ENGINEERING DOCUMENT CHANGE CONTROL

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Change Identification

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   - ☐ Supersedure ☐ Cancel/Void ☒ New
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WMP-16938, Revision 0, is a new document that evaluates the characteristics of the capsules stored in WESF pool cells for the Capsule Dry Storage Project.

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WMP-16938, Revision 0, performance criteria were developed to qualify the capsules for dry storage. The criteria include:
1. The acceptance criteria for the structural integrity of the capsules to ensure that the capsules do not fail during normal operational handling when they are placed in the dry storage overpacks.
2. The acceptance criteria for the capsules to ensure that the capsules maintain their structure for safe retrieval from the overpacks after 50 years dry storage if required.

13. Change or Document Description:
WMP-16938, Revision 0, is a new document.

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Document	Page	Revision	Document Title or Comments
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15. Technical Justification (Need):
WMP-16938, Revision 0, is a new document that evaluates the characteristics of the capsules stored in WESF pool cells to ensure that the capsules can be removed from the pool cells, placed in the dry storage overpacks, stored for 50 years, and retrieved safely from the overpacks if needed for permanent disposal.

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WMP-16938
Revision 0

Capsule Characterization Report for Capsule Dry Storage Project

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

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Contractor for the U.S. Department of Energy
Richland Operations Office under Contract DE-AC06-96RL13200

WMP-16938
Revision 0

Capsule Characterization Report for Capsule Dry Storage Project

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September 2003

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

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WMP-16938
Revision 0

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CAPSULE CHARACTERIZATION REPORT FOR CAPSULE DRY STORAGE PROJECT

September 2003

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EXECUTIVE SUMMARY

This report evaluates the characteristics of the capsules stored in the Waste Encapsulation Storage Facility pool cells to ensure that the capsules can be removed from the pool cells, placed in the dry storage overpacks, stored for 50 years, and retrieved safely from the overpacks if needed for permanent disposal.

Performance criteria were developed to qualify the capsules for the dry storage. The criteria include:

1. The acceptance criteria for the structural integrity of the capsules to ensure that the capsules do not fail during normal operational handling when they are placed in the dry storage overpacks.
2. The acceptance criteria for the capsules to ensure that the capsules maintain their structure for safe retrieval from the overpacks after 50 years dry storage if required.

The capsule characteristics were compared with the acceptance criteria. The evaluation of the capsule characteristics showed that:

1. The capsules were built to established standards, and are structurally sound for the overpack operational handling. Weld failures and stress corrosion cracking are not expected but can not be precluded. The capsules are capable of maintaining their structurally integrity in case of operational drops and collisions. To verify the capsule structural integrity, each capsule will be required to pass the Inner Capsule Movement test for gross leakage through the inner and/or outer capsule, and a visual test for gross surface defects.
2. Degradation for the capsule walls due to thermal aging, corrosion, radiation, and other potential degradation processes from the environment in the past had a minimal impact on the structural integrity of the capsules. The environment during 50-year storage is not expected to seriously degrade the capsule structural integrity. The capsules will maintain their integrity during the dry storage and can be retrieved safely if needed.

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^{137}Ba	^{137}barium
^{137m}Ba	^{137}barium metastable
^{90}Y	^{90}Yttrium
^{90}Zr	^{90}zirconium
ARECO	Applied Radiant Energy Corporation
BUSS	Beneficial Uses Shipping System
Cs	cesium
CsCl	cesium chloride
CDSP	Capsule Dry Storage Project
GTAW	gas tungsten arc welding
He	helium
ICM	inner capsule movement
IGA	intergranular attack
NaF	sodium fluoride
$NaNO_3$	sodium nitrate
NRC	Nuclear Regulatory Commission
PNNL	Pacific Northwest National Laboratories
QA	quality assurance
RSI	Radiation Sterilizers, Inc.
Sr	strontium
SrF_2	strontium fluoride
SS	stainless steel
SCC	stress corrosion cracking
UT	ultrasonic testing
VT	visual examination/visual test
WESF	Waste Encapsulation and Storage Facility

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1.0 INTRODUCTION

1.1 BACKGROUND

There are 1,936 cesium (Cs) and strontium (Sr) capsules stored in pool cells at the Waste Encapsulation and Storage Facility (WESF). These capsules will be moved to dry storage on the Hanford Site as an interim measure to reduce risk. The Cs/Sr Capsule Dry Storage Project (CDSP) is conducted under the assumption that the capsules will eventually be moved to the repository at Yucca Mountain, and the design criteria include requirements that will facilitate acceptance at the repository. The storage system must also permit retrieval of capsules in the event that vitrification of the capsule contents is pursued.

1.2 PURPOSE

The purpose of this report is to (1) develop performance criteria for the capsules to ensure that the capsules fall within the design and safety basis prior to being placed into the storage; (2) evaluate the current integrity of the capsules to determine whether they can be safely handled and loaded into dry storage system overpacks; and (3) establish criteria and evaluate the integrity of the capsules at the end of the 50-year dry storage life to assess whether they can be retrieved safely from the overpacks, if required. The evaluations are based on reviews of existing capsule documentation, results of capsule inspections and testing performed at WESF, and corrosion studies assessing current capsule conditions and predicting the extent of future capsule degradation.

1.3 DESCRIPTION OF THE CAPSULES

The cesium chloride (CsCl) and strontium fluoride (SrF_2) capsules are capsule-in-capsule construction with the inner capsule containing the solid radioactive material. Both the inner and outer capsules for the CsCl are made of 316L stainless steel (SS) with welded caps. In the case of SrF_2, the inner capsule is made of Hastelloy[1] C-276 (HNF-16138, *Performance Specification for Capsule Dry Storage Project Design and Fabrication*) and the outer capsule is 316L SS material. Some of the initial SrF_2 capsules were made with Hastelloy C-276 outer capsules.

The Cs capsules are 19.75 in. long and 2.625 in. in diameter. The Sr capsules are 20.1 in. long and 2.625 in. in diameter. Detailed dimensions and materials of construction are provided in WMP-16878, *WESF Capsule Databook*.

[1] Hastelloy is a trademark of Union Carbide and Carbon Corporation Corporation, New York, New York.

