**Report on Task Assignment #3
for the
WASTE PACKAGE PROJECT**

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Parts A & B:

**ASME PRESSURE VESSEL CODES REVIEW
FOR WASTE PACKAGE APPLICATION**

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Part C:

**LIBRARY SEARCH FOR RELIABILITY/FAILURE RATES
DATA ON LOW TEMPERATURE LOW PRESSURE PIPING,
CONTAINERS, AND CASKS WITH LONG DESIGN LIVES**

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DISCLAIMERS

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The authors of this report have written this report, in handbook format, to simplify possible future use of the ASME Pressure Vessel and Boiler Codes to waste package design. The authors give full credit for the contents of the codes to the ASME committees that authored them. The authors in no way claim any credit for the portions of this report that are based upon segments of the ASME codes. This report does not claim to be a substitute for the ASME codes; it merely organizes the process of reviewing the codes for nuclear waste package application.

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1. OVERVIEW OF TASKS FOR WASTE PACKAGE PROJECT RESEARCH TEAM UNDER THE DOE COOPERATIVE AGREEMENT

The Waste Package Project Research Team, at UNLV, has four general required tasks. Task one is the management, quality assurance, and overview of the research that is performed under the cooperative agreement. Task two is the structural analysis of spent fuel and high level waste. Task three is an American Society of Mechanical Engineers (ASME) Pressure Vessel Code review for waste package application. Finally, task four is waste package labeling. This report includes preliminary information about task three (ASME Pressure Vessel Code review for Waste package Application).

2. OBJECTIVES FOR TASK THREE OF DOE COOPERATIVE AGREEMENT

Our first objective is to compile a list of the ASME Pressure Vessel Codes that can be applied to waste package containers design and manufacturing processes. Our second objective is to explore the use of these applicable codes to the preliminary waste package container designs. Our final objective is to perform a library search for reliability and/or failure rates data on low pressure, low temperature, containers and casks with long design lives.

The remainder of this report is divided as follows. Section 3 provides a review of the current status of the nuclear waste container design. Section 4 provides an introduction to ASME codes. Section 5 provides an introduction to ASME material selection/identification and ASME pressure vessel design. Section 6 provides application of the ASME pressure vessel code to the preliminary design of the nuclear waste container, as an example. This application of the ASME codes to the preliminary waste container design is very generalized and thus it may be applied to any final design.

The findings of the first of the above objectives is presented in section 4.2 of this report. The findings of the second objective is presented in sections 5 and 6 of this report. This report is written in handbook format to assist future waste package designers and reviewers in fully utilizing the ASME Pressure Vessel and Boiler Codes potential. The findings of the final objective is included in Part C, at the end of this report.

NOTE: The authors realize that the waste packages contained within the waste package containers are not likely to create pressures, in the waste package container, higher than three or four atmospheres. This pressure value does not take any nuclear factors into consideration; it is based solely on temperature and thermodynamic considerations. However, the ASME pressure vessel code is still a widely accepted and informative document with a broad range of design criterion based on past experience (e.g. acceptable pressure vessel materials, maximum acceptable design temperature, minimum acceptable container wall thicknesses, vessel inspection criterion, nondestructive testing, etc.)

3. REVIEW OF THE CURRENT STATUS OF THE NUCLEAR WASTE CONTAINER DESIGN

3.1 Historical Background

Congress enacted the Nuclear Waste Policy Act of 1982 (Public Law 97-425), also called the Nuclear Waste Policy Act (NWPA), to establish a national effort to develop a permanent repository to store spent fuel and high level waste (HLW). These are byproducts of nuclear power plants and the nuclear weapons industry, respectively. Once enacted, the NWPA placed the DOE in charge of the siting, the construction, and the design of such a repository. The NWPA also placed the U.S. Environmental Protection Agency (EPA) in charge of declaring standards which would protect the environment from off-site leaks of radioactive material from the permanent storage site. The NWPA also place the Nuclear Regulatory Commission (NRC) in charge of declaring the technical requirements necessary to license all of the phases of repository operation. In 1987, Congress amended the NWPA to restrict the site characterization plan exclusively to Yucca Mountain, Nevada. This plan is hereafter referred to as the Yucca Mountain Project. [14]

In addition to the storage site design and construction, the YMP has necessitated extensive research in many areas including the following:

1. transportation of spent fuel and HLW to the repository
2. possible storage container materials
3. possible storage container designs
4. NRC licensing requirements and procedures

The U.S. Department of Energy subsequently contracted UNLV in July 1990 under DOE Cooperative Agreement number DE-FC08-90NV10872. One of the purposes of this agreement is to study the possibilities of applying the ASME codes to the waste package design.

3.2 Introduction to Nuclear Waste Storage Site

The purpose of the geologic storage site is to prevent hazardous materials from escaping the repository and consequently becoming health hazards. The proposed Yucca Mountain storage site is located in Nye County of southern Nevada, roughly 100 miles

northwest of Las Vegas (see figure 3.2.1). The site lies in the southern part of the Great Basin. This region is characterized by very little rainfall (about 4 inches annually), sparse desert vegetation, and a sparse human population in the immediately surrounding area. "The geologic repository will consist of surface facilities, underground facilities, and shafts and ramps connecting the surface and the underground facilities..." (see figure 3.2.2) [17]. This paragraph and the remainder of section 3.2 is based upon the Site Characterization Plan (SCP) [17].

3.2.1 Surface Facilities

The surface facilities will receive the waste and prepare it for permanent underground disposal. These facilities will be located to the east of Yucca Mountain on relatively flat ground. The surface facilities will consist of: an administration building, a series of shops, a pair of waste-handling buildings, a warehouse, and a waste receiving and inspection area.

3.2.2 Shafts and Ramps

The underground facilities and the surface facilities would be connected by two ramps and four shafts. The waste ramp would be used to transport filled waste containers from the surface to the underground storage site. This ramp will be about 1.25 miles long and will have a slope of nearly 9 percent.

3.2.3 Underground Facilities

The underground repository for the permanent emplacement for the nuclear waste would be about 1000 feet below the eastern flank of Yucca Mountain (see figure 3.2.3). The main component of the underground storage facility is the emplacement panel. The emplacement panel, which is composed of rock, would be about 1400 feet wide and 1500 - 3200 feet long. The preliminary layout requires 18 emplacement panels, based upon a calculated area power density of 57 kilowatts per acre.

The waste containers will be placed in a vertical position or in a horizontal position, vertical positioning was assumed under the SCP but both are under consideration. If the emplacement is vertical, the bore holes will be drilled into the floor of the emplacement drifts and will be about 25 feet deep and about 30 inches in diameter. If the emplacement is horizontal, the boreholes will be drilled horizontally into the walls of the emplacement drifts. The nuclear waste emplacement panels will be roughly the same size regardless if vertical or horizontal emplacement is chosen. A container of spent nuclear fuel will be approximately 15.5 feet long and 26 inches in diameter.

A sample vertical borehole with an emplacement package within it is shown in figure 3.2.4. A support plate would be inserted in the bottom of the borehole and a metal casing would line the walls of the borehole from the top of the hole past the top of the emplaced container, to protect the waste container. A several inch thick metal plug would be inserted

Figure 3.2.1 "Location of the Yucca Mountainn site in southern Nevada...." (reprinted from [17], page 13)

Figure 3.2.2 "Perspective of the proposed repository at Yucca Mountain." (reprinted from [17], page 35)

Figure 3.2.3 "Underground repository layout for vertical waste emplacement." (reprinted from [17], page 42)

Figure 3.2.4 "Vertical waste emplacement borehole"
(reprinted from [17], page 43)

in the borehole, after the waste container was emplaced, to provide shielding from radiation. Once this plug was in place crushed tuff would fill the remainder of the borehole and a metal cap would provide a seal for the top of the borehole.

3.2.4 Waste Retrievability and Subsequent Closure

The actual waste emplacement process is expected to take 26 years. Immediately following will be a 24 year "caretaker" period, during which various tests will be conducted to ensure that the repository was performing as expected. At the end of the caretaker period, the repository would be prepared for permanent storage by backfilling the underground areas and by permanently sealing the shafts and ramps.

3.3 Survey of the Nuclear Waste Container Design

Nuclear waste container research has been going on for several years now. One of the main thrusts of this research is selection of candidate materials for the nuclear waste container. The material(s) used for this purpose should be chosen based on the following, [7]:

1. metallurgical phase instability (weld, heat affected zone, and base metal)
2. mechanical stress
3. oxidation and general aqueous corrosion
4. localized corrosion (pitting, crevice)
5. stress corrosion cracking
6. hydrogen effects
7. microbiologically influenced corrosion

Several preliminary designs have resulted from this research effort [1, 2, 3, 5]. Of particular interest, was a study by Lawrence Livermore National Laboratories, [16]. This study was done for the purposes of cost analysis. It seemed, from the author's point of view, to be the most complete study thus far. The ASME Pressure Vessel Codes were applied, in Section 6 of this document, to this preliminary design for safety purposes. However, this application was of a generic style and it is thus useful to whatever final design is chosen.

We began our research by compiling information about the waste package containers. We collected extensive information from several sources which are listed in the reference section. These documents, that we compiled, contain information about:

1. the material that a waste package container is to be made from
2. the waste packages that the waste package container will be designed to hold
3. some possible configurations for the preliminary waste package container designs
4. the environment of the storage repository
5. the preliminary construction methods for the waste package containers

6. the amount of time that these waste package containers must maintain substantially complete containment of the waste package.

3.4 Nuclear Waste Container Materials

Paper [1] lists six possible candidate materials for the construction of the hazardous waste container. These six materials are:

1. AISI-304L - Chromium-Nickel stainless steel.
2. AISI-316L - Chromium-Nickel stainless steel.
3. Incoloy-825 - Nickel-Iron-Chromium-Molybdenum-Copper alloy.
4. CDA-102 - 99.95% pure copper.
5. CDA-613 - Aluminum-Bronze alloy.
6. CDA- 715 - Copper-Nickel alloy.

The above materials will be discussed in greater detail in the following sections.

4. INTRODUCTION TO ASME CODES

The ASME Pressure Vessel and Boiler Code is a widely accepted standard for the safe material selection and construction of pressure vessels and boilers. These codes are written by committees of engineers who work in fields related to their perspective assignments. The ASME codes consist of eleven volumes (of actual code) plus several volumes of code cases (Code cases are published records of written inquiries about the specific meaning of particular portions of the code. These inquiries have been answered in writing by the Boiler and Pressure Vessel Committee to clarify their meaning.). Section 4.1 contains the ASME table of contents for all of the ASME code volumes. Not all the ASME code sections are applicable to the nuclear waste container design (e.g. the design of power boilers). Sections 4.2 and 4.3 separate the code contents into relevant and irrelevant sections, as applied to waste package application.

