. Tests should be run in both an empty vessel and when the vessel is filled with a fluid having viscosity and density characteristics of those of the in-process nuclear or radioactive materials. Any evidence of vibrations, flexing, whipping, or oscillations beyond a pre-determined maximum acceptable limit should be cause for re-design or modification, or both, of the shaft dimensions, the mounting, and/or other factors affecting the rotational characteristics of the assembly.

9.2.4 Agitator bearings should be non-lubricated or permanently lubricated types when such bearings are external to any lubricant-filled gear case (see 9.1.4). It is not practical to provide separate lubricant lines to spaced bearings on shafts. Spent lubricants that have been in service in a radioactive environment must be treated as contaminated wastes. They cannot be recirculated back to occupied areas.

9.3 *Pumps for In-Cell/In-Canyon Service*:

9.3.1 Totally encapsulated (pump and motor) submersible pumps are available and have been used in this service. Overhung shaft pumps (with the impeller mounted at the end of a long shaft), with or without an immersed lower bearing, have also been used extensively in this service. The latter type are hung vertically or in a near vertical position from a flange mount on the vessel.

9.3.1.1 Many of the design constraints applicable to agitator assemblies apply also to cell or canyon pump assemblies.

9.3.1.2 Prototype testing of new pump designs should be carried out under simulated use conditions prior to the purchase or fabrication, or both, of a multiple number of pumps of the design in question. Such tests should be designed to reveal pump weaknesses and service life expectancy (mean time between failures), as well as the performance characteristics (flow/head curves) of the pumps.

9.3.1.3 Pumps should be designed with suction intakes placed at a level that will leave a minimal heel in the vessel when the vessel is pumped “dry.” The suction intake must also be positioned at a level such that cavitation at the suction inlet is minimized.

9.3.1.4 Pump shaft couplings and bearings should be located exterior to the vessel or above the liquid level when such a design is practicable. Also, see the design constraints set forth in 9.2.1-9.2.4.

9.3.2 Another class of "pumps" used extensively in nuclear materials processing applications are the ejectors and eductors. Ejector design is beyond the scope of this guide. (See Appendix X3, Ref.6.) However, both the shape of the venturi (entrance, throat, and diffuser sections) and placement of the motive steam (or air) nozzle in or near the throat are important to efficient jet siphon performance. Jet ejectors should be thoroughly tested under simulated and representative use conditions prior to installation. Non-radioactive solutions or slurries, or both, with viscosity and density characteristics that essentially duplicate those of actual processing conditions can be compounded and used for such tests.

9.3.2.1 Both steam and air powered ejectors have been used in applications such as those involving the transfer of corrosive solutions, movement of gases containing radioactive contaminants, and creation of a vacuum in process equipment. The jet siphon ejectors have the advantage of no moving parts, low cost, and low maintenance. They are extremely dependable pumps in both liquid and light slurry pumping applications. Steam is generally used when condensate dilution is not a problem. Air or inert gas powered ejectors have been used less frequently because of limited lift and discharge capacities (as compared with the steam jet siphon pumps), because of moisture or vapors pickup, and because of the need to capture and clean contaminated exhaust gases.

9.3.2.2 Eductors are jet siphon pumps that use liquids as the motive fluid. They have been used principally in applications where liquids transfer or mixing, or both, is required. "Air lift" pumps might be considered to be a special class of educator, being used in the vertical configuration to move and mix fluids and slurries. Air lifts have been installed in waste tanks holding radioactive liquids and sludge for purposes of reducing instances of localized "hot spots" (heat buildup from radioactive decay heat), and to circulate the wastes around heat removal coils in the tanks.

9.3.3 Diaphragm type pumps, both mechanically driven and fluid driven (liquids or gases) have seen wide application under conditions where corrosion or dilution might be a problem, or where slurries are being pumped. Gear pumps, screw pumps, progressive cavity pumps and "Acid Egg" type pumps have been used in specialized circumstances. Each installation has problems and requirements peculiar to the application, and the participation and advice of a variety of pump vendors would be appropriate to their resolution.

9.4 *Centrifuges*:

9.4.1 The use of centrifuges for separation tasks in this service can be the cause of frequent outage. The centrifuges used in these installations are often subject to heavy loads and stresses, some due to the mode of operation, and the mechanical parts as well as the electrical or hydraulic elements (used infrequently) are prone to frequent failure.