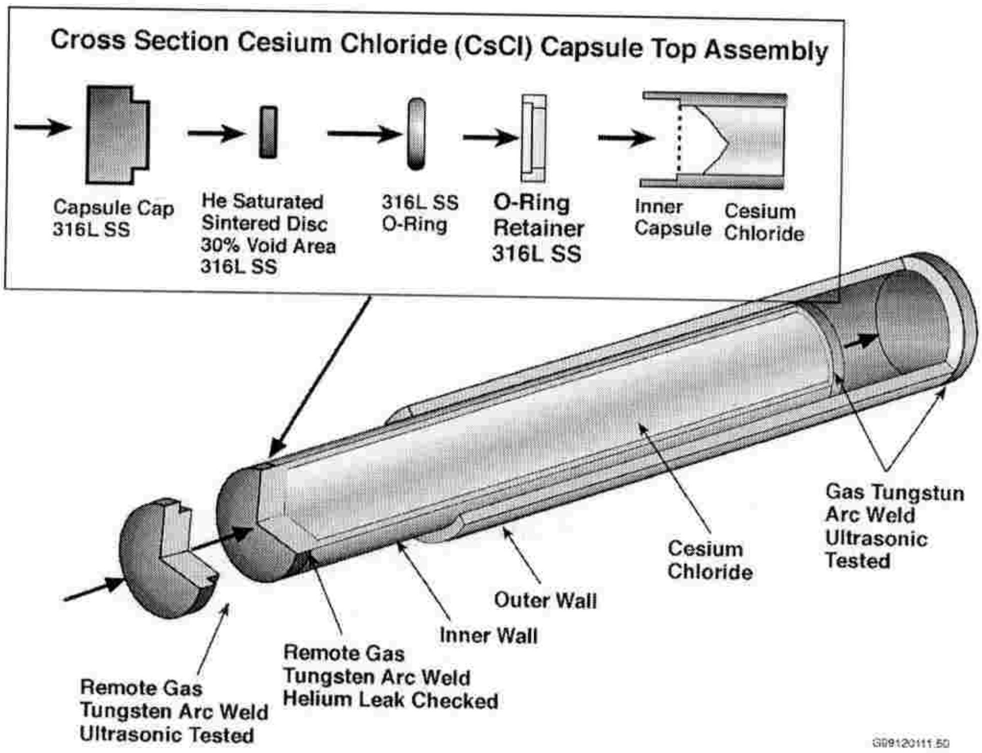

Figure 1.1. Typical Capsule Components.

1.4 OVERPACK DESIGN CONCEPT

The preliminary concept for the overpack used for the thermal calculations is based on a monolithic insert overpack with 16 holes. The insert is also referred to as the "gun barrel" or "ring." The outer diameter of the insert is 22 in. and the inner diameter is 10 in. Each of the 16 holes drilled into the monolith ring is capable of accepting a single Type 1, 2, or 3 Cs or Sr capsule. The details of this concept are provided in WMP-16940, *Thermal Analysis of a Dry Storage Concept for Capsule Dry Storage Project*. The CDSP contractor will provide the actual design for the overpack.

1.5 TRANSFER SYSTEM CONCEPT

This system will be used to transfer the overpacks from WESF to the storage pad. For the preliminary calculations, it is assumed that a cask similar to the Beneficial Uses Shipping System (BUSS) cask will be used for the transfer system. The description of the BUSS cask is provided in HNF-16138. The CDSP contractor will provide the actual design for the transfer system.

1.6 STORAGE SYSTEM CONCEPT

This system will be used to store the capsule overpacks for the interim period until the decision for final disposition is made. The capsule overpack assemblies inside the storage module will be cooled by natural air circulation. The conceptual configuration of the dry storage module is provided in WMP-16940. The CDSP contractor will provide the actual design for the dry storage module design.

1.7 CAPSULE DISPOSAL

This CDSP will provide interim storage for the capsules. It is anticipated that the overpack will be placed in a repository certified package for permanent storage and transported to the repository in a certified cask for disposal. If the capsules are removed from the dry storage overpack, the overpack will be taken into a hot cell with features similar to those in WESF where the lid will be removed. The capsules will be removed from the overpack for repackaging for the repository or reprocessing. Any capsule with leakage will be handled according to planned disposal.

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2.0 FINDINGS AND RECOMMENDATIONS

The Capsule Advisory Panel (CAP) has addressed the acceptability of key requirements of HNF-16138 and reviewed the technical basis for the CDSP. The following is a summary of the findings and recommendations related to this topical report. See WMP-17265, *Capsule Advisory Panel Topical Summary Report,* for a complete summary listing of findings and recommendations from all the CAP topical reports, including links to the topical reports for each of the findings and recommendations.

2.1 ACCEPTABILITY OF KEY PERFORMANCE SPECIFICATION REQUIREMENTS

The CAP was chartered to assess the acceptability of key design requirements for the CDSP to ensure they are conservative and defensible. The results of this assessment are listed below for this topical report.

2.1.1 Heat Rejection

A suitable dry storage system must be capable of passively dissipating the heat generated by decay of the concentrated CsCl and SrF_2, as well as radioactive decay products in the capsules. Temperatures of the capsules will be elevated over those seen in water pool storage, and must be maintained at levels that ensure safe, interim storage. Limiting temperatures were specified in the HNF-16138 for normal, processing, and accident conditions for both CsCl and SrF_2 capsules.

2.1.1.1 317 °C Maximum Temperature of Cesium Capsules at the Salt-Metal Interface During Dry Storage.

This report does not address this topic.

2.1.1.2 450 °C Maximum Temperature of Cesium Capsules at the Salt-Metal Interface During Processing.

This report does not address this topic.

2.1.1.3 600 °C Maximum Temperature of Cesium Capsules at the Salt-Metal Interface Under Accident Conditions.

This report does not address this topic.

2.1.1.4 540 °C Maximum Temperature of Strontium Capsules at the Salt-Metal Interface During Normal Dry Storage.

This report does not address this topic.

2.1.1.5 540 °C Maximum Temperature of Strontium Capsules at the Salt-Metal Interface During Processing Conditions.

This report does not address this topic.

2.1.1.6 800 °C Maximum Temperature of Strontium Capsules at the Salt-Metal Interface Under Accident Conditions.

This report does not address this topic.

2.1.2 Containment

This report does not address this topic.

2.1.3 Recovery Capability

HNF-16138 requires the dry storage system be designed to allow retrieval of the capsules from the system should a decision be made to dispose of the capsules in a manner not using the project-supplied overpack. An assessment of the long-term condition of the capsules was performed to determine the feasibility of capsule recovery.

WMP-16937, *Corrosion Report for Capsule Dry Storage Project*, concludes corrosion of the CsCl and SrF_2 capsule walls will be limited to a small percentage of the total wall thickness over the 50-year lifetime of dry storage. As noted, leakage of capsules within the overpack cannot be ruled out during the dry storage period, but any capsule failures are expected to be limited to cracks and small holes. As discussed in Section 2.1.4.3, metal aging is not expected to reduce the structural properties of the capsules walls or welds to unacceptable levels over the 50-year lifetime. No other mechanisms were identified in this report that would challenge the gross configuration of the CsCl and SrF_2 salts within the capsules.

The capsules will retain sufficient structural strength for normal handling activities to facilitate retrievability of the capsules should this be necessary. The effects of metal aging at the normal dry storage temperatures (250-300 °C) of the outer capsule walls will not substantially alter the structural strength of the capsules over the 50-year storage period. Aging effects will accelerate at the processing event temperatures, particularly for the SrF_2 capsules if the processing temperature limit is raised to 700 °C. However, the durations are short (a few hours to a few days) and the property changes are expected to be acceptable. If the SrF_2 processing temperature limit is raised, an analysis is recommended to confirm that retrievability goals can be achieved.

Raising the processing temperature above 540 °C and to 700 °C would result in degradation of metal and weld fracture toughness, which could compromise accident tolerance and possible future retrieval and handling (e.g., drop of capsule). Though no quantitative measurements were taken, a capsule tested for corrosion at 800 °C remained ductile after 5,000 hours, as determined qualitatively during crushing of the capsule wall for disposal. Thorough technical analysis of fracture mechanics and metallurgical aging of the capsule wall and welds will be required prior to proceeding with this change, however.

Therefore, if required, removal of capsules from the overpacks is feasible within a hot cell facility similar to the WESF used to load the overpacks.

2.1.4 Design Life

Design features and requirements were selected based on a 50-year lifetime for the dry storage system. Key elements of the design requirements were analyzed to assess the viability of achieving the 50-year lifetime based on these requirements.

2.1.4.1 Corrosion Allowance for 316L Stainless Steel Overpack Interior.

This report does not address this topic.

2.1.4.2 External Corrosion.

This report does not address this topic.