4.1 Listing of ASME Code Sections (by volume)

- I Power Boilers
- II Material Specifications
 - Part A - Ferrous Materials
 - Part B - Nonferrous Materials
 - Part C - Welding Rods, Electrodes and Filler Metals
- III Subsection NCA - General Requirements for Division 1 and Division 2
- III DIVISION 1
 - Subsection NB - Class 1 Components
 - Subsection NC - Class 2 Components
 - Subsection ND - Class 3 Components
 - Subsection NE - Class MC Components
 - Subsection NF - Component Supports
 - Subsection NG - Core Support Structures
 - Appendices
- III DIVISION 2 - Code for Concrete Reactor Vessels and Containments
- IV Heating Boilers

- V Nondestructive Examination
- VI Recommended Rules for Care and Operation of Heating Boilers
- VII Recommended Guidelines for the Care of Power Boilers
- VIII Pressure Vessels
 - Division 1
 - Division 2 - Alternative Rules
- IX Welding and Brazing Qualifications
- X Fiberglass-Reinforced Plastic Pressure Vessels
- XI Rules for Inservice Inspection of Nuclear Power Plant Components

4.2 Code Sections Relevant to Nuclear Waste Container Design

There are three main section of the ASME boiler and pressure vessel code that are applicable to the preliminary nuclear waste container design. The first is volume II which clearly identifies known pressure vessel materials. The second is volume VIII which gives the general requirements for all pressure vessels. The third is volume IX which discusses the brazing and welding qualifications for all ASME identified materials. A more detailed discussion of volume II and volume VIII is included in Section 5 of this report.

4.2.1 Relevant Material of Volume II - MATERIALS

Volume two consists of material specifications for pressure vessels and boilers. This volume includes information about: reference documentation, ordering information, heat treatment, chemical composition, certification, etc. Volume two consists of three parts. Part one deals with ferrous materials. Part two deals with nonferrous materials. Part three deals with welding rods, electrodes and filler metals. A list of the contents of volume two follows:

Part A - Ferrous Materials

- Specifications Listed by Materials - Pages XXIX-XXXV
- Specification Listed in Numeric Sequence - Pages XXXVII-XLI
- Mandatory Appendix 1 - Page XLIII
- SI Units - Pages XLV-XLVII

SAMPLE SPECIFICATION:

1. Scope

"This specification covers a group of common requirements which, unless otherwise specified in the individual material specification, shall apply to rolled steel plates for pressure vessels under each of the following specifications issued by ASTM:..." [14]

2. Reference Documents

3. Descriptions of terms Specific to this Standard

4. Ordering Information
5. Manufacture
6. Heat Treatment
7. Chemical Analyses
8. Metallurgical Structure
9. Quality
10. Test Methods
11. Tension Tests
12. Notch-Toughness Tests
13. Identification of Plates
14. Permissible variations in Dimensions or Mass
15. Inspection and Testing
16. Retests
17. Retreatment
18. Rejection
19. Test Reports
20. Packaging, Marking, and Loading for Shipment

Part B - NONFERROUS MATERIALS

Part B is identical to part A except that it covers non-ferrous metals.

Part C - WELDING RODE, ELECTRODES, AND FILLER METALS

- Covered carbon steel arc welding electrodes
- Iron and steel oxyfuel gas welding rods
- Covered corrosion-resisting chromium and chromium-nickel steel welding electrodes
- Low alloy steel covered arc welding electrodes
- Copper and copper alloy covered electrodes
- Copper and copper alloy bare welding rods and electrodes
- Brazing filler metal
- Corrosion resisting chromium and chromium-nickel steel bare -and composite metal cored and stranded welding electrodes and welding rods
- Aluminum and aluminum alloy bare welding rods and electrodes
- Nickel and nickel alloy covered welding electrodes
- Tungsten arc welding electrodes
- Solid surfacing welding rods and electrodes
- Nickel and nickel alloy bare welding rods and electrodes
- Welding rods and covered electrodes for cast iron
- Titanium and titanium alloy bare welding rods and electrodes
- Carbon steel electrodes and fluxes for submerged arc welding
- Composite surfacing welding rods and electrodes
- Flux cored corrosion-resisting chromium and chromium-nickel steel electrodes
- Low alloy steel electrodes and fluxes for submerged arc welding

- Zirconium and zirconium alloy bare welding rods and electrodes
- Consumables used for electroslab welding of carbon and high strength low alloy steels
- Consumables used for electrogas welding of carbon and high strength low alloy steels
- Copper and copper alloy gas welding rods
- Low alloy steel filler metals
- Low alloy electrodes for flux
- Consumable inserts
- Filler metal procurement guidelines.

4.2.2 Relevant Material of Volume V - NONDESTRUCTIVE EXAMINATION

- scope: This section of the code contains requirements and methods for nondestructive examination which are code requirements to the extent they are specifically referenced and required by other code section. These nondestructive examination methods are intended to detect surface and internal discontinuities in materials, welds, and fabricated parts and components. They include radiographic particle examination, eddy current examination, visual examination and leak testing.
- references, paragraphs, and standards
- manufacturer's examination responsibility
- duties of authorized inspector procedures
- inspection and examination qualifications of personnel

4.2.3 Relevant Material of Volume VIII - PRESSURE VESSELS

Volume eight covers pressure vessels in three sections. The first section is devoted to "the general requirements for all methods of construction and all materials." The second section is devoted to "requirements pertaining to methods of fabrication of pressure vessels." The third section covers "requirements pertaining to classes of materials." [14]

Subsection A - GENERAL REQUIREMENTS FOR ALL METHODS OF CONSTRUCTION AND ALL MATERIALS

This is the bulk of the pressure vessel design material. This subsection refers to many other sections of the ASME pressure vessel and boiler code, including many references to volume II (construction materials).

Subsection B - REQUIREMENTS PERTAINING TO METHODS OF FABRICATION OF PRESSURE VESSELS

CONTENTS:

- PART UW: Requirements for pressure vessels (fabricated by welding)
- PART UF: Requirements for pressure vessels (fabricated by forging)
- PART UB: Requirements for pressure vessels

(fabricated by brazing)

Subsection C - REQUIREMENTS PERTAINING TO CLASSES OF MATERIALS

This is a very long list so only a few sample entries have been included. Those who need the entire list may refer to volume VIII, subsection C.

- requirements for pressure vessels constructed of carbon steel
- requirements for welded pressure vessels constructed of material with corrosion resistant integral cladding, weld metal overlay cladding, or with applied linings
- requirements for pressure vessels constructed of high allow steel
- requirements for pressure vessels constructed of nonferrous metals

4.2.4 Relevant Material of Volume IX - WELDING AND BRAZING QUALIFICATIONS

The following statement is taken from the introduction of ASME volume IX.

"The following is a brief introduction to the 1986 edition of section IX and cannot be considered as a substitute for the actual review of appropriate sections of the document. However, this introduction is intended to give the reader a better understanding of purpose and organization of section IX.

Section IX of the ASME Boiler and Pressure Vessel Code relates to the qualification of welders, welding operators, brazers, and brazing operators, and the procedures employed in welding or brazing in accordance with ASME Boiler and Pressure Vessel Code and the ASME B31 Code for Pressure Piping...." [14]

PART QW - WELDING

ARTICLE I - Welding General Requirements

-general

"Section IX of the ASME Boiler and Pressure Vessel Code relates to the qualification of welders, welding operators, brazers, and brazing operators, and the procedures that they employ in welding and brazing according to the ASME Boiler and Pressure Vessel Code and the ASME B31 Code for Pressure Piping. It is divided into two parts: Part QW gives requirements for welding and Part QB contains requirements for brazing." [14]

(other article I entries):

- weld orientation
- test positions of groove welds
- types and purposes of tests and examinations
- tension tests
- guided-bend tests
- notch-toughness tests
- fillet-weld tests
- other tests and examinations
- rounded indication charts

ARTICLE II - Welding Procedure Qualifications

ARTICLE III - Welding Performance Qualifications

ARTICLE IV - Welding Data

PART QB - BRAZING

ARTICLE XI - Brazing General Requirements

The following statement is taken from part QB of ASME volume IX.

"The rules in this Section apply to the preparation of Brazing Procedure Specifications, and the qualification of brazing procedures, brazers, and brazing operators for all types of brazing processes permitted in other Sections. These rules may also be

applied, insofar as they are applicable, to other manual or machine processes." [14]

ARTICLE XII - Brazing Performance Qualifications

ARTICLE XIII - Brazing Performance Qualifications

ARTICLE XIV - Brazing Data

4.3.9 Relevant Material from CODE CASES - BOILERS AND PRESSURE VESSELS

"The Boiler and Pressure Vessel Committee meets regularly to consider proposed additions and revisions to the Code and to formulate Cases to clarify the intent of existing requirements to provide, when the need is urgent, rules for materials or constructions not covered by existing Code rules. Those Cases which have been adopted will appear in the appropriate 1986 Code Cases Book: (1) Boilers and Pressure Vessels, (2) Nuclear Components. Supplements will be sent automatically to the purchasers of the Code Cases books up to the publication of the 1989 Code." [14]

The code cases are written in the following format:

INQUIRY: This section contains a written question (or clarification) to the Boiler and Pressure Vessel Committee.

REPLY: This section contains the official ASME reply to the written question.

4.3 Code Sections Irrelevant to Nuclear Waste Container Design

4.3.1 Irrelevant Material of Volume I - POWER BOILERS

Volume one consists of rules for the construction of power boilers, electric boilers, miniature boilers, and high temperature water boilers to be used in stationary service and includes those power boilers used in locomotive, portable, and traction service.

4.3.2 Irrelevant Material of Volume III - RULES FOR CONSTRUCTION OF NUCLEAR POWER PLANT COMPONENTS

Volume three discusses the general requirements for Division one and Division two. Division one covers: class one components, class two components, class three components, class MC components, component supports, and core support structures. Division two covers the code for concrete reactor vessels and containments.

SUBSECTION NCA - GENERAL REQUIREMENTS FOR DIVISION 1 AND DIVISION 2

SCOPE: The rules of this section constitute requirements for the design, constructing, stamping, and overpressure

protection of nuclear power plant items such as vessels, concrete reactor vessels and concrete containments, storage tanks, piping systems, pumps, valves coresupport structures, and component supports for use, or containment of portions of the nuclear power system of an power plant.

SUBSECTION NB - CLASS 1 COMPONENTS

CONTENTS:

introduction
material
design
fabrication and installation
examination
testing
overpressure protection
nameplates, stamping, and reports

SUBSECTION NC - CLASS 2 COMPONENTS

(same as subsection NB except this subsection covers class 2 components).

SUBSECTION ND - CLASS 3 COMPONENTS

INTRODUCTION (scope): Subsection ND contains rules for the materials, design, fabrication, examination, testing, overpressure relief, marking, stamping, and preparation of reports by the certificate holder of items which are intended to conform to the requirements for class 3 construction.

SUBSECTION NE - CLASS MC COMPONENTS

SCOPE: Subsection NE establishes rules for material, design, fabrication, examination, inspection, testing, and preparation of reports for metal containment vessels.