9.4.1.1 Methods of unloading the sludge or solids cake and full recovery of the separated components, particularly the solids or cake, must be simplified and fail-safe to the extent that this can be effected. If the solids contain fissile materials, several additional constraints are placed on the design in order to preclude a criticality incident.

9.4.2 It is recommended that the centrifuge be designed for removal of the cake solids by means of dissolution rather than by scraping and flushing of the solids through internal passages of the centrifuge or connecting jumper lines, or both, in order to minimize pluggage problems. Removal of the cake or solids by jet nozzles impinging on the cake is sometimes assisted by an abrupt braking action to jolt and dislodge the solids.

9.4.2.1 Electrical braking procedures, as opposed to the use of a mechanical brake assembly, should be used when a centrifuge is to be braked.

9.4.3 It is preferable that the centrifuge drive motor and bearings be located exterior to the shield walls or enclosure in which the centrifuge is placed. (See 9.2.1-9.2.4 for references and constraints on the design and prototype testing of rotating equipment for use in this service.)

10. Instrumentation

10.1 *Design Considerations*:

10.1.1 Equipment used for handling and processing nuclear and radioactive materials should be equipped with instrument sensor components, circuitry, readout, control, and alarm elements that allow continuous and precise monitoring and control of the process operation(s) occurring in each of the locations where such materials are handled. Requirements for control of the following operational parameters may be applicable to each of the processing equipment pieces or sub–elements thereof.

10.1.1.1 The following is intended only as a convenient check list for instrumentation typically found on cell or canyon equipment used under these service conditions. The list is not purported to be a complete or a typical list for any one vessel or processing operation. The engineer must analyze the equipment and the processing operations being carried out therein, and must conduct a vigorous hazards analysis to uncover and clarify the instrumentation and alarm requirements for each specific application.

10.1.1.2 Safeguards against the loss or diversion of special nuclear materials during all phases of the processing and handling operations are dependent on highly accurate accounting steps at locations where streams diverge or converge. Accounting for the special nuclear materials is generally dependent on the ability to monitor the location of such materials throughout the plant. The accounting step requires representative sampling and volume measurement.

10.1.2 Volume determinations require knowledge of the following parameters:

10.1.2.1 Measure: (*1*) Liquid level in the vessel, (*2*) Foam level (if any) in the vessel, (*3*) Coolant volume in closed loop coolant systems, (*4*) Specific gravity of vessel contents, and (*5*) Presence of and volume of any solids heel.

10.1.2.2 For control or alarm, or both, monitor the following: (*1*) Excessive high or low liquid levels in the vessel. Also, changes in the liquid level that occur without concurrent execution of a command signal, (*2*) Volume changes that alter the criticality potential unfavorably, (*3*) Foaming conditions/quantity at the inlet to any vapor condenser or offgas treatment and cooling system, (*4*) Out-of-range changes in the volume of liquid in any closed loop cooling system, and (*5*) Out-of-range changes in the volume of liquids in closed loop steam, hot water, or heat transfer solution loops.

10.1.3 Temperature determination requires knowledge of the following parameters:

10.1.3.1 Measure: (*1*) Vessel contents temperature, (*2*) Coolant temperatures, in and out of the vessel jacket or cooling coils, and (*3*) Heating medium temperature or steam pressure.

10.1.3.2 For control or alarm, or both, monitor: (*1*) Heating rate, (*2*) Coolant flow rate, (*3*) Vapor or offgas system temperature conditions, and (*4*) Temperature extremes, high and low.

10.1.4 Pressure or vacuum determinations require knowledge of the following parameters:

10.1.4.1 Measure: (*1*) Absolute vessel pressure, (*2*) Pressure differential across successive vessels in a multi-vessel processing system, for example, an offgas treatment or vapor scrubbing system, and (*3*) Pressure differential: vessel to cell/canyon.

10.1.4.2 For control or alarm, or both, monitor: (*1*) Vessel pressure, (*2*) All pressure differentials, and (*3*) Vacuum suckback or siphoning conditions.

10.1.5 Flow measurement requires knowledge of the following parameters:

10.1.5.1 Measure: (*1*) Quantities of liquids, slurries, vapor, or gases passing from one processing vessel or step to another and through specific lines or points, (*2*) Coolant flow rates, (*3*) Steam or heating medium flow rates, (*4*) Quantities and rates for cold feed additions to the processing vessels, and (*5*) Quantities, rates, and time of addition of solid feed materials to the process vessel.