2.1.4.3 Metal Aging.

Structural metals exposed to elevated temperatures are potentially susceptible to changes in properties that can challenge their long-term suitability. Since dry storage will elevate capsule temperatures well above those experienced in water pool storage, an assessment of the effects of metal aging was performed.

This document and WMP-16939, *Capsule Integrity Report for Capsule Dry Storage Project*, considered the significance of aging of the capsule and overpack materials. The effect of aging during the 50-year design life at capsule dry storage operating and processing temperatures, including the potential loss of ductility, is insufficient to affect capsule performance. The outer capsule walls, which provide the structural strength for the capsules, never exceeded 300 °C at the irradiator facilities. These walls will remain below 300 °C at normal dry storage conditions and below 440 °C (maximum for the high power Sr capsules) at processing conditions. Temperatures at these levels are not expected to produce damaging aging effects in the capsule outer walls. Data show the 316L and Hastelloy C-276 wall materials experience negligible long-term aging effects at temperatures below 450 °C. The material properties have not been significantly altered by use at the irradiators, nor will they be in dry storage.

The higher potential temperatures for accident conditions can result in loss of fracture toughness, depending on the actual temperature of the outer wall and the duration of the accident. The capsules will survive the accident conditions without massive failure. Recovery actions will be addressed following the accident, including analyses of effects on material properties as needed and definition of the associated controls to be placed on handling of the capsules.

Therefore, aging effects will be acceptable over the 50-year lifetime and will not impact the viability of dry storage.

If the SrF_2 capsule processing temperature limit is considered to be raised to 700 °C, it is recommended an analysis be performed to confirm retrievability and handling goals can be achieved. See Section 2.1.3.

2.2 OTHER CONSIDERATIONS

Other aspects of the CDSP were assessed to ensure the viability of the approach. These primarily focused on characterizing the capsules to assess their suitability for dry storage and evaluation of some special capsule families.

2.2.1 Capsule Characterization

Capsule characterization is the analysis and tests necessary to demonstrate the capsule conditions are suitable for dry storage.

2.2.1.1 Capsule Integrity.

The current integrity of the capsules is a key element in assessing their viability for dry storage. Available information was analyzed for the capsules, including fabrication, testing, and service history. The capsules were fabricated and inspected under a controlled program and were certified for shipment and use in commercial, licensed facilities. The effects of service at commercial irradiator facilities were analyzed. Other than those capsules identified as suspect and subsequently sealed in Type W overpack assemblies, no significant deleterious effects were identified due to the thermal cycling or extended higher temperature operations at these facilities. The CsCl capsules are routinely tested using the inner capsule movement (ICM) test to verify capsule integrity. Analyses of routine loads and potential drops during handling were performed to verify the capsules retained sufficient strength for overpacking and retrieval operations.

A review of the welding history of the capsules revealed the challenges in making and testing the capsule welds. The automated process was qualified in a development program to produce full penetration welds. However, the difficulties of remote weld setup and ultrasonic examination in a hot cell were substantial and significant weld rework was required. A lower limit of 55% penetration for the welds, as measured by ultrasonic examination, was ultimately established after testing demonstrated a weld with this penetration level had comparable strength to the wall of the capsule. Even with these changes, investigations showed some uncertainty in the accuracy of the ultrasonic measurements remained.

Although welds on all capsules cannot be verified to have the required 55% weld penetration, only two weld failures and one additional weld defect have been identified since the capsules were fabricated. Both weld failures were on capsules that had experienced several thousand substantial thermal cycles at a commercial irradiating facility. Neither weld failure was related to weld penetration. The experience in handling, shipping, use at the irradiator facilities, and testing of the capsules, including the ICM test, provide confidence that weld failures should not be expected, but cannot be ruled out. Furthermore, precautions can be taken during capsule handling, and the WESF authorization basis already addresses potential leakage from a capsule should a weld fail during handling.

New weld examinations at this point would not be feasible or warranted, given the scope and requirements for overpacking into dry storage. Once loaded into the overpacks, the likelihood of weld failures would be small and the consequences minimal. Given the above rationale, capsule welds are considered adequate for dry storage processing and are expected to perform in a safe manner and meet specified requirements.

Though there has been little observed evidence of stress corrosion cracking on the capsules, the one detected outer capsule weld failure appeared to exhibit some cracking. Since it is impractical to inspect the capsules for this type of cracking, the possible existence of cracking could not be eliminated. As noted for capsule welding, experience in handling, shipping, etc., provides confidence that if cracking exists, it is limited, and has not resulted in capsule leakage or altered the ability to handle capsules. Similarly, precautions could be taken during capsule handling, and the WESF authorization basis already addresses potential leakage from a capsule should one fail during handling. The need for specific handling precautions will be assessed as part of the safety analysis and production planning for capsule overpacking. Once loaded into the overpacks, capsule weld failures caused by stress corrosion cracking are not anticipated, and if occur, will not jeopardize safe dry storage or the ability to retrieve capsules, if necessary.

Based upon this analysis, the capsules meet the acceptance criteria for structural integrity required for overpack operations. ICM testing and enhanced visual examinations prior to overpacking are recommended to verify these conclusions. Additional tests and examinations may be considered, depending on the outcome of the CDSP's review of the capsule fabrication records and validation of the CDSP capsule database.

2.2.1.2 Calorimetry.

The power level of most capsules was measured when the capsules were fabricated. These power levels must be known to safely and efficiently load capsules into an overpack without exceeding the 2,540 watt (W) limit.

Past evaluations of WESF calorimetry were reviewed. This review bounds the uncertainty of capsule decay heats at +/- 10%, and supports the use of existing data without new calorimetry. This level of uncertainty is deemed to be acceptable for design analysis and for planning for capsule loading.

2.2.1.3 Capsule Fit into Overpack.

Visual examination of the capsules before they were placed in the pool cells showed none of the capsules exhibited deformation that could cause binding or sticking in a shipping cask. However, binding of a capsule partially inserted into an overpack during loading could be a significant challenge and could cause schedule delays. A test to verify the ability to fit a capsule into an overpack prior to insertion into the overpack should be developed and performed.

2.2.2 Strontium Waste Capsules

SrF_2 waste capsules contain SrF_2 and impurities collected from the hot cell deck and floor during operations. Nearly 190 of these capsules were filled and remain in the WESF pools. The type and quantity of impurities are not specifically known, but can be bounded. Comparison of power-to-weight ratios with SrF_2 production capsules filled near the same time period as the waste capsules suggest some of these capsules contain substantial quantities (~50%) of "waste" material. Estimates of the types and quantities of wastes that could have been incorporated into these capsules were assembled based upon interviews with the crew members who performed these operations. These estimates were used to estimate the corrosion potential for these capsules and assess impacts on capsule life in dry storage.

Possible waste materials in these capsules can be grouped into three major categories: Carbonaceous materials, Metals, and Ceramics and other inorganics. Carbonaceous materials, such as plastics, rubber, wood, cotton, rags, etc., would be mostly reduced to carbon when the material was heated up to 800 °C for 8 hours. Metals include steel nuts, bolts, manipulator fingers, high-nickel alloy chips, tungsten, and titanium. Ceramics and other inorganics include concrete, glass, asbestos, and some chemicals such as tri-sodium phosphate. In addition, trace quantities of other materials such as lead (Pb) and copper (Cu) could have been included in these capsules, but the quantities would have been small (< 1%).