RULES FOR CLASS MC CONTAINMENT VESSELS: Class MC containment vessels shall be constructed in accordance with the rules of this subsection, except as provided in NCA-2134. Only containment vessels and their appurtenances shall be classified as class MC. Pipes, pumps, and valves which are part of the containment system (NEE-1130) or which penetrate or are attached to the containment vessel shall be classified as class 1 or class 2 by the design specification and meet the requirements of the applicable subsection. Figure NE-1120-1 shows some typical penetrations with different class designations.

SUBSECTION NF - COMPONENT SUPPORTS

SCOPE: Subsection NF contains rules for the material, design, fabrication, examination, installation, and preparation of reports for supports for components and piping which are intended to conform to the requirements for classes 1, 2, 3, and MC construction as set forth in subsections NB, NC, ND and NE, respectively, of this

section.

SUBSECTION NG - CORE SUPPORT STRUCTURES

SCOPE: Subsection NG establishes rules for material, design, fabrication, examination, and preparation of reports required in the manufacture and installation of core support structures.

DIVISION I - RULES FOR CONSTRUCTION OF NUCLEAR POWER PLANT COMPONENTS

Appendix 1 - DESIGN STRESS INTENSITY VALUES, ALLOWABLE STRESSES, MATERIAL PROPERTIES, AND DESIGN FATIGUE CURVES.

(sample entries):

1. design stress intensity values for class 1 components
2. yield strength values
3. tensile strength values
4. nominal coefficients of thermal conductivity and thermal diffusivity
5. nominal coefficients of thermal expansion
6. moduli of elasticity of material for given temperatures
7. design stress values

Appendix 2 - EXPERIMENTAL STRESS ANALYSIS

Appendix 3 - BASIS FOR ESTABLISHING DESIGN STRESS INTENSITY VALUES AND ALLOWABLE STRESS VALUES

Appendix 4 - APPROVAL OF NEW MATERIALS UNDER THE ASME BOILER AND PRESSURE VESSEL CODE FOR SECTION 3 APPLICATION

Appendix 5 - CERTIFICATE HOLDERS DATA REPORT FORMS, INSTRUCTION, AND APPLICATION FORMS FOR CERTIFICATES OF AUTHORIZATION FOR USE FOR CODE SYMBOL STAMPS

Appendix 6 - ROUNDED INDICATIONS...

DIVISION 2 - CODE FOR CONCRETE REACTOR VESSELS AND CONTAINMENTS

CONTENTS:

subsection CB - concrete reactor vessels (prestressed)
 subsection CC - concrete containments (prestressed or reinforced)

4.3.3 Irrelevant Material of Volume IV - HEATING BOILERS

The requirements of part HG apply to steam heating boilers, hot water heating boiler, hot supply boilers, and

to appurtenances thereto, and shall be used in conjunction with the specific requirements in part HF, Boilers of Wrought Materials, and part HC, Cast Iron Boilers, whichever is applicable. Part HG is not intended to apply to potable water heaters except as provided for in a part HW.

4.3.4 Irrelevant Material of Volume VI - RECOMMENDED RULES FOR THE CARE AND OPERATION OF HEATING BOILERS

This portion of the rules is intended to cover general description, terminology, and basic fundamentals of heating boilers, controls, and automatic fuel burning equipment. Because of the wide variety of makes and types of equipment in use, it is general in scope.

4.3.5 Irrelevant Material of Volume VII - RECOMMENDED GUIDELINES FOR THE CARE OF POWER BOILERS

Volume seven consists of recommended guidelines for the care of power boilers.

- (sample entries)
- steam generation
 - boiler types
 - package boilers
 - field assembled boilers
 - combustion
 - boiler efficiency...

4.3.6 Irrelevant Material of Volume X - FIBERGLASS-REINFORCED PLASTIC PRESSURE VESSELS

General: "The use of fiber-reinforced plastics for the manufacture for pressure vessels presents unique materials consideration in the design, fabrication, and testing of these vessels. Metallic vessels, being made from materials which are normally isotropic and ductile, are designed by using well-established allowable stresses based on measured tensile and ductility properties. In contrast, fiber-reinforced plastics are usually anisotropic and the physical properties are dependent upon the fabrication process, the placement and orientation of the reinforcement, and the resin matrix. It is the purpose of this introduction to describe in a general way the criteria that were used in preparing Section X, Fiber-Reinforced Plastic Pressure Vessels." [14]

4.3.7 Irrelevant Material of Volume XI - RULES FOR INSERVICE INSPECTION OF NUCLEAR POWER PLANT COMPONENTS

general:

"The rules of this Section constitute requirements to maintain the nuclear power plant and to return the plant to service, following plant outages, in a safe and expeditious manner. The rules require a mandatory program of examinations, testing, and inspections to evidence adequate safety. The rules also stipulate duties of the Authorized

Nuclear Inservice Inspector to verify that the mandatory program has been completed, permitting the plant to return to service in an expeditious manner." [14]

DIVISION I - Rules for Inspection and Testing of
Components of Light-Water Cooled Plants

DIVISION II - Rules for Inspection and Testing of
Components of Gas-Cooled Plants

DIVISION III - Rules for Inspection and Testing of
Components of Liquid-Metal Cooled Plants

5. INTRODUCTION TO ASME PRESSURE VESSEL CODE RULES FOR MATERIAL SELECTION AND PRESSURE VESSEL DESIGN

5.1 Introduction:

The first step that one should take, when designing a pressure vessel, is to select the building material(s). The material must be selected on the basis of its suitability for the intended service with respect to:

- a. retention of satisfactory mechanical properties
- b. resistance to corrosion, erosion, oxidation, and other deterioration factors during their intended service life.

The second step is to check the pressure vessel design using the formulae contained in volume VIII.

5.2 Material Selection Procedure Using ASME Code Volume II:

The following is a description of how to extract information from ASME code Vol. II. The ASME codes do not include an numerical metal-identification index. Therefore, we were not able to look up any of the candidate materials without several preliminary steps.

The first step is to determine the chemical composition of the metal and break the material down into one of the following three categories:

1. Section A (Ferrous Materials)
2. Section B (Nonferrous Materials)
3. Section C (Welding Rods, Electrodes and Filler Metals).

The second step is to look through the index that precedes the applicable subsection and turn to the indicated pages for the corresponding appropriate chemical composition.

The third step is to turn to the table at the end of the above subsection and look through it to verify that the material that one is looking up has the chemical composition which is included in this table.

As an illustrative example, consider stainless steel "AISI-304L". The chemical composition of this metal is: Carbon (max) 0.030 % by mass, Manganese 2.00% (max), Phosphorus 0.045% (max), Sulfur 0.030% (max), Silicon 1.00% (max), Chromium 18.00-20.00%,

Nickel 8.00-12.00%, Nitrogen 0.10% (max). Section A (Ferrous Materials) is the appropriate section for this metal. The appropriate Subsection for this material is: "Specification for Heat-Resisting Chromium and Chromium Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels."

Once the above search is completed the researcher has access to the following information about the material under consideration:

1. Scope - [This section gives the UNS metal identification number, so that the reader can be sure that he has found the correct material.]
2. Referenced Documents - [This section lists several documents which were used by ASME such as the American Standard for Testing and Materials (ASTM).]
3. Definition of Terms Specific to This Standard - [This section defines terms such as plate, sheet and strip.]
4. General Requirements for Delivery [This section covers the specifications that a material should have in order to be of acceptable quality.]
5. Ordering Information - [This section contains the minimum ordering information that one needs in order to ensure that the material being ordered is the correct material.]
6. Process - [This section states that any special type of melting process must be written on the purchase order.]
7. Heat treatment - [This section states any heat treatment specifications that must be performed.]
8. Chemical Composition - [This section states that an analysis of each melt must be made by the manufacturer to ensure that the chemical composition is within the limits specified in this section.]
9. Mechanical Properties - [This section states the required tensile, bending, and hardness properties that the material must process.]
10. Special Tests - [This section states if any special tests are required to be performed on the material.]
11. Dimensions and Permissible Variations - [This section states that unless otherwise stated on the purchase order the material must conform to the tolerances in this section.]

12. Workmanship, Finish, and Appearance - [This section states that the material should be uniform in appearance and should have quality standards consistent with good inspection and manufacturing processes.]
13. Number of Tests - [This section states the number of tests that must be completed (e.g. Two hardness tests and 1 bending test per coil is required.).]
14. Specimen Preparation - [This section states how to prepare a material specimen for a test.]
15. Test Methods - [This section outlines the methods to be used for the specified tests.]
16. Retreatment - [This section states that if any of the specimens fails to meet any of the requirements it may be reheated and resubmitted for another test.]
17. Inspection - [This section states that any inspection criterion must be agreed to by both the buyer and the seller and written on the purchase order.]
18. Rejection and Reheating - [This section states the time period that a buyer must hold on to any specimen which failed a test and the time in which he must notify the seller.]
19. Material Test Report - [This section states that a report of the results of all test required by this specification must be given to the purchaser.]
20. Certification - [This section states that at the purchasers request, the seller must give the purchaser the producer's certification and testing results.]
21. Product Marking - [This section states the marking requirements that each strip, sheet or plate must have.]

5.3 Contents of ASME Code Volume VIII:

The objective of this section is to separate the sections of the ASME Code, that may be relevant to the waste package container, from the sections that are believed to be irrelevant.

ASME Code vol. VIII consists mainly of part UG (pages 9 - 94) which is entitled "General Requirements for All Methods of Construction and All Materials". "The requirements of part UG are applicable to all pressure vessels and vessel parts and shall be used in conjunction with the specific requirements in Subsections B and C and the Mandatory Appendices that pertain to the method

of fabrication and the material used" [vol. VIII, p.13]. The remainder of the volume (pages 95 - 805) consists of supporting tables, appendices, and indices for part UG.

5.4 Subsections of ASME vol. VIII (Part UG) Which May Be Applicable to the Hazardous Waste Container

The following sections are likely to be applicable to the preliminary designs.

A. MATERIALS:

1. UG-5 Plate Requirements:

This section requires that all plates, sheets, and strips conform to the allowable stress requirements in Section II unless they are exempted by the named sections.

2. UG-6 Forgings:

This section states specifications and maximum allowable stress value for forged construction of a pressure vessel.

3. UG-7 Castings:

This section states the specifications and maximum allowable stress values for casting material to be used in the construction of pressure vessels.

4. UG-9 Welding Materials:

This section states detailed requirements and specifications concerning welded materials to be used in the construction of pressure vessels.

5. UG-10 Material Identified With or Produced to a Specification Not Permitted by This Division, and Material Not Fully Identified:

This section covers the requirements that a material, which has not been fully identified, must satisfy.

6. UG-11 Miscellaneous Pressure Parts:

This section states the specifications that prefabricated or preformed pressure parts must comply with.

7. UG-15 Product Specification:

This section states the conditions under which a material, without an ASME specification, can be used in the construction of a pressure vessel.

B. DESIGN:**1. UG-16 General:**

This Section states the general design requirements that pressure vessels and pressure vessel parts must conform with, in order for the code to be applied to them.