10.1.5.2 For control or alarm, or both, monitor: (*1*) Valve openings and closures, (*2*) Pump or siphon jet transfer rates, (*3*) Cold feed or solids addition rates, and (*4*) Pump motor power monitors (on/off).

10.1.6 Neutron and gamma field intensity, or flux intensity determination, requires knowledge of the following parameters:

10.1.6.1 Measure: (*1*) Flux intensity and (*2*) Gross gamma intensity.

10.1.6.2 For control or alarm, or both, monitor: (*1*) Excessive flux levels, (*2*) Out-of-range changes in the flux level, and (*3*) Criticality condition or occurrence (Requires a nuclear incident monitor (NIM) at locations that have the potential for such an incident.)

10.1.7 Composition determination requires knowledge of the following parameters:

10.1.7.1 Measure/determine: (*1*) Vessel contents: composition, (*2*) Cold chemical and solids feeds composition, (*3*) Special nuclear materials content, species, and quantity, (*4*) Form of materials: liquid; solution; solids; gaseous; slurry: precipitate/solute content and relationships, and (*5*) Specific gravity of vessel contents.

10.1.7.2 For control or alarm, or both, monitor: (*1*) High or low concentration of soluble poisons, (*2*) Fissile materials content, (*3*) Acidity (pH) level, (*4*) Vapors or offgas composition, or both, at each of the sequential steps in any treatment or scrubbing treatment process, and (*5*) Humidity level of offgas at various points in a treatment or scrubbing system.

10.2 *General*:

10.2.1 Instrumentation should include installed spare sensors elements and circuits or other indirect indication capabilities for any vessel or system where loss of any instrument(s) can result in a condition where it could directly cause or result in an accident (see 3.2.1).

10.2.2 Consideration should be given to the use of a dualized set of instrument components or an alternative means of assessing measuring instrument performance for temperature, specific gravity, and volume sensing instrumentation on all vessels used as accountability vessels.

10.2.3 Offgas system instrumentation, controls, and monitors should have the ability to monitor temperature, pressure, flow rates, humidity, gas composition, and other parameters at each of the successive scrubbing and treatment steps to determine the efficacy and efficiency of the treatment steps and to determine if the offgas composition meets basic data requirements for discharge to successive treatment steps. The offgas system instrumentation should show if regulatory requirements for discharge to the environment are being met. The instrumentation should be capable of reporting on a continuous basis while the equipment is being operated.

10.2.4 Instrumentation shall be provided to detect the occurrence or cause of all credible accidents on a continuous basis while the installed and operable equipment is either being operated or is in a stand-by mode.

10.2.5 The design, performance requirements, testing, and installation of the nuclear incident monitoring system shall meet the intent of and be in accordance with the requirements of ANSI/ANS 8.1.

11. Materials and Equipment Handling/Transport Facilities

11.1 *General*:

11.1.1 Manipulators and cranes, like other equipment, are subject to radiation damage effects and contamination when used in this service. Decontamination and maintenance work is carried out by personnel working in air suits, with masks and a dual or triple set of gloves. The work is tedious, awkward, and time consuming, and is carried out under conditions where personnel suffer radiation exposures of one degree or another. By law, such exposures must be minimized. The materials handling equipment covered in this section should be designed and fabricated to accommodate fast, simple cleanup routines, and so that components repair or changeout procedures are simplified.

11.1.2 The use of materials of construction and a physical configuration that permit materials handling equipment to operate in a hot, humid environment and to be readily decontaminated is of paramount importance. The manipulators and cranes generally operate in an environment where the temperature can be 50°C or more and where the humidity is not controlled. The decontamination sequences may include anything from wiping the equipment down with rags to pressure spraying sequences. Spraying can be the use of a steam lance, pressurized chemical (including dilute acid) cleaning solution sprays, and a shower or hose rinse procedure. The equipment must be designed, fabricated, and assembled to accommodate such aggressive decontamination procedures to be carried out monthly without functional deterioration of components, and without damage to or outage caused by moisture sensitive components.

11.1.3 The use of stainless steel alloys, to the extent practicable, is suggested for all metallic components on manipulator and crane installations in order to eliminate decontamination problems arising from the use of coatings and paint, and from rust and corrosion.