These wastes consist mainly of materials that are chemically reducing or inert in the capsules. The metals are similar to the materials of construction for the capsules. Even though the amount of waste materials could be large, the types of materials will not promote significant corrosion of these capsule walls. Therefore, the corrosion within the SrF_2 waste capsules is expected to be similar to corrosion for the SrF_2 production capsules. The integrity of these capsules is not expected to be challenged by dry storage.

2.2.3 Type W Overpack Capsules

A small number of capsules with suspect integrity, as well as materials from capsule destructive examinations and test programs, were sealed inside welded containers (Type W overpacks) for additional assurance against leakage. A total of 23 Type W overpacks were fabricated and are currently stored in WESF.

2.2.4 Consequences of Capsule Leakage

This report does not address this topic.

2.3 KEY RECOMMENDATIONS

Recommendations to assist the Project through detailed design and beyond are summarized below:

- Review of historical information recently disclosed several of the SrF_2 capsules were fabricated with both inner and outer walls of Hastelloy C-276 rather than a 316L SS outer capsule over a Hastelloy C-276 inner capsule. Documentation in use by the CDSP at the time did not identify this design alternative for the SrF_2 capsules. This shortfall in the capsule documentation as well as some apparent discrepancies in the capsule database such as capsule weights must be corrected. It is recommended the original capsule fabrication documentation be reviewed to verify the validity of the capsule descriptions and to validate the data in the capsule database that is pertinent to the CDSP.

- Though the probability of damaging a capsule or discovering a suspect capsule during overpack loading is low, the schedule consequences of recovering from this event could be severe. It is recommended the capability, such as a Type W-type container, to address damaged or suspect capsules be assessed and design work completed prior to beginning the overpack operations to minimize schedule impacts of a damaged capsule.

- High weight capsules should be re-evaluated for validity of the salt weight to ensure that the thermal loading of the capsules is correct based upon the results of the capsule database validation. New weight measurements should be considered for anomalous overweight capsules.

- Capsules returned from the Radiation Sterilizers, Inc.(RSI), Westerville, Ohio, irradiator facility have a surface coating that can be removed by scrubbing with a metal brush. This coating should be removed prior to loading the capsules into overpacks for dry storage.

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3.0 CAPSULE PRODUCTION AND LIFE HISTORY

3.1 CESIUM CAPSULE PROCESS SYSTEM (CONVERSION AND ENCAPSULATION)

This is a brief summary of the Cs capsule process system based on the information provided in "Preliminary Analysis for Cesium and Strontium Capsule Storage at the Canister Storage Building" (O'Brien 1995).

A batch of Cs carbonate solution was reacted with hydrochloric acid under controlled pH conditions to produce a solution of CsCl. The CsCl solution in water was then evaporated to solid CsCl that was heated to approximately 740 °C to produce molten mass. Each batch of molten CsCl salt filled up to seven inner capsules. The capsules, with one end cap welded and tested in the shops, were brought into a hot-cell and the molten CsCl was transferred into these capsules. The other end cap was welded on the capsules, and the capsules were leak tested (helium [He] leak check and bubble test) and decontaminated to remove any surface contamination.

The completed and decontaminated inner capsule was placed in an outer capsule, with one end cap welded and tested in the shops. The other end cap on the outer capsule was welded in the hot cell. The weld on the capsule was visually examined. An ultrasonic test was performed on the outer capsule weld performed in the hot cell to determine the level of weld penetration into the weld joint. Once the completed capsule passed all the tests, the heat generation rate was measured, for most capsules, with a calorimeter, and then the capsule was placed in the water pool cell. For some capsules, the heat generation rate was inferred from the net weight of the capsule and the calorimetric data from another capsule in the same batch. The calorimetric test is discussed in detail in Section 3.3.

3.2 STRONTIUM PROCESS SYSTEMS (CONVERSION AND ENCAPSULATION)

A batch of Sr nitrate solution was reacted with sodium fluoride to produce SrF_2 precipitate and sodium nitrate solution. The SrF_2 precipitate was filtered and washed to remove any sodium nitrate from the SrF_2 solids. The washed SrF_2 solids were then placed in Inconel[2] 600 pans and placed in the sintering furnace. The furnace was heated to approximately 950 °C, changed to 800 °C in 1982 to minimize the pan corrosion, and SrF_2 cake was kept in the furnace for about 8 hours to remove any water and nitrate volatiles (*Hanford Waste Encapsulation: Strontium and Cesium* [Jackson 1976]). The furnace was continuously purged with argon gas to minimize corrosion.

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[2] Inconel is a trademark of Inco Alloys International, Inc. Corporation Delaware, Huntington, West Virginia.

The dry SrF_2 material was packed in Hastelloy C-276 inner capsules. One end cap of the capsules was welded and tested in the shops before bringing them into the hot cell. Each batch of the SrF_2 powder filled about one inner capsule. The SrF_2 material from the drying pans was broken into small pieces and transferred into the capsule incrementally using a funnel. The material in the capsule was compacted after each addition using a compactor operating at 80 lb/in^2 motive air. Addition of the material was repeated until the product was within one inch from the top of the capsule. Partially filled capsules were filled from the next batch.

The other end cap of the capsules was welded on the capsules in the hot cell after the capsule was filled with SrF_2 powder. After welding the cap, the capsule was tested for leaks (He leak check and bubble test) and decontaminated to remove any surface contamination. The inner capsule was then placed in a 316L SS outer capsule and the end cap was welded to seal the capsule. The outer capsule was visually inspected for flaws in the weld. Each outer capsule weld was inspected using ultrasonic equipment to determine the weld penetration. Once the capsule passed all the tests, the heat generation rate was measured with a calorimeter and the capsule was then placed in the water pool cell.

3.2.1 Strontium Waste Capsules

The transfer of SrF_2 material from the drying pans was not an easy task. The dry material had to be removed mechanically from the drying pans using a chisel. This caused a considerable amount of the material to fall onto the working deck and cell floor. Based upon the quantity of the material accumulated, periodically this material was swept off the deck or floor, placed in the drying pan, heated in the closed furnace at 800 °C for 8 hours, and transferred to a new capsule called a "strontium waste capsule." The drying pan was covered with the Inconel lid and the atmosphere in the furnace purged with argon continuously. Out of the 601 Sr capsules in the WESF pool cells, approximately 190 capsules are waste SrF_2 capsules.

In the beginning of the SrF_2 capsule campaign, the SrF_2 precipitate from the filtration process was transferred to the drying pan without washing. The residual liquid in the filter cake contained chemicals (i.e., sodium nitrate [$NaNO_3$], sodium fluoride [NaF]) that were present in the supernatant solution. These chemicals made the dried solids stick to the pan and had to be removed with a chisel. Considerable quantity of the solids fell on the deck and the floor. These solids were swept into the drying pan, placed in the furnace for 8 hours at 800 °C, and packaged into an Sr waste capsule.

Several meetings were held with the operations personnel to determine the foreign materials that could have been placed in these waste capsules in addition to SrF_2 powder. Details of these meetings are provided in Appendix C. Even though it was difficult to attach quantities to these foreign materials, an attempt was made to identify all the possible materials and make an estimate of the materials that could have been placed in the drying pan prior to heating for eight hours at 800 °C, mostly in argon atmosphere.