2. UG-17 Methods of Fabrication in Combination:

Section states the requirements and limitations that a pressure vessel, constructed by a combination of methods of fabrication, will mandate.

3. UG-18 Materials in Combination:

This section state the conditions under which a pressure vessel may be constructed of any combination of ASME approved materials (including the requirements for welding dissimilar metals).

4. UG-20 Design Temperature:

This section states a method for determining the maximum design temperature and the minimum design temperature of a pressure vessel. (e.g. The maximum design temperature shall not be less than the mean metal temperature (through the thickness).) "Design temperatures listed in excess of the maximum temperatures listed in the tables of Subsection C are not permitted." [14]

5. UG-21 Design Pressure:

This section states that the maximum pressure differences and maximum temperature encountered must be considered in the design process and states how to calculate the design pressure.

6. UG-22 Loadings:

This section states some of the loads that a pressure vessel designer must consider in his or her design (e.g. weight of vessel and contents, internal and external pressures, cyclic and dynamic reactions due to pressure or thermal variations, seismic reactions, temperature gradients and differential thermal expansion, etc.).

7. UG-23 Maximum Allowable Stress Values:

This section states the maximum allowable tensile stress and the maximum allowable longitudinal compressive stress values in spherical and cylindrical pressure vessels.

8. UG-24 Castings:
This section states the quality factors, the examination and testing specifications, acceptable defects, and identification and markings specifications that must be followed for castings to be used in pressure vessel construction.
9. UG-25 Corrosion:
This section states that the user or his designated agent shall specify corrosion allowances other than those specified by the ASME codes when necessary. The section also states, the corrosion allowance shall be added to the thickness calculated by the design formulas or by using some other suitable means of environment protection.
10. UG-26 Linings:
This section states that linings in the pressure vessel shall contribute to the strength of the wall unless the lining material is exempted by Part UCL (appendix F).
11. UG-27 Thickness of Shells Under Internal Pressure:
This section gives design formulas that may be used to calculate acceptable container wall thicknesses, circumferential stress, and longitudinal stress values for both spherical and cylindrical pressure vessels which undergo internal pressure loadings.
12. UG-28 Thickness of Shells and Tubes Under External Pressure:
This section states design formulas which will yield the acceptable wall thicknesses for a spherical or cylindrical pressure vessel which exposed to pressure external to its shell.
13. UG-32 Formed Heads, Pressure on Concave Side:
This section states design formulas which will yield the required thickness of heads, with pressure on the concave side after the forming process is complete (including the following shapes: ellipsoidal, torispherical, hemispherical, and toriconical).
14. UG-33 Formed Heads, Pressure on Convex Side:
This section states design formulas which will yield the required thickness of heads, with pressure on the convex side after the forming process is complete (including the following shapes: ellipsoidal, torispherical,

hemispherical, and conical).

15. UG-34 Unstayed Flat Heads and Covers:

This section states design formulas which yield the minimum required thicknesses of unstayed flat heads on pressure vessels. The section also contains illustrative examples of some acceptable shapes for flat heads.

C. FABRICATION:

1. UG-75 General:

This section states that the fabrication of pressure vessels and their parts must follow the guidelines in sections UG-76 through UG 85.

2. UG-76 Cutting Plates and Other Stock:

This section states a set of rules that must be followed when one cutting plates or other stock including: edges of heads, ends of nozzles, and exposed inside edges.

3. UG-77 Material Identification:

This section states that one complete set of pressure vessel identification marking shall be visible when the vessel is completely assembled.

4. UG-78 Repair of Defects in Materials:

This section state the conditions under which defects in material may or may not be repaired.

5. UG-79 Formed Shell Sections and Heads:

This section states limitations on the forming processes for shell sections and for heads so that the forming process will not adversely effect the physical properties of the metal (including limits on cold working and rolling processes).

6. UG-80 Permissible Out-of-Roundness of Cylindrical, Conical, and Spherical Shells:

This section provides design formulas which will yield the permissible out-of-roundness for internal and external pressures.

7. UG-81 Tolerance for Formed Heads:

This section states the maximum allowable deviation from design shape that is permissible in formed heads (includes: torispherical, toriconical, hemispherical, ellipsoidal heads).

8. UG-82 Lugs an Fitting Attachments:

This section states that all lugs, fittings, and attachments shall conform reasonably to the

curvature of the shell to which they are attached.

9. UG-83 Holes for Screw Stays:
This section states the depth, plate, and thread requirement for screw stays.
10. UG-84 Charpy Impact Tests:
This section states that all pressure vessels and all pressure vessel part which are subject to stress (induced by pressure) must undergo Charpy impact tests according to the procedures outlined in this section, if they are required to undergo impact tests by the rules in Subsection C.
11. UG-85 Heat Treatment:
This section states that if the plate specification heat treatments are not performed by the material manufacturer, they must follow the rules of this section.

D. INSPECTION AND TESTS:

1. UG-90 General:
This section states that all pressure vessels which required a "U" or a "UM" pressure vessel marking must conform to the general requirements of this section in addition to the specific requirements for "Inspections and Tests" given in subsections B and C.
2. UG-91 The Inspector:
This section defines the qualifications that an inspector must have as required by ASME.
3. UG-92 Access for Inspector:
This section explains the access that the inspector must have to the plant and all areas related to the manufacturing of the pressure vessel and its parts.
4. UG-93 Inspection of Materials:
This section states the minimum requirements for the acceptance of materials furnished by the material manufacturer.
5. UG-94 Marking on Materials:
This section states that the inspector is required to ensure that all materials which are required to be code-marked are so marked.
6. UG-95 Examination of Surfaces During Fabrication:
This section states that all surface imperfections that have been uncovered during the manufacturing

process must be inspected and the parts themselves must be inspected to ensure that the fabrication was performed properly.

7. UG-96 Dimensional Check of Component Parts:
This section states that the manufacturer must measure all manufactured pressure containing parts to ensure that they are still within specifications.
8. UG-97 Inspection During Fabrication:
This section states that a final inspection of the pressure vessel must be made (as completely as possible) just before the vessel undergoes final closure.
9. UG-98 Maximum Allowable Working Pressure:
This section state a procedure for determining the maximum allowable working pressure that a vessel may be subjected to.
10. UG-99 Standard Hydrostatic Test:
This section states that all completed vessels (unless exempted by this section) must undergo a hydrostatic test according to the procedures outlined in this section.
11. UG-100 Pneumatic Test (see UW-50):
This section states the conditions under which a pneumatic test may be performed instead of the hydrostatic test prescribed in UG-99.
12. UG-101 Proof Tests to establish Maximum Allowable Working Pressure:
This section states the conditions under which a testing is required to verify that the maximum allowable working pressure is acceptable.
13. UG-102 Test Gages:
This section states that a pressure gauge shall be installed on the pressure vessel during the test procedure such that the operator can see the gage at all times.
14. UG-103 Nondestructive Testing:
This section states that magnetic particle division and liquid penetrant examination tests must be performed (when required) under the provisions in appendix 6 and appendix 8, respectively.

E. MARKINGS AND REPORTS

1. UG-115 General:
This section requires that all pressure vessels built under the ASME codes are to be marked and reported on under the requirements in this section.
2. UG-116 Required Marking:
This section states the code-symbols that all pressure vessels must be marked with.
3. UG-117 Methods of Marking:
This section states that the required markings shall be "stamped directly the vessel as provided in UG-118 and UG-119.
4. UG-118 Stamping:
This section states the specifications that the stamped-marking on pressure vessels must meet.
5. UG-119 Nameplates:
This section states when nameplates may be substituted for direct stamping and the specifications that the nameplates must follow.
6. UG-120 Data Reports:
This section states that a data report shall be filled out (on the appropriate form) for each pressure vessel marked with the code "U" symbol.

5.5 Subsections of ASME vol. VIII (Part UG) Which May Not Be Applicable to the Hazardous Waste Container

The following sections are not likely to be applicable to the preliminary designs.

F. MATERIALS - [As of the date of this report, the preliminary waste package designs do not have any pipes, tubes, bolts, washers, rods or bars.]

1. UG-2 through UG-4 do not exist.
2. UG-8 Pipes and Tubes
3. UG-12 Bolts and Studs
4. UG-13 Nuts and Washers
5. UG-14 Rods and Bars

G. DESIGN - [The use of stiffening rings or other types of enclosures has not been mentioned in any of the preliminary designs to the best of the authors' knowledge.]

1. UG-19 Special Constructions

2. UG-29 Stiffening Rings for Cylindrical Shells Under External Pressure
3. UG-30 Attachment of Stiffening Rings
4. UG-31 Tubes, and Pipe When Used as Tubes or Shells
5. UG-35 Other Types of Closures

H. OPENINGS AND REINFORCEMENTS - [As of the date of this report, there has been no mention of permanent openings in any of the preliminary designs.]

1. UG-36 Openings in Pressure Vessels
2. UG-37 Reinforcement Required for Openings in Shells and Formed Heads
3. UG-38 Flued Openings in Shells and Formed Heads
4. UG-39 Reinforcement Required for Openings in Flat Heads
5. UG-40 Limits of Reinforcement
6. UG-41 Strength of Reinforcement
7. UG-42 Reinforcement of Multiple Openings
8. UG-43 Methods of Attachment of Pipe and Nozzle Necks to Vessel Walls
9. UG-44 Flanges and Pipe Fittings
10. UG-45 Nozzle Neck Thickness
11. UG-46 Inspection Openings

I. BRACED AND STAYED SURFACES - [As of the date of this report, braced or stayed surfaces have not been formally introduced into any of the preliminary designs.]

1. UG-47 Braced and Stayed Surfaces
2. UG-48 Staybolts
3. UG-49 Location of Staybolts
4. UG-50 Dimensions of Staybolts
5. UG-51 and UG-52 do not exist.

J. LIGAMENTS - [As of the date of this report, ligaments and supports have not been formally presented in any of the preliminary designs.]

1. UG-53 Ligaments
2. UG-54 Supports
3. UG-55 Lugs for Platforms, Ladders and Other Attachments to Vessel Walls
4. UG-56 through UG-74 do not exist.

K. PRESSURE RELIEF DEVICES - [Pressure relief devices have
(for obvious leakage
considerations) never been
considered.]

1. UG-125 General
2. UG-126 Pressure Relief Valves
3. UG-127 Nonreclosing Pressure Relief Devices
4. UG-128 Liquid Relief Valves
5. UG-129 Marking
6. UG-130 Use of Code Symbol Stamp
7. UG-131 Certification of Capacity of Pressure Relief
Devices
8. UG-132 Certification of Capacity of Safety and
Safety Relief Valves in Combination With
Nonreclosing Pressure Relief Devices
9. UG-133 Determination of Pressure Relieving
Requirements
10. UG-134 Pressure Setting of Pressure Relief Devices
11. UG-135 Installation
12. UG-136 Minimum Requirements for Pressure Relief
Valves

6. APPLICATION OF THE ASME PRESSURE VESSEL CODE TO THE PRELIMINARY DESIGN OF THE NUCLEAR WASTE CONTAINER

Introduction:

Although the final design of the nuclear waste container has not been decided, several preliminary designs are available [1, 2, 3, 5, and 16]. The most complete of these preliminary designs is found in paper [16]. The following analysis is of generic nature and may be applied to any final design.