11.1.4 Through-the-wall manipulators, by definition, are operated by means of a direct mechanical linkage between the master and the slave ends. They are operated from behind a shield wall or confinement barrier. This type of manipulator does not come under the definition of "equipment mounted in the cell or canyon environment" and is not within the scope of this guide. Note that these manipulators can be removed for maintenance or, when required, replaced in their entirety except for the through-the-wall sleeves, also not covered by this guide. This guide will only address usage conditions or constraints.

11.1.5 Reliance on the use of master-slave manipulators or any other type of manipulator to bring about or maintain a safe condition in the cell or canyon is unacceptable. This requires having an operable manipulator available on a full–time basis. Manipulators should not be used under conditions that would require their use to initiate, execute, or control equipment or operations that are vital to the safe operation of the facilities in the cell or canyon.

11.1.6 Electrical design constraints and precautions or suggestions related to viewing capabilities for materials handling equipment as covered in subsequent sections are generally applicable to either a crane or a carriage-mounted manipulator installation.

11.2 *Through-the-Wall Manipulators*:

11.2.1 The use of through-the-wall and over-the-wall master-slave manipulators in a remote operated cell or canyon facility is acceptable only on a qualified basis. The use of this type of manipulator in smaller cells approximately 12×12 ft^2 is often required and justifiable. These manipulators are mostly suited to routine handling operations that cannot be accomplished in any other fashion. These manipulators are often used in conjunction with batch processing operations involving nuclear or radioactive materials in particulate, granular, or solid form, or when processing steps are conducted in small scale equipment and the process requires physical handling and transfer operations.

11.2.2 Master-slave manipulators should be installed in pairs to provide maximum handling dexterity.

11.2.3 All master-slave through-the-wall manipulators should have a protective boot or sleeve that covers the slave arm in order to minimize the contamination on the assembly extending into the cell or canyon space.

11.3 *Carriage-Mounted Manipulators*:

11.3.1 Carriage-mounted manipulators have both a complex mechanical makeup and sophisticated control circuitry. Like other complex mechanical equipment, they are subject to failure and outage. Coupled with the outage frequency for television monitoring systems on which they are most often dependent for operation, the on-line attainment factor for carriage-mounted manipulator installations may be low. See Appendix X4 for a definition of equipment availability.

11.3.2 Carriage-mounted manipulators placed completely inside the cell or canyon shield walls on either a wall-mount or an overhead-mount carriage configuration have been used in specialized situations. Such maneuverable manipulator assemblies have been used in specially equipped cells to maintain and repair other equipment under high radiation exposure conditions. This is one example of an installation where their use may be warranted, provided an overhead crane is also supplied to retrieve the manipulator and its carriage or trolley in their entirety.

11.3.3 The use of paired, carriage-mounted manipulators under conditions that call for the use of one or a pair of manipulator arms to effect maintenance and repair operations on another manipulator arm in order to have a cell or canyon facility remain operable is only conditionally acceptable. To be acceptable, in-process radiation sources would have to be removed from the cell or placed in shielded locations by means separate and independent of manipulators usage since the worse case failure scenario would prohibit manipulator access to such sources even with paired manipulator installations. Residual (background) radiation levels in the cell or canyon (after removal of or shielding of in-process radiation sources) must be low enough to permit maintenance personnel to enter the cell to effect emergency repairs and replacement of failed elements or assemblies.

11.4 *Cranes*:

11.4.1 Cranes should be designed and built in general conformity with ANSI/ASME NOG-1. That standard is primarily intended to cover cranes in service in nuclear power installations. Thus, many of its provisions are not applicable to this service. Detailed supplementary specifications are required to assure acquisition of an overhead crane adapted to this service.

11.4.2 All crane components susceptible to radiation decay damage should be shielded and placed in locations on the crane where radiation exposure is minimized.

11.4.3 Mechanical components should be placed in sealed enclosures, to the extent practicable, to prevent particulates and vapors from collecting on surfaces that require periodic maintenance and servicing, particularly bearings, gear boxes, shaft pillow blocks, hoist assemblies, brake assemblies, and all of the electrical components.

11.4.4 A remotely operable cable cutter assembly should be provided on the main crane hoist cable assembly, and any cable for any hoist having a rated capacity in excess of five tons. The cable shear(s) shall be capable of severing all of the cable strands so as to unload the hoist assembly in the event of a failure scenario that offers no alternative method or scheme for returning the crane to its maintenance and servicing location (in the cell or canyon crane maintenance area).