The following table shows the materials and best estimates of the probabilities and quantities that could be present in the feed to the strontium waste capsules prior to heating:

Material	Probability*	Quantity**
Strontium Fluoride	C	H
Small pieces of plastics, rubber, wood, broom bristles, paper, cotton rags, tape, Styrofoam, tygon tubing, and wire insulations	H	L
Iron and stainless steel metal from nuts and bolts, screws, manipulator parts, and other equipment parts	H	M
Metallic oxide from oxidized parts	H	L
Inconel 600 metal chips from drying pans	H	M
Hastelloy chips from capsule cutting for rejected welds	H	M
Abrasive cutting blade debris from cutting rejected capsules	H	M
Tri Sodium Phosphate for cleaning	H	L
Concrete (spalled pieces) and powder	M	M
Glass pieces from light bulbs and sample bottles	M	L
Ceramics from furnace and glo-bars	M	L
Asbestos	M	L
Tungsten tips from welder	L	L
Sodium fluoride	L	L
Lead metal from shielding bricks and broken light bulbs	L	N
Lead Oxide from paint chips	L	N
Copper/brass from electrical connector pins, clips and welder sleeves	L	N
Titanium from titanium block used for electropolishing	L	L

* Probability: C (certain) 100%
H (high) > 50%
M (Medium) 10-50%
L (low) <10%

** Quantity: H (high) > 20% of the capsule contents
M (medium) 1-20% of the capsule contents
L (low) <1% of the capsule contents
N (negligible) <0.1% of the capsule contents

The specific power (watts/kg) of the Sr capsule contents including production and waste capsules was calculated and plotted as shown in the following figure. Figure 3.1 shows that, except for a few capsules, the waste capsules have lower specific power in comparison to the production capsules. When compared to the production capsules produced during the same time period, some of the waste capsules had approximately 50% of the production capsule specific power, indicating that the "waste" materials contained in some capsules was as much as 50%, or slightly more in a few cases, of the mass of materials in the capsules.

At the end of the SrF_2 capsule production campaign, C-cell was cleaned with a high pressure water to clean the walls, ceiling, and equipment. The liquid waste was sent to B-Plant and the solids collected were placed in the pans for processing through the furnace. These materials were never placed in waste capsules; the pans are still in the C-cell.

Note: All the Sr capsules (production and waste) may contain trace amount of zinc that was added from the corrosion of the funnel used for pouring the SrF_2 powder from the pan into the capsule. The funnel was galvanized steel and was corroded by SrF_2 and other impurities. The funnel was changed several times.

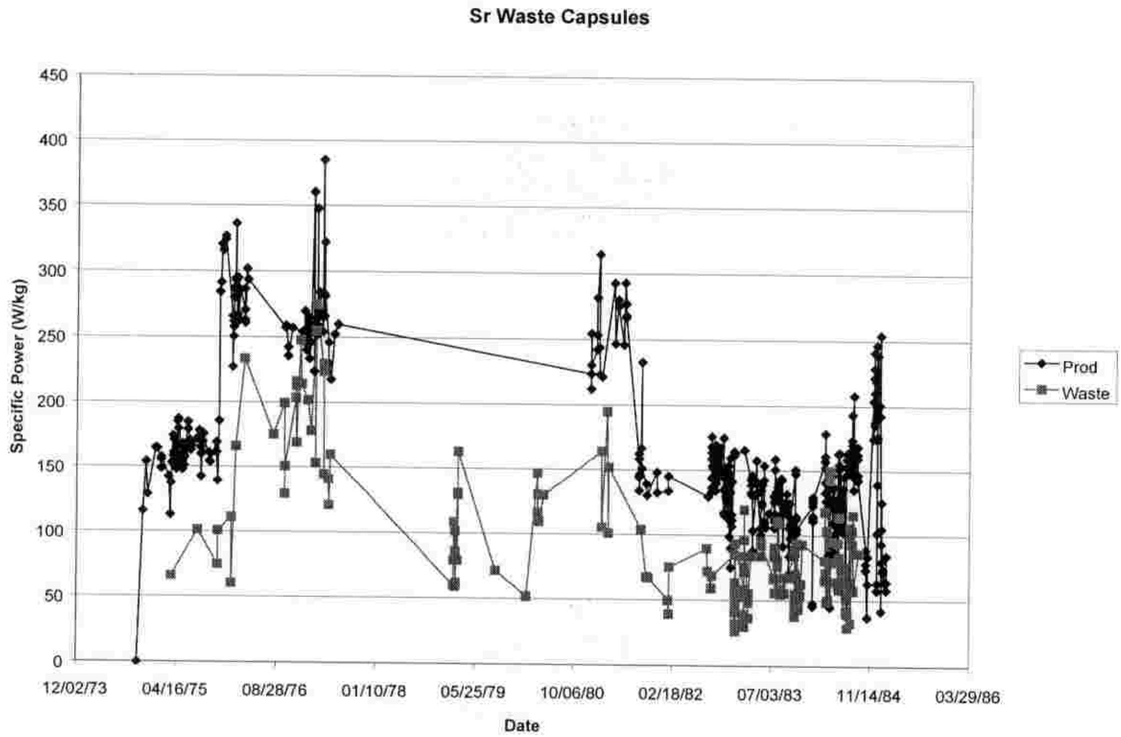

Figure 3.1 Specific Power of Sr Waste Capsules and Sr Production Capsules.

3.3 CALORIMETRY AND WEIGHING

Cesium-137 (^{137}Cs) in the Cs capsule is the radioactive isotope that has a half-life of 30.17 years. ^{137}Cs decays following one of two distinct decay modes. The first decay mode corresponds to a direct decay to the ground state of barium-137 (^{137}Ba) by beta emission that occurs 5.4% of the time. In the second decay mode ^{137}Cs decays into the barium-137 meta-stable (^{137m}Ba) form by beta emission, which then decays into ground state ^{137}Ba by gamma and/or electron emission. This decay mode occurs 94.6% of the time.

Strontium-90 (^{90}Sr) in the Sr capsule is a beta emitter and has a half-life of 28.6 years. It decays into yttrium-90 (^{90}Y) that has a half-life of 64 hours. ^{90}Y decays into stable zirconium-90 (^{90}Z) by emitting beta. The decay process generates power in the capsule material that is a key input for the thermal, radiation dose rate, and shielding calculations (*Capsule Project of B-Plant Strontium and Cesium Inventories* [Rasmussen 1984]).

Calorimetric testing was performed on the CsCl and SrF_2 capsules to determine their radioactive Cs and Sr content. Capsule heat output is proportional to the number of curies of radioactive isotopes. In the beginning of the production campaign, one of the capsules from a batch was tested using a calorimeter to determine the power of the material in the capsule. The power of the balance of the batch capsules was determined from the weight ratio with the capsule tested with the calorimeter. This practice was changed on August 29, 1979, when every capsule was tested with the calorimeter to determine its power.

Each capsule was weighed to determine the weight of the radioactive material and the specific power (curie/gram [Ci/g]) of the material in the capsule. The production run books (WESF Run Books 74-0' to 83-32) include the calorimetric test results and the weights for the capsules.

A material balance for the B-Plant operations using radiochemical analysis technique was performed to determine the Cs inventory and to project the number of capsules that would be produced. A comparison of the material balance results and WESF calorimetric test results showed that calorimeter test results were approximately 20% lower than the material balance results. This discrepancy raised concerns about the accuracy of the calorimetric test results.

In order to resolve this discrepancy, the accuracy of the radiochemical analysis and calorimeter was evaluated in *Capsule Project of B-Plant Strontium and Cesium Inventories* (Sloughter 1981). Each process step (volume measurement, sampling, sample handling, and radiochemical assay) in the radiochemical analysis was evaluated for accuracy. The evaluation concluded that the radiochemical analysis technique used in the B-Plant material balance had an accuracy of ±20% based on the accumulative accuracy of the process steps.