6.1 Identification of the Nuclear Waste Container Candidate Materials in ASME Code Volume II

We began our search in ASME Code - volume II, by attempting to locate each of the six candidate materials. The chemical composition of these materials is listed in [1]. Refer to Section 5.2 of this document for the method of identifying a material in ASME Code, Volume II.

1. AISI-304L was found under the UNS designation S30403 on page 265.
2. AISI-316L was found under the UNS designation S31603 on page 265.
3. Inco'loy-825 was found under the UNS designation N08825 on page 405.1.
4. CDA-102 was not found, so we substituted CDA-102 by UNS designation C11000 which is 99.90 % pure copper. The differences between the specified material (CDA-102) and the ASME identified material is listed in Table 6.1.1, at the end of section 6.1.
5. CDA-613 was not found. CDA-614 is the ASME code listed material with the nearest chemical composition to CDA-613. CDA-614 was found under UNS designation C61400 on page 179. The chemical compositions of the specified CDA-613 and ASME identified CDA-614 are listed in table 6.1.2, at the end of section 6.1.

6. CDA- 715 was found under the UNS designation C71500 on page 179.

TABLE 6.1.1
DOE SPECIFIED CONTENT FOR COPPER
Vs. ASME IDENTIFIED MATERIAL

MATERIAL	SPECIFIED CONTENT % (CDA-102)	ASME CONTENT % (UNS-C11000)
Copper	99.95	99.90
Oxygen	0.0	(not listed)

TABLE 6.1.2
DOE SPECIFIED CDA-613 Vs. THE MOST
SIMILAR ASME IDENTIFIED MATERIAL (CDA-614)

MATERIAL	SPECIFIED CONTENT % (CDA-613)	ASME CONTENT % (CDA-614)
Iron	3.5 (max)	1.5-3.5
Lead	0.0	0.01 (max)
Tin	0.2-0.5	0.0
Aluminum	6.0-8.0	6.0-8.0
Manganese	0.5 (max)	1.0 (max)
Nickel	0.5 (max)	0.0
Zinc	0.0	0.20 (max)
Phosphorus	0.0	0.015 (max)
Copper (pure)	92.7 (nom) (pure)	remainder (incl. silver)

6.2 Case Study: Evaluation of Preliminary Waste Container Design

6.2.1 Objective

The following section consists of using the specified preliminary design [16] and the candidate materials to ensure that the design parameters comply with these widely accepted safety standards.

6.2.2 Design Temperature for Waste Container

The temperature is expected to rise considerably during the first few years of nuclear material storage. The magnitude of this temperature rise will depend upon the particular fuel that is used and the amount of time that the fuel has been in temporary storage before it is deposited into permanent storage. In [6], LLNL provided extensive information about the temperature rise of stored fuel over time. Figure 6.2, (reprinted from figure 15, [6] on page 38), is used in this study to determine the temperature rise of the stored spent fuel. Each of the candidate materials, or its closest match (as explained in section 6.1 of this report), is listed in the ASME codes Vol. XIII subsection C (tables UNF-23.2, UNF-23.3, and UHA-23). These tables list the maximum allowable stress values in tension (over the acceptable design temperature range) for their respective metals. Table 6.2.1, at the end of section 6.2, lists the candidate materials (or their closest match) and the maximum allowable design temperature for that material.

In subsection UG-20 - Design Temperature, it is specified that an operating temperature higher than those listed in the tables of subsection C, for a specific material, is not permitted. Studying Table 6.2, it is clear that both CDA-102 (pure copper) and CDA-614 (Aluminum-Bronze) are not permitted by the ASME pressure vessel and boiler code. To change this recommendation, one or more of the following factors has to be changed.

1. spent fuel rods temperature at the time of loading into waste container and the number of rods loaded into each container.
2. waste container wall-thickness (see note 3 of 6.2.2)
3. waste container material grade

6.2.3 Corrosion

The ASME Pressure Vessel Codes require that a corrosion allowance be calculated for a container over its useful life. This corrosion allowance is to be subtracted from the nominal thickness prior to any calculations (wall-thickness, pressure, etc.). However, the codes also specify (in UG-25) that the designer can perform subsequent calculations (wall-thickness, pressure, etc.) if he/she specifies that these calculations have been performed without the necessary corrosion thickness

Figure 6.2 "Temperature histories of waste package components and host rock for horizontally emplaced preconsoildated (boxed) PWR spent fuel (case 22)." (reprinted from [6], page 38)

TABLE 6.2.2
DESIGN TEMPERATURE AND STRESS OF CANDIDATE MATERIALS

MATERIAL	MAXIMUM ALLOWABLE DESIGN TEMPERATURE (F):	MAXIMUM ALLOWABLE STRESS AT THIS TEMPERATURE (ksi):
AISI 304L (ASME = SA-240)	850	9.4
AISI 316L (ASME = SA-240)	850	9.4
Incoloy 825 (ASME = SB-424)	1000	16.6
CDA 102 (ASME = SB-11)	400	3.0
CDA 613 (CDA 614) (ASME = SB-169)	500	16.5
CDA 715 (ASME = SB-402)	600	6.0

Notes:

1. The maximum design temperature is 505 degrees F.
2. For several of the above materials, the design temperatures and strength may depend on the thickness, product form, or grade. In the above table, the values were listed for 3/8" thick plate. Where two strength values were listed in the ASME codes, the lowest strength value of the corresponding material was chosen.
3. It is noted that the maximum allowable strength remains the same or decreases as the plate thickness increases.

allowance.

The most extensive study of expected corrosion rates on the six candidate materials for waste containers is in paper [11]. In this study, overall corrosion in various environments ranging from arid desert regions to sea water were conducted. These environments represent the best and the worst case scenarios, respectively. However, [11] is a short term study (1 to 30 years) and it usually supplies only one or two data points for each corrosion case. The authors feel that it is inappropriate to extrapolate any useful long-range (on the order of 300-1000 years) results from such limited data. Thus, the authors have chosen to perform subsequent calculations (wall-thickness, allowable pressures, etc.) without including corrosion allowance effects, until more extensive corrosion data is available.

The following calculations are based on linear extrapolation of the data results from the sea water case, [11]. The calculations in the remainder of this section are to provide the reader with possible material losses due to corrosion, based on linear extrapolation of the [11] results. The results of these extrapolations are shown in 300, and 1000 year time periods.

NOTE: THE REMAINDER OF THE CALCULATIONS IN THIS REPORT DO NOT INCLUDE THE MANDATORY CORROSION ALLOWANCE THAT IS REQUIRED BY THE ASME PRESSURE VESSEL AND BOILER CODES, DUE TO LACK OF CORROSION DATA OVER AN EXTENDED TIME PERIOD. THEREFORE, THESE CALCULATIONS WILL BE VALID UNDER ASME RULES AS SOON AS THE CORROSION ALLOWANCE IS INCLUDED IN THEM.

TABLE 6.2.3
CALCULATION INDEX FOR THE SIX CANDIDATE
MATERIALS AS USED IN VARIOUS MATHCAD DOCUMENTS
(THROUGHOUT SECTION 6 OF THIS REPORT)

MATERIAL INDEX	NUCLEAR WASTE CONTAINER CANDIDATE MATERIALS
0	AISI-304L: Chromium-Nickel stainless steel.
1	AISI-316L: Chromium-Nickel stainless steel.
2	Incoloy-825: Nickel-Iron-Chromium-Molybdenum-Copper alloy.
3	CDA-102: 99.95% pure copper.
4	CDA-613: Aluminum-Bronze alloy.
5	CDA-715: Copper-Nickel alloy.

PRELIMINARY CORROSION RATES FOR THE SIX CANDIDATE MATERIALS
 (based on "Survey of Degradation Modes of Candidate Materials
 for High-Level Radioactive-Waste Disposal Containers -
 volume 2 Oxidation and Corrosion, LLNL, [11])

ARID CORROSION RATES
 (ATMOSPHERIC)

time(t): t := 300 years
 T := 1000 years
 k := 39.37 inches/meter
 (k is a conversion factor
 to get inches from meters)

i := 0 ..5 material index, see table 6.2.3

	cr :=
	i
304L	0.025
316L	0.025
825	0.025
102	0.2
614	0.2
715	0.2
	(μm/yr)

The following possible corrosion rates are based on linear extrapolation for 300 and 1000 years respectively.

$$ec300_i := \frac{t \cdot cr_i \cdot k}{\frac{6}{10}} \quad \text{inches}$$

$$ec1000_i := \frac{T \cdot cr_i \cdot k}{\frac{6}{10}} \quad \text{inches}$$

CANDIDATE MATERIALS RESULTS FOR ARID ATMOSPHERIC CORROSION

material:	expected corrosion rate	expected corrosion penetration depth after 300 years	expected corrosion penetration depth after 1,000 years
	cr i	ec300 i	ec1000 i
304L	0.025	0.0003	0.001
316L	0.025	0.0003	0.001
825	0.025	0.0003	0.001
102	0.2	0.0024	0.0079
614	0.2	0.0024	0.0079
715	0.2	0.0024	0.0079
	($\mu\text{m}/\text{yr}$)	(inch)	(inch)

$$\frac{3}{8} - 0.0079 = 0.367 \text{ inch}$$

The original thickness minus the deepest corrosion related penetration.

$$\frac{0.367}{0.375} \cdot 100 = 97.867$$

Thus, most severe corrosion penetration occurs in the copper-based materials. Yet, almost 98% of the original material is still present.

CONCLUSION: It is clear from the above results that the original thickness of the container, for all the candidate materials, is almost unchanged for arid conditions.

MARINE CORROSION RATES

i := 0 ..5

material index, see table 6.2.3

time(t): t := 300 years
 T := 1000 years
 k := 39.37 inches/meter
 (k is a conversion factor
 to get inches from meters)

	cr :=
	i
304L	36.25
316L	14.99
825	1.01
102	2.29
614	2.5
715	2.5
	($\mu\text{m}/\text{yr}$)

$$\text{ec300}_i := \frac{t \cdot \text{cr}_i \cdot k}{10^6} \quad \text{inches}$$

$$\text{ec1000}_i := \frac{T \cdot \text{cr}_i \cdot k}{10^6} \quad \text{inches}$$

CANDIDATE MATERIALS RESULTS FOR MARINE CORROSION
(UNDER SEA WATER CORROSION)

	expected corrosion rate	expected corrosion penetration depth after 300 years	expected corrosion penetration depth after 1,000 years
material:	cr	ec300	ec1000
	i	i	i
304L	36.25	0.4281	1.4272
316L	14.99	0.177	0.5902
825	1.01	0.0119	0.0398
102	2.29	0.027	0.0902
614	2.5	0.0295	0.0984
715	2.5	0.0295	0.0984
	($\mu\text{m}/\text{yr}$)	(inch)	(inch)

CONCLUSION - The above marine corrosion extrapolations may be interpreted as follows:

1. 300 YEAR CASE - Material 304L is completely corroded. All other materials are corroded to varying degrees.
2. 1000 YEAR CASE - All the candidate material are completely corroded away.