11.4.5 The crane should be equipped with an air-operated or alternative type of emergency drive assembly, independent of the crane power supply, in order to permit the crane to be returned to the maintenance area in the event of total loss of electrical power, or a mechanical failure that immobilizes the crane.

11.4.6 The use of hydraulically actuated systems or components should be minimized. Hydraulic systems, when supplied, must be leak-tight and equipped with a hand pump backup to the motorized pump. Piping should be Type 304L stainless steel with welded fittings, except for the connections at points requiring periodic inspection, and the unions provided to effect quick component changeout maintenance.

11.4.7 All crane hoists having a lift capacity in excess of one ton should have two independent hoist braking systems. Both braking systems shall be fail-safe with respect to holding any load suspended/hanging on the hoist hook. The brakes must have provisions for controlled release and lowering of the load(s) under emergency power outage/failure conditions.

11.4.8 Axle/wheel design should allow for shaft replacement in the event of a catastrophic bearing failure. Crane axles should be of the rotating type. Wheel axle disassembly should not require use of a hydraulic press.

11.4.9 The crane wheels and the alignment provisions for the wheels must be readily accessible for purposes of maintenance. Alignment provisions are required for each wheel, on a separate wheel-by-wheel basis. These provisions must accommodate adjustment in three planes and have lock-down features to preserve wheel alignment. The crane must track on the rails accurately without excessive "flanging." Wheels must not climb the rails and derail.

11.4.10 Jack-down idler wheels should be provided at each end truck position for use as an emergency backup in the event of wheel bearing failure or wheel fracture. The jack-down mechanisms for such wheels must be accessible or remotely operable under predicated failure scenarios.

11.4.11 Crane (or manipulator carriage) and main hoist trolley wheels should have treads that have been induction hardened to approximately 320 HB (Brinell Hardness Number). Drives should be provided at each end of the crane so that a front wheel drive configuration is maintained regardless of crane travel direction. Drive wheels on each end of the bridge and hoist trolley should be machined to have matching diameters to provide parallel tracking of the end trucks.

11.4.12 The total crane assembly should be designed, manufactured, and installed so that the crane cannot fall into the canyon or cell under any credible failure scenario, barring violent acts of nature that distort the building structure.

11.4.13 The crane's main hoist trolley must be designed and configured to remain on the crane bridge under expected and predictable failure scenarios.

11.4.14 The crane should have a working walkway platform extending the length of the crane, along both sides of the crane carriage, with protective railings on both sides of the platforms. Step or ladder access to the walkways should be provided, meeting 29CFR1910 and ANSI A14.3 safety standards. The working (or access) platforms should be positioned so as to allow for personnel access to all components requiring periodic inspection or maintenance, or both. The working platforms should not be placed or constructed in a fashion that will hinder or obstruct decontamination sequences on any portion of the crane.

11.5 *Electrical Design Considerations for Cranes*:

11.5.1 All electrical motors, starters, circuit breakers, transformers, fuses, and other circuit elements should be totally enclosed and waterproof. Explosion proof elements may be required under certain circumstances.

11.5.2 All wound rotor motors should be rated for 60 h continuous crane duty. Induction motors should be rated for continuous duty.

11.5.3 Electrical power supply and control wiring should meet NFPA 70 and NEMA 250 (Type 4) requirements. Wiring should be totally enclosed in rigid stainless steel conduit, continuous between switches, junction boxes, motors, panels, and other elements of the system. Access to wiring junctions, as required, should be made through use of water and vapor proof junction boxes.

11.5.4 All wiring connections in the control enclosure and between control enclosures and electrical components should be 600V No. 14 AWG minimum, insulated 90°C copper conductors. Electrical insulation on wiring or cable should remain functionally operable after having been subjected to an integrated radiation dosage of 2×10^8 rd, minimum.

11.5.5 Wiring insulation should not release toxic or corrosive fumes at temperatures under 230°C.

11.5.6 All of the electrical and control gear should be housed in a control room-type enclosure to the extent practicable. The enclosures should be air conditioned and built for ease of cleanup and decontamination. The enclosure should be sized to allow sufficient headroom and clearances for maintenance personnel to enter, walk and work inside the enclosure while effecting electrical and controls circuitry maintenance and repair procedures. The shielding provided for this control room enclosure must limit radiation exposure to the levels applicable under continuous occupancy conditions.