The WESF calorimeter accuracy was verified by five major evaluations:

- Engineering Analysis: Engineering analysis of the design and construction of the calorimeter assembly and its operation was performed. A test of the calorimeter using an electrically heated standard capsule was conducted to confirm the engineering calculations. Results confirmed that the calorimeter was accurate to 5%.
- Sample Calorimetry: Comparison of the WESF calorimeter was made to a sample calorimeter in the laboratory. A series of 1 g Sr product samples were tested with the calorimeter in the laboratory. The energy output (watt/g) measured with the laboratory calorimeter agreed within 5% of the energy output (watt/g) measured with the WESF calorimeter.
- Capsule Surface Temperature: Pacific Northwest National Laboratory (PNNL) developed a heat balance mathematical model that related capsule tube surface temperature to the heat generation rate. Heat generation rate calculated from the capsule surface temperature using the model and algometry were found to agree within 3%.
- WESF Mass Balance: Sr mass balance around the Sr encapsulation process was made based on fluoride ion material balance. The total Ci production of Sr processing as

determined by calorimetry agreed within 1% of the Ci output calculated from the mass balance.

- Isotopic Analysis: Isotopic analysis of Cs in WESF feed solutions was used to provide another check on the accuracy of the Cs capsule material balance. Calorimetry results from 130 Cs capsules were used in this analysis. Comparison of the Ci/g determined from the calorimetry and Ci/g determined by isotopic analysis agreed within 5%.

The conclusion from these evaluations was that the WESF calorimeter was accurate to within ±5%. The evaluation also concluded that the variance between the B-Plant material balance and calorimeter measurements was due to the inaccuracy in the radiochemical analysis technique used in the radiochemical analysis.

Twelve capsules that were sent to Sandia National Laboratories (SNL) were tested for power with a calorimeter at SNL. The decayed power calculated from the calorimetric test at WESF was compared with the power calculated form the calorimeter test at SNL. The comparison showed that the variation between the two tests ranged from -2.6% to +10%.

Rasmussen (1984) performed another review of the WESF calorimetric method used to measure the capsule power, and concluded that the uncertainty of the capsule power measurements was -2% to +7%.

The results of the power measurements using the WESF calorimetric method have been reviewed several times for accuracy. Each review has concluded that the uncertainty associated with this method is within ± 10%. This uncertainty is acceptable for the storage system thermal and design calculations because the calculations are based on conservative assumptions.

3.4 WELDING HISTORY AND QUALITY

3.4.1 Welding Process

Capsule design (both inner and outer), with regard to welding, consists of a seamless tube (shell) with a flat lid (head) welded at both ends. The lid is stepped forming a plug that extends down into the tube creating a square-groove corner joint in which the plug portion serves as weld backing, see Figure 1.1. The joint is welded with the gas tungsten arc welding (GTAW) process using an *autogenous* (defined as fusion weld made without the addition of a filler [*Standard Welding Terms and Definitions* (AWS A3.0)]), single-pass technique. Base materials are Type 316L SS for the Cs inner and outer capsule, and Hastelloy C-276 for the Sr inner capsule and Type 316L SS and Hastelloy C-276 for the Sr outer capsule.

Capsule "cold" ends, lid to tube weld made prior to loading product into the capsule, were welded in a nonradioactive environment (shop) where immediate access to the weld was available. The "hot" ends or closure welds were made after product had been loaded and were performed in the shielded-cell under fully remote conditions.

All welding was performed in accordance with a systemic, quality controlled program, which included training and qualification of the welding operators and qualification of the welding process and procedures in accordance with Section IX of the *American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code.*

3.4.2 Weld Inspection and Acceptance

The capsule package consists of an inner and outer capsule with the function of the inner designated as "corrosion barrier" and the outer as "containment" (RHO-CD-1049, *Criteria for ^{137}Cs and ^{90}Sr Capsules*). A review of the types of weld inspection and its application supports this description for the following reasons:

- The primary weld inspection of the inner capsule closure consisted of leak testing, both gross (bubble check) and sensitive (He check) indicating the need to ensure product containment (seal or barrier).
- Ultrasonic testing (UT) was applied to the outer capsule closure to verify weld penetration ensuring product confinement (structural function necessary to maintain capsule geometry under specified loading conditions).
- No leak testing of the outer capsule closure was performed. Inspection requirements for the inner and outer, when considered together, verify the integrity of the double encapsulation package for both containment and confinement functions.
- All welds were examined visually to establish weld soundness.

Tables 3.1 and 3.2 identify the weld inspection and acceptance criteria applied to the capsule welds (O'Brien 1995).

Table 3.1. Inner Capsule Weld Inspection and Acceptance Criteria.

Test method	Acceptance	Capsule end*	Test purpose
Visual Test	No cracks, porosity, arc strikes, weld spatter and no pits with diameter > 0.04" (Cs) and > 0.05" (Sr)	Both ends	Determine weld soundness
Liquid Penetrant Test	No indications of cracks	Cold end only	Determine weld soundness
Ultrasonic Test	Weld penetration ≥ 55% of tube wall thickness	Cold end only	Determine weld depth of penetration
Bubble Leak Test	No bubbles	Both ends	Check for gross leaks
Helium Leak Test	Leak rate ≤ 1 x 10^{-8} std cc/sec He	Hot end only	Check for fine leaks

* **"Cold end"** welds were made prior to loading product into the capsule in a non-radioactive environment (shop).

* **"Hot end"** welds were made subsequent to loading product into the capsule in a radioactive cell under fully remote conditions.

Table 3.2. Outer Capsule Weld Inspection and Acceptance Criteria.

Test method	Acceptance	Capsule end*	Test purpose
Visual Test	No cracks, porosity, arc strikes, weld spatter and no pits with diameter > 0.04" (Cs) and > 0.05" (Sr)	Both ends	Determine weld soundness
Liquid Penetrant Test	No indications of cracks	Cold end only	Determine weld soundness
Ultrasonic Test	Weld penetration ≥ 55% of tube wall thickness	Both ends	Determine weld depth of penetration

* "**Cold end**" welds were made prior to loading product into the capsule in a non-radioactive environment (shop).

* "**Hot end**" welds were made subsequent to loading product into the capsule in a radioactive cell under fully remote conditions.

The process of inspecting for weld penetration was quite rigorous in that it included pre- and post-production calibration standards. In addition, an end cap weld mockup, containing the minimum specified penetration, was scanned along with the standards for direct comparison to assist in interpretation of the UT results. All welds accepted into the WESF system met specified quality and weld inspection requirements.

3.4.2.1 Capsule Weld Flaws Identified Subsequent to Fabrication.

Two of the capsules, after being put into service, were subsequently identified as containing weld flaws:

C-1592 (Cs capsule) failed the inner capsule movement (ICM) test upon return from the RSI commercial irradiator facility. Cracking at the outer capsule closure weld was observed, allowing water and steam to pass into and out of the capsule annulus. A failure analysis was performed and it was determined that the through-wall cracking was associated with a large void midway through the cross section of the weld ("Failure Analysis of Waste Encapsulation and Storage Facility Cesium Capsule C 1592, Parsons Infrastructure and Technology Group, In., September 30, 1997). The void, produced during the original fabrication welding, appears to have influenced the time to failure by cracking. Though the specific mechanism for the weld failure was not identified, it is believed that service conditions at the commercial irradiator were the cause of failure.