6.2.4 Design Pressure

This section (UG-21) requires that all vessels must at the least be designed for the most severe conditions of pressure and temperature that are to be expected during normal use of the pressure vessel. This section is closely related to UG-27 and UG-28 which deal with vessel wall thickness calculations due to internal and external pressures, respectively.

6.2.5 Design Loadings

This section (UG-22) states the design loading shall include the following considerations:

1. internal and external design pressures
2. the weight of the vessel and its contents
3. the weight of all attached equipment
4. internal and external supports and flanges
5. cyclic and dynamic reactions due to:
 - a. pressure
 - b. thermal variations
 - c. mounted equipment
 - d. mechanical loadings
6. wind, snow, and seismic reactions, where required
7. impact reactions
8. temperature gradients and thermal expansion

Some of the above factors, such as wind and snow loads, clearly do not apply to the nuclear waste container.

Our calculations include only the weight of the container and its contents. The preliminary nature of the nuclear waste canister and the lack of necessary repository environment tests makes the other design considerations difficult or impossible to calculate at this time. The remaining seven loading considerations will have to be considered in the final design process.

The total container load is the sum of part 1 and part 2, and is calculated in part 4. These calculations are done in the following order:

- PART 1 - Load due to container (weight of candidate material per container).
- PART 2 - Load due to 18 consolidated Boiling Water Reactor (BWR) assemblies, [3] (see figure 6.2.6).
- PART 3 - Load due to "fully packed" container, Fig. 6.2.5. This is the worst loading case. Heat generated will likely prohibit any practical use of this case.
- PART 4 - Total load due to packed container

Part 1 consists of calculating the weight of the container when it is empty. For our purposes, the most relevant container dimensions data that we have is a sketch that was used in a cost estimate for a DOE waste storage container cost study [16]. This container is a cylinder which is 187.5 inches tall and 26 inches in diameter. The walls of this container are 0.375 of an inch thick and the flat top and bottom are both 1.50 inches thick.

Figure 6.2.5 Load due to "fully packed" spent nuclear fuel container. The external container wall is $\frac{3}{8}$ " thick. The center compartment will be filled with the fuel assembly hardware from the fuel rods. The compartment dividers are $\frac{1}{8}$ " thick. This configuration was based on the dimensions in figure 6.2.6.

Figure 6.2.6 "Configuration 2 - Eighteen Consolidated BWR Assemblies", (this figure was taken from [3], page 4)

Part 2 is a fuel rod load estimate based on the maximum anticipated fuel rod weight. The maximum anticipated fuel rod weight is 18 consolidated BWR assemblies (Exxon/ANF BWR 7x7 fuel rod assembly), [3] (see figure 6.2.6).

Part 3 is the maximum fuel rod weight possible, assuming that the central hexagon of configuration 2 in paper [3] is left empty of fuel rods (this central hexagon will later include fuel assembly hardware). This calculation is based upon a layout of configuration 2, [3], with the maximum possible number of consolidated fuel rods fit into the container (see figure 6.2.5).

Part 4 is an estimate of the total weight of the container, including: container material, fuel rods, and fuel assembly hardware. This estimate is based on the information in figure 6.2.6 and information on the weight of intact fuel assemblies in [18]. The following list is presented to clarify exactly what this estimate includes:

1. load due to empty container weight, (from part 1)
2. load due to 18 consolidate BWR assemblies, (from part 2)
3. load due estimated fuel assembly hardware, (from part 2)

The final calculation for the total load on each container must also include the weight of the internal dividers which separate the different compartments inside the canister. Due to the preliminary nature of the nuclear waste container, the authors were not able to include such a calculation.

The following is an estimate of the approximate loadings that a spent fuel canister will undergo due to static loading (including: canister weight and fuel rod weight)

PART 1 - LOAD DUE TO CONTAINER (WEIGHT OF CANDIDATE MATERIAL/CONTAINER)

i := 0 ..5 material index, see table 6.2.3

l := 187.5 inches

d_{outside} := 26.0 inches

t_{plate} := 1.25 top and bottom plate thickness (inches)

volume of end plate:

$$v_{\text{plate}} := \pi \cdot \frac{d_{\text{outside}}^2}{4} \cdot t_{\text{plate}}$$

volume of can:

d_{inside} := 26 - 2 · 0.375

d_{inside} = 25.25

=====inches=

$$v_{\text{can}} := \left[\pi \cdot \frac{d_{\text{outside}}^2}{4} - \pi \cdot \frac{d_{\text{inside}}^2}{4} \right] \cdot [1 - 2 \cdot t_{\text{plate}}]$$

$$v_{\text{total}} := 2 \cdot v_{\text{plate}} + v_{\text{can}}$$

$$v_{\text{total}} = 6.912 \cdot 10^3 \text{ cubic inches}$$

convert units from cubic inches to cubic centimeters:
(cubic inches times 16.387 equals cm³):

$$k := 16.387$$

$$v_{\text{tot}} := v_{\text{total}} \cdot k$$

$$v_{\text{tot}} = 1.133 \cdot 10^5 \text{ cm}^3$$

Densities of materials [d]

	d := i
304L	8.00
316L	8.00
825	8.14
102	8.94
614	7.89
715	8.94

These density values were
obtained from 1988 ASME Codes

$$\text{can load}_i := v_{\text{tot}} \cdot d_i \text{ grams}$$

can load	i
$9.062 \cdot 10^5$	5
$9.062 \cdot 10^5$	5
$9.22 \cdot 10^5$	5
$1.013 \cdot 10^6$	6
$8.937 \cdot 10^5$	5
$1.013 \cdot 10^6$	6
grams	

convert mass (grams) to Newtons
 $([\text{grams}/1000] * 9.81 = \text{Newtons})$:

$$\text{can Newtons}_i := \frac{\text{can load}_i}{1000} \cdot 9.81$$

convert Newtons to pounds (force)
 $(\text{Newtons} / 4.448 = \text{pounds (force)})$:

$$\text{can weight}_i := \frac{\text{can Newtons}_i}{4.448} \quad \text{pounds (force)}$$

These are the respective weights of the respective candidate canisters when they are empty.

304L
 316L
 825
 102
 614
 715

can weight	i
1998.5	
1998.5	
2033.5	
2233.4	
1971.1	
2233.4	
pounds (force)	

PART 2 - LOAD DUE TO PAPER [3]'s 18 CONSOLIDATED BWR ASSEMBLIES

Each Exxon/ANF assembly weighs 619.1 pounds and this configuration is 7 rods X 7 rods.

A) NUMBER OF RODS IN THIS PARTICULAR ASSEMBLY:

$$n := 7 \cdot 7$$

$$n = 49 \quad \text{rods/assembly}$$

B) WEIGHT/ROD OF THIS ASSEMBLY:

$$W := 619.1 \quad \text{lbf, for an entire 7 X 7 assembly}$$

$$\begin{array}{rcl} \text{hweight} & & W \\ & := & -- \\ \text{rod} & & n \end{array}$$

$$\text{hweight} = 12.635 \quad \text{lbf, weight/rod}$$

C) NUMBER OF RODS IN 18 CONSOLIDATED BWR ASSEMBLIES

$$\text{numrods} := n \cdot 18$$

$$\text{numrods} = 882 \quad \text{rods in 18 BWR assemblies}$$

D) TOTAL WEIGHT OF 18 CONSOLIDATED BWR ASSEMBLIES

$$\text{BWR18} := \text{numrods} \cdot \text{hweight}$$

$$\text{BWR18} = 11143.8 \quad \text{lbf}$$

PART 3 - LOAD DUE TO FULLY PACKED CASE, Fig. 6.2.5

$l := 187.5$ The height of the canister in inches

$d_{rod} := 0.562$ The diameter of the fuel rods in inches

A) MAXIMUM POSSIBLE NUMBER OF FUEL RODS PER CONTAINER:

$numrods := 1308$ based on computer drawing

B) TOTAL WEIGHT OF PACKED AUTOCAD DRAWING

$numrods = 1308$

$hweight_{rod} = 12.635$ lbf/rod

$packed_{weight} := numrods \cdot hweight_{rod}$

$packed_{weight} = 16526.18$ lbf/packed container

PART 4 - TOTAL LOAD OF CONTAINER LOADED WITH FUEL RODS AND
FUEL ROD ASSEMBLIES

load := can + BWR18
total weight
i i

load
total
i

These are the load totals for
each respective candidate
canister (loaded with eighteen
"Exxon/ANF BWR 7 X 7"
consolidated fuel rods assemblies).

304L	13142.3
316L	13142.3
825	13177.3
102	13377.2
614	13114.9
715	13377.2

6.2.6 Calculations of Nuclear Waste Container Shell Stresses

The container design that we are analyzing is divided into three parts: a flat top plate, a hollow circular cylinder, and a flat bottom (see figure 6.2.7). The container's pintle is not considered in this study. The analyses in this section apply to the shell (hollow cylinder) portion of the nuclear waste container, as formatted in the codes. The head and bottom of the container will be analyzed in section 6.2.7 below. The ASME codes provide separate design formulas for various head shapes e.g., spherical, ellipsoidal, etc..

6.2.6.1 Maximum Allowable Stress Values

This section (UG-23) contains the rules under which the maximum allowable stress value for a particular container material shall be determined using the ASME codes. These calculations are basic in nature due to the preliminary status of the nuclear waste container design. They are based primarily on the dimensions of the container, the candidate materials strength at the maximum expected temperature, [14] as listed in table 6.2.2 in ASME code volume VIII tables UCS-23 through UHT-23, and the design formulas in section UG-23 of Volume VIII. The final stress calculations must take into account any additional factors which may increase the container stresses.

Figure 6.2.7 Preliminary Spent Nuclear Fuel Container Design, based on [16]. (Note: We were forced to use this simplified design for calculation purposes--due to the lack of detailed dimensional information about the exact curvatures of the top and bottom heads of the container.)

MAXIMUM ALLOWABLE STRESS VALUES - UG-23(b)
 (as applied to a pressure vessel according to 1988 ASME CODE)

" The maximum allowable longitudinal compressive stress to be used in the design of cylindrical shells or tubes, either seamless or butt welded, subjected to loadings that produce longitudinal compression in the shell or tube shall be the SMALLER of the following values:" (ASME Codes XIII.20)

- (a) The maximum allowable tensile stress permitted in the applicable tables of Subsection C (UCS-23, UNF-23, UHA-23, UCI-23, UHT-23, ULT-23).
- (b) The value of "B" determined by the following procedure where:

$$A = 0.125 / (R / t)$$

; t is the minimum thickness of the cylindrical shell or tube (in inches) after the corrosion allowance for each respective material has been subtracted.

; R is the outside radius of cylindrical shell or tube (in inches).