11.6 *Crane Lighting and Viewing*:

11.6.1 The use of in-cell or in-canyon materials handling equipment requires concurrent availability of a television monitoring system or equivalent viewing capabilities, coupled with high level (very bright) illumination. Any such equipment has to be usable any time the materials handling equipment is being operated.

11.6.2 When used in this service, an in-canyon TV system should be mounted in a position such as to provide overall in-cell viewing capability for monitoring the crane or carriage-mounted manipulator movements in order to avoid collisions with other in-cell equipment and piping. The capability of viewing crane hooks and manipulator arm movements is particularly important. Two independent viewing systems should be provided. Shielded viewing windows in the radiation shield wall are often provided to guarantee visual monitoring capabilities.

11.6.3 The use of limit switches and bumpers provides the means of setting limits for the movement of materials handling system components. Viewing capabilities must permit operators to monitor all crane (or manipulator installation) movements.

11.6.4 Computer program instructions incorporated in the crane or manipulator control system are another means of limiting the movement of materials handling system components. Crane hooks or manipulator arms can be excluded from areas where collisions with or damage to other equipment may occur. The ability to override such pre-programmed limits should be provided, but only under controlled and supervised conditions.

11.6.5 Auxiliary high intensity lighting should be mounted to provide viewing illumination for the use of either periscope viewing or television systems. The actual intensity of the lighting necessary will depend on canyon or cell reflection characteristics, as well as television lens quality. Both the television system components and lighting elements should be fully accessible for maintenance and replacement under the maintenance conditions that prevail for the facility.

11.6.6 Closed circuit television (CCTV) systems used on or in conjunction with in-canyon cranes or carriage-mounted manipulator installations are usually equipped with camera on/off controls, plus lens focus, lens iris opening, zoom, and pan/tilt controls. Control signals should be encoded with a digital address, message and cyclic redundancy check character, and a radio frequency (RF) system which includes a slotted coax and dipole antenna system. Decoding of the serial digital signal should include error detection to validate control system data before it appears as control system output.

11.6.7 The crane control system should constantly verify the integrity of the communications link. Crane controls are often linked together with CCTV system controls. Errors in signals data transmission, communications channel noise, and equipment dropouts should not cause any improper or unintended controls system action. Crane or manipulator movements must not result from an improper signal.

11.7 *Installation of Materials Handling Equipment*:

11.7.1 Materials handling equipment received on-site and stored while awaiting installation in the cell or canyon environment should be stored under conditions that prevent heat, moisture, or corrosive damage. The equipment should also be stored under conditions that protect it from damage caused by transfer handling, dropped loads, flying debris, or vandalism.

11.7.2 Installation of materials handling equipment such as cranes and carriage-mounted manipulator systems must be accomplished under closely controlled and supervised conditions to guard against damage to functional components. Complete functional testing should be carried out at the crane manufacturer's site and again on-site (at the final user's site) before installation in the canyon or cell environment. Tests should include a pressurized cleaning and "decontamination" cycle to prove out water tightness requirements.

11.7.3 Crane bridge, trolley and hoist tracking and alignment functions should be completed and locked in place prior to installation, then rechecked and realigned as necessary after installation.

12. Keywords

12.1 design; equipment; nuclear materials; processing

APPENDIXES

(Nonmandatory Information)

X1. RESPONSIBILITY FOR EQUIPMENT INTEGRITY

X1.1 The cost of a piece of equipment intended for use in the processing of nuclear or radioactive materials can range from a few thousand dollars up to well in excess of a million dollars. If design, procurement, inspection, testing, installation, and all other costs are correctly posted to the equipment, true equipment costs can be double, triple, or even more than the bare purchase cost. The cost of equipment failure once equipment is placed in "hot" service in an environment susceptible to particulate radioactive contaminants can be extremely high. Equipment failure under such use conditions can be life threatening as well as a potential cause of an environmental contamination incident.

X1.2 Whenever equipment failures occur, there are hearings and investigations to determine the cause or causes of failure, and to "fix" responsibility. Such responsibility fixing reviews are held even under circumstances when some involved or concerned group or individual questions the integrity of the equipment. When either type of question arises, there is a tendency for involved groups and individuals to attempt to place blame. Under conditions where responsibilities have been split among and delegated to several groups and contractor firms, it becomes an automatic response to deny having the responsibility for the work on that particular aspect of the equipment that has been established as the precipitating cause of the failure. Prime examples of such situations exist in the nuclear power industry, and the astronomical costs resulting therefrom are cited frequently.