C-287 (cesium capsule) failed a visual examination upon return from the IOTECH commercial irradiator facility. An asymmetrical hole of unknown depth and porosity in the outer capsule closure weld exceeded specified acceptance limits (O'Brien, O. J., 1995, "Preliminary Analysis for Cesium and Strontium Capsule Storage at the Canister Storage Building," (letter 9502756B R5, Rev. 0, to J. E. Mecca, U.S. Department of Energy, September 21), Westinghouse Hanford Company, Richland, Washington). These flaws appear to have been produced during the original fabrication welding. Though no breach of containment was caused by or associated with these flaws, the capsule was placed into a Type W overpack.

3.4.3 Issues Raised Regarding Welding and Inspection During Production Operations

While the above statements regarding the welding and inspection activities are correct, some issues related to the quality of these activities were identified during the course of production operations. In particular, questions regarding adequacy of the welding process and UT examination techniques were raised. The following provides a brief treatment of these concerns.

3.4.3.1 Welding Process.

Prior to production, the welding process was developed and demonstrated to meet specified design requirements, including full weld-joint penetration (ARH-3043, *Welding Development for the Waste Encapsulation Program, Final Report* [O'Brien 1974]). During the first few years of production however operations experienced difficulty in consistently meeting specified closure weld acceptance criteria. Several equipment improvements were implemented and issues of inconsistent weld penetration and weld porosity were eventually resolved.

Specifically, two major improvements were made affecting weld quality—cleaning procedures (protection of the weld joint preparation from salt contamination) and the addition of a cam-follower (stabilization of the welding arc gap). These changes reduced the weld reject rate by making more consistent welds.

The GTAW process is well-suited for this type of welding and has been applied successfully many times in similar applications. A review of these issues (see DOE/ORO-914, *Interim Report of the DOE Type B Investigation Group*) indicates the problems were primarily equipment related (fixturing) having to do with the difficulties of the fully-remote application, as opposed to challenges related to the process (parameter).

3.4.3.2 UT Examination.

As with the welding activities, the remote application of the UT process created challenges and required equipment improvements as well. Because of uncertainties associated with the UT interpretation and the ability to confirm, with high confidence, weld penetration levels (DOE/ORO-914), a re-evaluation of the design basis for this criterion was made. A series of tests was performed demonstrating that at approximately 60% weld penetration (*Outer Capsule Weld Evaluation Program* [SD-RE-ES-026 1983]); the strength of the weldment was shown to be equivalent to that of the capsule wall, when internally pressurized to failure. This lead to a revision of the UT acceptance criterion, set originally at 100%, to 55%. Even with this change however, uncertainty in the accuracy of the ultrasonic measurements persisted making it difficult to conclude that all capsule closure welds have at least 55% weld penetration.

It would not be feasible at this point to evaluate by examination the capsule weld penetration levels, and establish the original fabrication acceptance criteria. However, with regard to the suitability of handling and processing associated with overpacking into dry storage, capsule service history gives reason to believe weld penetration levels are adequate.

Since fabrication, the capsules have been subjected to shipping, handling (including minor drops), processing operations at both WESF and irradiator facilities, and testing (including the ICM test) without incidence, i.e., catastrophic failure. This provides a strong indication that weld penetration levels are suitable for and will support the dry storage handling and processing requirements -- failure is not expected. Even so, one final measure of protection against catastrophic failure is afforded by the WESF facility, and that is that the WESF is designed to accommodate leakage from a capsule, should a failure occur during overpacking and processing into dry storage.

3.5 CAPSULE HISTORY

The WESF went into operation in September 1974 and began converting the radioactive Sr and Cs isotopes into solid compounds. These solid compounds were then encapsulated into double-shell capsules and stored in water basins called pool cells. The encapsulation of Sr and Cs solids was completed in 1984. A government program to use Cs and Sr capsules experimentally for sludge and sewage irradiation began near that time. The capsules were also used for commercial medical and wood products irradiation programs. Capsules were packaged and shipped to various facilities to support these programs (*Cesium Capsule Family Characteristics* [Nogales 1992]; *Capsule Integrity Program Plan for WESF Cs and Sr Capsule Storage* [Simmons 1998]).

The detailed information on all these programs, shipment dates, number of capsules shipped and returned, and details of the facilities are provided in WMP-16878 and supporting database.

3.5.1 Capsules with Elevated Temperature and Thermal Cycling History

This section describes the history of conditions associated with the groups of Cs capsules that were exposed to thermal cycling at higher temperature conditions at various irradiator facilities and then returned to WESF. The exposure to higher temperatures enhances the corrosion rate at the capsule walls in contact with the radioactive material and thermal degradation of the metals. Thermal cycling of some of the capsules resulted in multiple phase transitions of the CsCl salts and ultimate swelling of some of the capsules. The history of these capsules is important for the assessment of these capsules for 50-year dry storage.

All the capsules at the irradiators were tested using the ICM test before they were returned from the irradiators. Most of these capsules passed the ICM test and were returned to WESF pool cells. The capsules that did not pass the ICM test were either cut up for analysis or placed in the Type W overpack and returned to the WESF pool cells. The capsules that remained in the WESF pool cells were not exposed to conditions that will impact the integrity of the capsules. The following sections briefly describe the conditions the capsules were exposed to at the irradiator facilities. The number in the parenthesis shows the capsules returned "as is" to WESF from that particular facility. These capsules were smear tested in the G-cell before placing them in the pool cells.

Out of the total 1,936 capsules in the WESF pool cells, 716 normal CsCl capsules and 16 CsCl capsules placed in the Type W overpacks were exposed to thermal cycling. Of the 785 Cs capsules sent to the irradiators, 741 were exposed to thermal cycling. Twelve of the capsules sent to the irradiators bulged and failed the ICM test after being thermally cycled. One capsule tested at PNNL for thermal cycling was suspected to have bulged the inner capsule wall, two had weld defects (one failed in the pool), and one gave false indication of water in the annulus. All capsules with defects were either placed in Type W overpacks or destructively examined.

3.5.1.1 Applied Radiant Energy Corporation (ARECO) (25).

These capsules were stored and used under water for irradiation of wood products. The water was maintained at approximately 33 °C and continually monitored for radioactive contamination. The capsules were examined annually by ARECO with Hanford Site and Nuclear Regulatory Commission (NRC) staff witnessing the examination. These capsules were not exposed to high temperature thermal cycling.

3.5.1.2 Radiation Sterilizers, Inc. (RSI), Atlanta/Decatur, Georgia (236).

These capsules were stored in water and used for irradiation of medical products in the air. The capsules were thermally cycled in and out of water more than 7,300 times. The water storage temperature was not controlled and the water was not monitored for radioactive contamination. The capsules were placed next to each other in air during the irradiation process. One of the capsules leaked and contaminated the water basin. The interim report on Type B investigation (DOE/ORO-914) provides details of the circumstances that lead to the failure of the capsule. A thermal analysis of the Decatur irradiation system, performed by Eyler (*Cesium Capsule Thermal Analysis* [1989]), predicted a maximum centerline CsCl temperature of 468 °C and a maximum surface temperature of 289 °C for worst case conditions. All the capsules were tested using an ICM test and ring gauge test (Appendix A). Of the 252 capsules shipped to RSI, 236 passed the tests and were returned to WESF. Of the capsules that did not pass the tests at RSI, 11 had bulged. The failed capsule (C1502) was destructively examined and 10 others were placed in Type W overpacks. One of the capsules gave false indication of water in the annulus during ultrasonic testing and was placed in the Type W overpack.