; E is the modulus of elasticity of material at design temperature (in psi). The modulus of elasticity to be used shall be taken from the applicable materials chart in Appendix #5.

R := 13 inches (outside radius, according to DOE document #3)

t := $\frac{3}{8}$ inch wall thickness of shell of container

i := 0 ..5 material index, see table 6.2.3

$A_i := \frac{0.125}{R}$		A_i	
	R	304L	0.0036
	-	316L	0.0036
	t	825	0.0036
		102	0.0036
		614	0.0036
		715	0.0036

The above values are used in table 6.2.6.1 to determine maximum allowable tensile and compressive stresses

ALL B VALUES CALCULATED AT 505 DEGREES F.	MAXIMUM ALLOWABLE COMPRESSIVE STRESS (psi) [App. 5]	MAXIMUM ALLOWABLE TENSILE STRESS (psi) [Table C]	MAXIMUM ALLOWABLE LONGITUDINAL COMPRESSIVE STRESS (psi)
SA-240-[by UCS-28.1&2] (520)			
304L - 28.1.....	B = 9,546	10,875	9,546
316L - 28.2.....	B = 12,569	13,265	12,569
SB-424 - by UNF-28.25 (536).	B = 11,028	18,275	11,028
SB-11 - by UNF-28.9 (529). [note 1]		(400 F MAX)	(NOT LISTED)
SB-169 - by UNF-28.14 (532). B = 9,517		(500 F MAX)	(NOT LISTED)
SB-402 - by UNF-28.11 (530). B = 3190		7,900	3,190

NOTE-1: Annealed copper only goes up to 400 degrees F on The ASME Chart.

NOTE-2: All of the above Maximum Allowable Compressive Stress values were calculated using 505 degrees F as the temperature value. No extra safety factor was used in these calculations.

NOTE-3: The Maximum Allowable Tensile Stress Values (tabulated above), reflect the smallest value that was listed in subsection C (of volume XIII). [We have adopted this convention because the table lists many stress values for many DOE candidate compositions.]

	LOWEST STRESS (Appendix 5 or Table C)		MAXIMUM PRIMARY MEMBRANE STRESS	
	$\sigma :=$		$\sigma \cdot 1.2$	
	1		1	
SA-240-				
304L.....	9546	...	11455.2	The general primary membrane stress SHALL NOT EXCEED THE VALUE FOR THE MAXIMUM PRIMARY MEMBRANE STRESS as permitted by UG-23 (a, b, & C).
316L.....	12569	...	15082.8	
SB-424..(825)....	11028	...	13233.6	
SB-11...(102)....	0	...	0	
SB-169...(614)....	0	...	0	
SV-424..(715)....	3190	...	3828	
	(psi)		(psi)	

NOTE: Both 102 and 613 were eliminated by ASME chart
(section C) due to temperature prohibitions, see section 6.2.2.

R	
i	
12.625	
12.625	
12.625	
12.625	
12.625	
12.625	
(inch)	

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(see notes 1 & 2 at the end of this document)	S :=		SA-240 304L 316L SB-424 SB-11 SB-169 SB-402	These values for maximum allowable stress were INTERPOLATED from the Maximum Allowable Tensile Stress Tables of Subsection C (under the temperature of 505 F).
	i	i		
	0	9546		
	1	12569		
	2	11028		
	3	0		
	4	0		
	5	3190		

E := .90 joint efficiency, (assuming that all of the welds are single welded butt joints of type A, B, C, or D according to UW-12 [XIII.100]; and that all of the welds undergo a 100% RADIOGRAPHIC EXAMINATION).

$$P_{cir} := \frac{S \cdot E \cdot t}{R + 0.6 \cdot t}$$

(2) LONGITUDINAL STRESS (Circumferential Joints). When the thickness does not exceed one-half of the inside radius, or P does not exceed (1.25 * S * E), the following formula shall apply:

$$P_{long} := \frac{2 \cdot S \cdot E \cdot t}{R - 0.4 \cdot t}$$

RESULTS OF (1) & (2):

Pcir	Plong	
i	i	
250.7	516.5	SA-240
330.1	680.1	304L
289.6	596.7	316L
0	0	SB-11
0	0	SB-169
83.8	172.6	SB-402
(psi)	(psi)	SB-424

THICKNESS OF SHELLS UNDER INTERNAL PRESSURE - UG-27
 (as applied to a pressure vessel according to 1988 ASME CODE)

"(A) The thickness of shells under internal pressure shall be not less than that computed by the following formulas. In addition, provisions shall be made for any of the other loadings listed in UG-22, when such loadings are expected. (See UG-16)"

(ASME Codes XIII.23)

(B) t = minimum thickness of shell (inches)

P = design pressure, or MAXIMUM ALLOWABLE WORKING PRESSURE (psi)

R = inside radius of the shell course under consideration (inches)

S = maximum allowable stress value, see application table of stress values in Subsection C, and the stress limitation specified in UG-24. (psi)

E = joint efficiency for the appropriate joint, see UW-12 (unitless)

(C) CYLINDRICAL SHELLS. The minimum thickness or maximum allowable working pressure of cylindrical shells shall be the GREATER THICKNESS or LESSER PRESSURE as given (1) or (2) below.

(1) CIRCUMFERENTIAL STRESS (longitudinal joints). When the thickness does not exceed one-half of the inside radius, or P does not exceed $0.385 * S * E$, the following formula applies:

$$P = (2SEt) / (R - 0.4t)$$

$i := 0 \dots 5$ material index, see table 6.2.3

$$t := \frac{3}{8} R_i - t$$

6.2.6.2 Thickness of Shells Under Internal Pressure

This section (UG-27) contains calculations to determine the minimum allowable wall thickness that is required for the worst internal pressure conditions that are expected over the life of the vessel. This is done by comparing the results of:

1. the circumferential membrane stress
2. the longitudinal membrane stress

The minimum thickness (or maximum allowable working pressure of cylindrical shells) shall be the greater thickness (or the lesser pressure), as determined by 1 or 2 above.

Since the circumferential stress is always smaller than the longitudinal stress for a canister made of each respective candidate material, WE MUST USE THE CIRCUMFERENTIAL STRESS CALCULATION TO DETERMINE THE MAXIMUM ALLOWABLE WORKING PRESSURE...

Pcir i	Plong i	
251	517	SA-240
330	680	-304L
290	597	-316L
0	0	SB-11
0	0	SB-169
0	0	SB-402
84	173	SB-424

...THEREFORE, THE MAXIMUM ALLOWABLE WORKING PRESSURE (psi) THAT EACH RESPECTIVE CYLINDRICAL PRESSURE VESSEL CAN ENDURE at 505 degrees F (according to the ASME Pressure Vessel & Boiler Code) is:

Pcir i	
251	304L
330	316L
290	825
0	102
0	614
84	715
(psi)	

NOTE-1 Pure copper (SB-11) and aluminum-bronze (CDA-613) are represented by zero permissible internal pressure because the ASME Codes DO NOT PERMIT THE BUILDING OF A PRESSURE VESSEL WHICH WILL HAVE A DESIGN TEMPERATURE IN EXCESS OF THE TEMPERATURES LISTED IN TABLES OF SUBSECTION C. The maximum temperature listed for SB-11 is only 400 degrees F. The maximum temperature listed for CDA-613 is 500 degrees F, but the vessel is expected to reach 505 degrees F for a period of many years (according to "Nuclear Waste Packages for a Repository in Tuff" (LLL-TB-92, August 1988)).

NOTE-2 It is important to stipulate that the actual permissible maximum internal pressure values may be larger than the values above. Once the exact chemical composition for a candidate material has been chosen, a more accurate calculation is possible and necessary. THE ABOVE VALUE REPRESENT THE WEAKEST THAT A GIVEN CANDIDATE MATERIAL IS LIKELY TO BE.

6.2.6.3 Thickness of Shells and Tubes Under External Pressure

This section (UG-28) contains calculations for determining the minimum allowable wall thickness due to the greatest external pressure that is expected over the life of the vessel. The following calculations follow the format in section C (Cylindrical Shell and Tubes).

THICKNESS OF SHELLS AND TUBES UNDER EXTERNAL PRESSURE -
 UG-2 (as applied to a pressure vessel according to
 1988 ASME CODE)

 "(A) Rules for the design of shells and tubes under external pressure given in this Division are limited to cylindrical shells (with or without stiffening rings), tubes, and spherical shells. Three typical forms for cylindrical shells are shown in Fig. UG-28. Charts used for determining the minimum required thicknesses of these components are given in Appendix #5. (ASME CODE XIII.23)

(C) CYLINDRICAL SHELLS AND TUBES - The required minimum thickness of a cylindrical shell or tube under external pressure, either seamless or with longitudinal butt joints, shall be determined by the following procedure:

- (1) Cylinders having (outside diameter) / (t) values less than or equal to 10:

STEP-1: Assume a value for t and calculate the following ratios. (L/D & D/t)

D_o := 26 (inches) the outside diameter of the canister

i := 0 ..5 mathematical index

t := $\frac{3}{8}$

L := 187.5 (inches) the assumed height for the canister
 (DOE Document #3 page 5).

$$\frac{L}{D_o} = 7.212$$

$$\left[\frac{D_o}{t} \right] = 69.333$$

STEP-2 & 3: Use fig. 5-UGO-28.0 A := .0036
 (ASME, Vol. VIII, Appendix 5) i
 to determine value for the
 "A factor."

STEP-4 & 5: Using the value of A from step 3, enter the
 applicable materials chart in appendix 5 and find the
 corresponding value of B.

MATERIAL	B VALUE
-----	-----
304L	9,546
316L	12,569
825	11028
102	N/A
614	N/A (note AA)
715	3,190

NOTE AA: Although a "B" value for 613 can be taken off of the
 appropriate materials chart, this value may not be used because the
 maximum allowable design temperature for 613 is 500 degrees fahrenheit.

Step-6: Using this value of B, calculate the value of the maximum
 allowable external pressure (P_{sub_A}) using the following formula:

$$P_a = \frac{4 \cdot B}{3 \cdot \left[\frac{D}{t} \right]}$$

B :=
i
9546
12569
11028
0
0
3190

THIS IS THE CALCULATED VALUE
 OF THE ALLOWABLE EXTERNAL
 WORKING PRESSURE FOR THE WALL-
 THICKNESS OF 3/8 OF AN INCH.

P _a
i
183.577
241.712
212.077
0
0
61.346
(psi)

CONCLUSION:

These are the calculated values for the ASME ALLOWABLE EXTERNAL WORKING PRESSURE for each respective candidate material. These values were calculated without a corrosion allowance which is required for the final design calculation.

P	
a	i
184	304L
242	316L
212	825
0	102
0	614
61	715
(psi)	

6.2.7 Unstayed Flatheads and Covers

This section (UG-34) contains calculations which are used to determine the minimum required thickness for unstayed flat heads, cover plates and blind flanges. These requirements apply to both circular and noncircular heads and covers. Some acceptable types of flat heads and covers are shown in ASME volume VIII, page 37.