X1.3 The developers of this guide believe that there is much to be gained in the way of equipment integrity when responsibility splits are minimized. When responsibilities are split, the responsibilities of each involved group require sharp definition. Shared responsibility for any one aspect of a job is seldom achievable. If an action or a decision requires acceptance and approval by another individual or group, it is believed that it is the approving group that really has the responsibility.

X1.4 This guide does not assume the existence of a standardized table of organization for either owner-operator or sub-contractor firms, wherein responsibility splits are sharply defined for and within the firm. Stating and fixing the responsibilities for any and all aspects of equipment design, procurement, inspection, and installation are beyond the scope of this guide.

X1.5 An idealized situation would be for one group to have real and effective overall responsibility for nuclear and radioactive processing equipment. Whether or not this is achievable in the real world is not addressed in this guide. To the extent that it might be achieved, it is believed that the owner-operator organization is best qualified for exerting and executing such complete and overall responsibility (see 3.2.5). Engineers assigned the responsibility for equipment engineering should have both an initial and a continuing involvement in and responsibility for the equipment. Owner-operator engineers assigned engineering responsibility are assumed to do the following:

X1.5.1 Fully define the processing step and/or functions to be carried out in the equipment, including definition of the service exposure conditions and associated processing hazards;

X1.5.2 Develop, study, and select definitive equipment configuration concepts and specify materials of construction specifically suited to the end use;

X1.5.3 Perform required engineering calculations, analysis, or computer-assisted simulation studies, and create engineering drawings and documents that encompass and define the shape, size, configuration, layout, or arrangement of component elements of the equipment;

X1.5.4 Produce a set of definitive specifications for the equipment, either as part of drawings or as separate documents;

X1.5.5 Create (or assist, review, and approve) procurement specifications that assure that the design intent and integrity provisions are preserved;

X1.5.6 Participate in the selection or approval, or both, of qualified vendors or fabricators, or both, in order to assure that design intent and requirements can be met, and that quality and integrity objectives are understood, agreed upon, accepted, and preserved during equipment fabrication, inspection, testing, and shipping sequences;

X1.5.7 Participate in all inspection and test procedures or have specific and definitive input and control over conditions, findings, or circumstances that determine or require inspector acceptance or approval, or both, during the equipment fabrication sequence; and

X1.5.8 Define, establish, and prepare specifications that set down the conditions and constraints that are to apply to and be complied with during the equipment installation sequences, in order to preserve the integrity of the total installation.

X2. MISCELLANEOUS TECHNICAL REFERENCES

X2.1 Documents having applicability to the design, fabrication, inspection, testing, and installation of equipment used in the subject service environments include the following:

X2.1.1 ERDA 76-21 *Nuclear Air Cleaning Handbook*, Design, Construction, and Testing of High-efficiency Air Cleaning Systems for Nuclear Application; Natl. Tech. Info. Service (NTIS), U.S. Dept. of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

X2.1.2 PNL-3594 *International Nuclear Fuel Handbook*, Harmon, K. M., 9-82, (Batelle) Pacific Northwest Laboratory, Richland, WA 99352.

X2.1.3 "Chemistry of the Purex Process," McKibben, J. Malvyn, *Radiochemica Acta*, 36.3-15 (1984), R. Oldenbourg Verlag, München (Germany), 1984.

X2.1.4 "Corrosion of Stainless Steels," 2nd Ed., A. J. Sedriks, John Wiley and Sons, Inc., New York, NY (1996).

X2.1.5 "Fundamentals of Designing for Corrosion Control: A Corrosion Aid for the Designer," R. J. Landrum, National Association of Corrosion Engineers, Houston, TX (1990).

X2.1.6 "Materials Selection for Corrosion Control," S. L. Chawla and R. K. Gupta, ASM International, Materials Park, OH (1993).

X2.1.7 Various titles covering radiation damage, various authors, *Nucleonics*, Vol 13, No. 10, Oct. 1955; Vol 14, No. 9, September 1956; Vol 18, No. 9, Sept. 1960.