UNSTAYED FLAT HEADS AND COVERS - UG-34 (as applied to
a pressure vessel according to 1988 ASME CODE)

"(a) The minimum thickness of unstayed flat heads, cover plates and blind flanges shall conform to the requirements given in this paragraph. These requirements apply to both circular and noncircular heads and covers. Some acceptable types of flat heads and covers are shown in Fig. UG-34. In this figure, the dimensions of the component parts and the dimensions of the welds are exclusive of extrametal required for corrosion allowance."

(ASME CODE 1988)

(b) The symbols used in this paragraph and in Fig. UG-34 are defined as follows:

;C = a factor depending upon the method of attachment of head, shell dimensions, and other items as listed in (d) below, (dimensionless). The factors for welded covers also include a factor of 0.667 which effectively increases the allowable stress for such constructions to $1.5 * S$.

;d = diameter, or short span, measured as indicated in Fig. UG-34 (inches)

;E = joint efficiency, from Table UW-12, of any Category A weld as defined in UW-3(a)(1).

;m = the ratio of $(t_{\text{sub } r}) / (t_{\text{sub } s})$, dimensionless

;P = The design pressure [see 3-1(b)] (ps.).

;S = maximum allowable stress value, psi, from applicable table of stress values in Subsection C.

;t = the minimum required of flat head or cover, (inches).

;(t sub r) = the required thickness of seamless shell.

;(t sub s) = the actual thickness of shell in inches.

- (c) The thickness of flat unstayed heads, covers, and blind flanges shall conform to one of the following three requirements:

(1) We will not use this method at the present time.

(2) The minimum required thickness of flat unstayed circular heads, covers and blind flanges shall be calculated by the following formula:

$$t = d * \sqrt{C \cdot P / S \cdot E} \quad \text{therefore} \quad P = \frac{(S \cdot E \cdot t^2)}{(C \cdot d^2)}$$

i := 0 ..5 material index, see table 6.2.3

	S :=	E := 0.90	t := 1.25 inches
	i		
304L	9546		d := 26 inches
316L	12569		
825	11028		
102	0	C := 0.20	
614	0	min	
715	3190		
	(psi)		

$$P_i := \frac{S_i \cdot E \cdot t^2}{C_{\min} \cdot d^2}$$

Therefore the maximum allowable pressure [internal] on the flat head of the pressure vessel (if the head thickness is 1.25 inches), for each respective candidate material is shown to the right.

	P
	i
304L	99.3
316L	130.7
825	114.7
102	0
614	0
715	33.2
	(psi)

7. CONCLUSIONS AND RECOMMENDATIONS (for PARTS A & B of this report)

The ASME Pressure Vessel and Boiler Code is relevant to the design process of the spent nuclear fuel containers, for the Waste Package Project. See sections 5.1 through 5.4 to understand the enormous potential of the codes (i.e. the codes cover many procedures from ordering information about materials to final inspections of the finished product).

Unless the spent fuel rod temperature, at the time of final storage container closure, is lower than (and will remain lower than) the temperature indicated in [6] (see figure 6.2), the use of UNS C11000, pure copper, (almost identical to CDA-102, see table 6.1.1) is not recommended. The temperature stated in [6] is approximately 263 degrees celsius which is 505 degrees fahrenheit. The ASME codes do not permit the use of pure copper (CDA-102) above 400 degrees fahrenheit. Similarly, the CDA 613, Aluminum-Bronze alloy, (almost identical to CDA 614, see table 6.1.2) is not permitted by the ASME codes above temperatures of 500 degrees fahrenheit. Although this is only a five degree temperature infraction in the CDA-614 case, the possibility of this infraction lasting on the order of twenty years or more, makes this temperature infraction a major design concern.

All of the ASME pressure vessel calculations herein were performed without subtracting the corrosion allowance of material from the nominal thickness of the container over its design-life. The authors feel that more long term corrosion research must be conducted before a reliable corrosion allowance can be calculated. An area of special concern is the study of localized corrosion on each candidate material.

For the portion of the design that was completed in section 6 of this report, the current 3/8" shell thickness appears to ensure shell integrity (except where noted above) under normal circumstances which are expected at the permanent storage site at Yucca Mountain. A flat headed design will not be an efficient design because this design will use far more material to obtain stress levels which are easily obtained (with far less material) using curved heads.

Our study of the current preliminary design using the six candidate materials suggests that the best candidate materials, with no special preference to either, to use in the nuclear waste

containers construction are:

1. Nickel-Iron-Chromium-Molybdenum-Copper Alloy also known as Incoloy-825
2. Copper-Nickel alloy also known as CDA-715.

These materials were chosen due to their superior properties (within the scope of this document) in the following areas:

1. heat resistance
2. strength

The authors feel that there should be further research in optimal head shapes for the permanent nuclear waste storage containers.

Nuclear waste containers are a borderline design case between nuclear and non-nuclear considerations due to the relatively low level of nuclear activities. The calculations presented here are based on Volume VIII, Section UG, formulae for pressure vessels. Future comparison with Volume V, nuclear power plant components, is recommended. .

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ABSTRACT
(for Part C)

A library search was conducted for statistical data on failure rates in low temperature piping, casks with long design lives, and storage containers. Relevant articles are summarized and /or cited in the bibliography. This search demonstrated that, despite the enormous literature on the mechanics of failure, on the statistical analysis of failures, and on case studies of failures, little information is available on actual failure rates of pipes and containers not operated in extreme conditions.

PART C:**LIBRARY SEARCH FOR RELIABILITY SEARCH FOR
RELIABILITY/FAILURE RATES DATA ON LOW TEMPERATURE
LOW PRESSURE PIPING, CONTAINERS, AND CASKS WITH
LONG DESIGN LIVES**

Under this task a library search was conducted for information on failure rates in low temperature piping and containers. Hand searches of certain key journals such as the A.S.M.E. Journal of Pressure Vessel Technology, A.S.M.E. Journal of Heat and Mass Transfer, and the A.S.C.E. Journal of Pipelines, were initially conducted. The Engineering Index was also searched by hand. Computer searches of the NTIS database and of the Engineering Index using a variety of key words were then conducted back about 15 years. The attempt was made to find any studies relating to failure rates in storage tanks, piping of all types, boilers, and pressure vessels. Any titles which appeared to be relevant were then gathered and examined. Finally, a computer search of the Science Citation Index was conducted to locate any additional works which cited the works or authors which were identified in the previous searches. The librarian for the engineering collections at the Library of the University of Nevada, Las Vegas assisted in this process and suggested possible relevant databases and appropriate search techniques. Although the search was quite thorough and extensive, was professionally guided, and examined all of the relevant databases, the result of this search process were quite meager. Those publications which were found are summarized in the following. As a result of this information search, some general observations can be made. There is an enormous literature on the mechanics of failure. Specific case studies also abound. Using the abundance of works on a particular topic as an indicator, it appears that problem areas and prime causes of failures are:

- stress corrosion cracking
- welds
- corrosion
- thermal fatigue
- mechanical fatigue
- manufacturing defects
- seismic effects
- foundation problems such as differential settling (for large storage tanks)

- vibration failure
- load failure

Of these, the three most important appear to be failure of welded joints, corrosion, and thermal fatigue.

Likewise, a vast literature exists on the techniques of probabilistic risk analysis. Actual data on failures exist only within the nuclear industry and with respect to boilers and pressure vessels. No data on low pressure storage tanks or piping such as water supply piping could be located. If such data exists it is probably proprietary data within the insurance industry. One of the better sources of statistical information is contained in papers by Bush [1,2] which presents broad overviews of failure statistics for both pressure vessels and piping. Although the focus of these papers is on safety issues related to nuclear power generation, the information and results in these papers has a wider application. The pressure vessel data upon which these analyses are based come from the United States [3,4], the United Kingdom [5,6,7], and the Federal Republic of Germany [8,9,10]. The piping data contained in the Bush paper is entirely for nuclear systems as are some of the pressure vessel data. A number of conclusions are derived from this data in this paper and which are listed as follows:

1. The failure probabilities for larger sizes of nuclear piping are considered to be in the range of 10^{-4} to 10^{-6} per reactor year (exclusive of IGSCC).
2. Smaller pipe sizes of lesser safety significance have much higher failure rates.
3. In BWRs, IGSCC can cause failure rates much higher than 10^{-4} (e.g. 10^{-2}) in piping 4 to 10 in. in size.
4. Suggested failure mechanisms apply in most instances, exclusive of IGSCC.
5. Catastrophic failures would appear more likely from operator error or design and construction errors (water hammer, improper handling of dynamic loads, and undetected fabrication defects) rather than conventional flaw initiation and growth or fatigue. Weld metal and weld affected material are the most likely sites for failure initiation. Experience shows that this type of event is more likely to occur in areas of complex geometry such as nozzles where volumetric inspection is at best difficult and often impossible.
6. Research into the effects of thickness either by experiment or by a further breakdown of data should be undertaken by organizations processing relevant data.

7. Evidence seems to suggest that all industrialized countries encounter similar service experience from conventional plants but process their experience differently for the purposes of deriving failure statistics.
8. Inservice inspection tends to restore probability figures to those assessed at the beginning of the inspection interval.
9. Data gathered by the various reporters are always retrospective. Caution should be exercised when applying the results or conclusions to a new plant as there is always difficulty assessing the effects of introducing changes in design, allowable stress levels, materials of construction, new fabrication techniques and requirements.
10. Treatment of data should reflect the nature of the use to which it is to be put and the accuracy with which it is collected.
11. Application of the Sections I and VII A.S.M.E. Pressure Vessel Codes are believed to be responsible for the relatively low incidence of noncritical failures early in life.

A survey paper by Sundararajan [11] is a good source of information on the state of the art in probabilistic assessment of pressure vessel and piping reliability. Methods of assessing reliability directly from historic data and indirectly by a probabilistic analysis are discussed. Various methods of probabilistic reliability assessment are presented and major projects where these methods are applied, for pressure vessel and piping problems, are discussed. No sources of data, other than those already cited, are contained in the references within Part C of this paper. However, this paper includes a very extensive list of references on the techniques and applications of probabilistic risk assessment.

Data for water distribution systems are examined by Cullinane [12]. This paper is an extension of a similar work by Shultz and Parr [13]. In this study, water distribution systems are subdivided into seven basic subsystems: pumps, motors, power transmissions, valves, controls, pipes, and tanks. Reliability, availability, and maintenance data, obtained from [14,15,16,17,18,19,20], for five of these subsystems (i.e. pumps, motors, power transmissions, valves, and controls), are presented. No data was presented on pipes or on storage tanks, although the author was mindful of the need for such data. Apparently, no source of such information could be found.

CONCLUSIONS
(for Part C)

The collection of failure data for piping systems, pressure vessels, and storage containers which are not operated under extreme conditions is an area which has been neglected. Very little information exists in the technical literature. Such data would be very useful in estimating the design lives of wide variety of engineered systems and therefore ought to be accumulated.

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