X2.1.8 REIC Report No. 21 "The Effect of Nuclear Radiation on Elastomeric and Plastic Components and Materials," Radiation Effects Information Center, Battelle Memorial Institute, 505 King Ave., Columbus, OH (see also Addendum to Report 21).

X2.1.9 REIC Report No. 36 "The Effect of Nuclear Radiation on Electronics Components Including Semiconductors," Radiation Effects Information Center, Battelle Memorial Institute, 505 King Ave., Columbus, OH (see also: REIC Reports on other materials and devices).

X2.1.10 "Radiation Damage of Materials Engineering Handbook: Part I: A Guide to the Use of Plastic," M. H. Vande Voorde and G. Pluym, European Organization for Nuclear Research, Geneva, Switzerland (1966).

X2.1.11 "Radiation Damage of Materials Engineering Handbook: Part II: A Guide to the Use of Elastomers," M. H. Vande Voorde, European Organization for Nuclear Research, Geneva, Switzerland (1966).

X2.1.12 STP 1125 "Effects of Radiation on Materials: 15th International Symposium," R. E. Stoller, A. S. Kúmar, and D. S. Gelles, Editors, American Society for Testing and Materials, West Conshohocken, PA (1989).

X3. OTHER USEFUL REFERENCES

X3.1 DOE Orders:

420.1 Facility Safety.

-6301.1A General Design Criteria (cancelled by DOE Order 420.1).

X3.2 ANSI Standards:

ANSI B15.1 Safety Standard for Mechanical Power Transmission Apparatus.

ANSI B30.2 Overhead and Gantry Cranes.

ANSI B30.10 Hooks.

ANSI MH27.1 Monorail Systems.

X3.3 American Gear Manufacturer's Association (AGMA):

AGMA 908, Geometry Factors for Determining Pitting Resistance and Bending Strength of Spur, Helical and Herringbone Gear Teeth.

AGMA 2001, Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gears.

X3.4 *National Electrical Manufacturers Association (NEMA) Standards:*

NEMA WC-5 Thermoplastic Insulated Wire and Cable for Transmission and Distribution.

NEMA MG-1 Motors and Generators.

NEMA ICS Industrial Control Systems.

X3.5 *National Fire Protection Association (NFPA) Standards:*

NFPA 12A Halon–1301 Fire Extinguishing Systems.

NFPA 72 National Fire Alarm Code.

X3.6 D. W. Green and J. O. Maloney, Editors, "Perry's Chemical Engineers' Handbook," 6th Edition (see sections 5 and 6 for ejector/eductor design), McGraw-Hill Book Co. Inc., New York, NY (1984).

X4. EQUIPMENT AVAILABILITY AND PLANT ATTAINMENT

X4.1 Knowledge of the failure frequency cycles for cell or canyon type equipment is important for analyzing the impact of equipment outages on production. Having such information can help with decisions on whether or not installed spares or standby (off-the-shelf) spares might be needed to attain forecast production rates, and which equipment items are most critical to attainment.

X4.2 The time needed to repair equipment in place and/or to remove the equipment from the cell or canyon space, repair it, and then re-install it, or to remove equipment and install a standby spare, is also a factor in determining plant attainment capabilities. The availability of surge or holdup capacity can also be a factor. All processing steps need not proceed at the same throughput rate. If surge or holdup capacity is available for certain processing steps, production can continue for that step until such capacity is exhausted. In this interval, repairs or equipment changeout might be effected in prior or subsequent processing sequences without impacting plant attainment.

X4.3 The mean time between failure or outage for each piece of equipment and each component needed to operate the plant might be determined from plant operational and maintenance records, or they might be available from a plant or installation having a duplicate or similar processing mission or equipment complement. Note, however, that records showing the time necessary to change out or repair equipment items, or both, will vary depending on maintenance methods and materials handling equipment used in and for maintenance handling sequences. The availability of such historic records might permit study of the impact of alternative equipment or handling methods on the production rate.

X4.3.1 The *availability factor* for equipment can be defined as follows:

$$A = \frac{MTBF}{(MTBF + MTTR)} \times 100 \qquad \text{(X4.1)}$$

where:

A = system availability (% of time),
$MTBF$ = mean time between failures, h, and
$MTTR$ = mean time to repair or replace, or both, h.

X4.3.1.1 The MTTR figure should include the time necessary to diagnose the problem and determine how best it might be resolved.

X4.3.2 Multiplication of all of the availability factors for a defined processing step provides the attainment factor for that processing step.

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