3.5.1.3 Radiation Sterilizers, Inc. (RSI), Westerville, Ohio (172).

These capsules were exposed to the same type of conditions as the capsules used in RSI, Decatur, Georgia. Of the 180 capsules shipped to Westerville, Ohio, 175 were returned to WESF and stored in the pool cells. Three of the remaining 5 capsules were placed in Type W overpacks and 2 had no damage and were cut up for examination. One of the three capsules placed in the Type W overpack had originally passed the ICM test at the irradiator facility and was placed in the WESF pool cell. This capsule (C1592) subsequently failed the ICM test due to a leak in the outer capsule weld. The second capsule bulged at the irradiator facility and the third had no damage and its outer capsule was removed for destructive examination.

3.5.1.4 IOTECH, Northglen, Colorado (308).

These capsules were also stored under water and employed for the irradiation of medical products in the air. Thermal cycling was limited to about 300 times. The de-ionized water temperature was maintained at approximately 35 °C. The water was monitored weekly for contamination. Of the 309 capsules shipped to IOTECH and later returned to WESF, 308 were placed in pool cells and 1 was determined to have a visible pit and weld flaw that was detected during receipt examination. This was fitted with a new outer capsule and placed in a Type W overpack (designated as W-287) before being returned to the pool cells.

3.5.1.5 Sandia National Laboratory (SNL) (12).

These capsules were stored and used in air at the Sandia Irradiator for Dried Sewage Solids (SIDDS) and Gamma Irradiation Facility at SNL. The capsules were cooled by forced convection. Of the 19 shipped to SNL, 12 were sent to Rocketdyne at Canoga Park, California, for BUSS cask thermal test. These twelve capsules were returned to WESF for storage in the pool cells. Of the remaining 7 capsules at SNL, 3 were cut up for examination and 4 were sent to France.

3.5.1.6 Other Capsules at WESF (1,167).

The other capsules at WESF include 559 Cs capsules, 601 Sr capsules, and 7 Cs capsules in Type W overpack capsules that have been stored in the water and have not been exposed to elevated temperatures. These Type W overpack capsules contained CsCl powder left over from capsules cut up for examination and pellets from Building 324 cleanout; WMP-16878 provides more details of these capsules. The pool water has been maintained at approximately 22 °C by cooling it with river water using a heat exchanger. The pool water has been continually monitored for radioactive contamination to detect any leaks. The regular Cs capsules have been examined regularly using the ICM test.

4.0 PERFORMANCE CRITERIA

The following performance criteria apply to the condition of the capsules prior to overpacking for dry storage, and to the capsule condition at the end of the interim dry storage period. The criteria in Section 4.1 must be satisfied before the capsules can be placed in a dry storage system overpack. The capsule attribute evaluation process described in Section 5.0 will be used to demonstrate the capsules' compliance with these criteria.

By way of explanation, the following criteria, performance (Section 4.0) and evaluation (Section 6.0), were established based on principles similar to those identified for the standard "fitness-for-service" approach as defined in API 579, *Recommended Practice on Fitness for Service*. That is, the service associated with the dry storage effort was first defined (performance) and then criteria for the evaluation to demonstrate fitness for that service (evaluation) developed. Any differences between the evaluation criteria and the original design and fabrication criteria result from differences in the required service.

4.1 CAPSULE OVERPACKING

The inner and outer capsules will be structurally sound, and both capsule walls, inner and outer, will be free of detectable leaks when they are placed in the overpacks for transfer and storage. These initial loading criteria will be satisfied if the following acceptance criteria are satisfied:

4.1.1 The inner and outer capsules were fabricated and inspected to documented fabrication requirements when they were constructed.

4.1.2 The inner and outer capsule welds met the documented weld inspection criteria when they were originally fabricated. It is acknowledged there are some issues associated with this criterion – see Section 3.4.3 for a discussion of these.

4.1.3 The inner capsule is capable of sliding inside the outer capsule while submerged in water. This verifies that:

- The inner capsule has not corroded through the wall and leaked a significant quantity of radioactive material into the annulus between the inner and outer capsules.
- The outer capsule has not leaked a significant amount of water into the annulus between the inner and outer capsules.
- The inner capsule has not bulged to a point that it presses against the outer capsule.

4.1.4 The outer capsule exterior is free of smearable contamination.

4.1.5 The capsule has not deformed to a point that it will bind or stick while being placed into an overpack.

4.1.6 The outer capsule is of visible cracking and surface pits/dents greater than 1/16 inch.

4.1.7 The capsule is capable of maintaining containment during normal handling, including minor collisions and drops, during overpacking. These requirements are:

- Capsules survive normal manipulator gripping force (50 lb) without the release of any capsule contents.
- Capsules survive a drop of 4 ft without the release of any capsule contents (10 CFR Ch. 1, Section 71.71, "Normal conditions of transport").

4.1.8 Material properties of the outer capsule (structural member of the double encapsulation) have not degraded to a point where capsule integrity would be severely compromised (suffer catastrophic failure) under normal handling loads (see Section 6.8 for a detailed discussion of this criterion.

Degradation processes include:

- Thermal aging
- Stress corrosion cracking
- Intergranular attack
- Hydrogen embrittlement
- Radiation embrittlement
- Cyclic fatigue
- Liquid metal embrittlement.

4.1.9 The inner and outer capsule walls have not experienced gross bulk thinning due to corrosion prior to loading the capsules into an overpack based on corrosion predictions. Specifically:

- Bulk corrosion of the inner capsule wall is predicted to not exceed 25% of the original wall thickness.
- Bulk corrosion of the outer capsule wall is predicted to not exceed 10% of the original wall thickness.

4.2 INTERIM DRY STORAGE

The Sr and Cs outer capsules will maintain their physical structure at the end of 50-year dry storage life. The Cs and Sr outer capsule will not leak significant amounts of salt into the overpack container. The criteria will be satisfied if the following acceptance criteria are satisfied:

4.2.1 The capsules satisfied the criteria for initial loading into the overpacks.

4.2.2 The outer capsule wall structure maintains sufficient physical integrity to contain the bulk Cs and Sr materials. Specifically corrosion predictions show that leakage from CsCl and SrF_2 through the outer capsule wall is limited to a small percentage of the total capsule contents.

4.2.3 The capsule is capable of maintaining containment during normal handling, including minor collisions and drops, during retrieval of the capsules from the overpacks if needed. These requirements are:

- Capsules will survive normal manipulator gripping force (50 lb) without the release of significant (~1%) amount of capsule contents.
- Capsules will survive a drop of 4 ft without the release of significant amount of capsule contents.

4.2.4 Material properties of the outer capsule (structural member of the double encapsulation) have not degraded to a point where capsule integrity would be severely compromised (suffer catastrophic failure) under normal handling loads (see Section 6.8 for a detailed discussion of this criterion).

Degradation processes include:

- Thermal aging
- Stress corrosion cracking
- Intergranular attack
- Hydrogen embrittlement
- Radiation embrittlement
- Cyclic fatigue
- Liquid metal embrittlement.

4.2.5 The capsules have not deformed due to swelling or bulging (e.g., induced by CsCl phase changes) sufficiently to prevent meeting the leakage criteria listed above.

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5.0 CAPSULE EVALUATION PROCESS

The process to be used to determine whether the capsules can meet the specified performance criteria is to compare known capsule characteristics and forecasted performance during dry storage to the performance criteria. Section 6.0 describes the comparison with the performance criteria. Figure 5.1 outlines the capsule evaluation process.

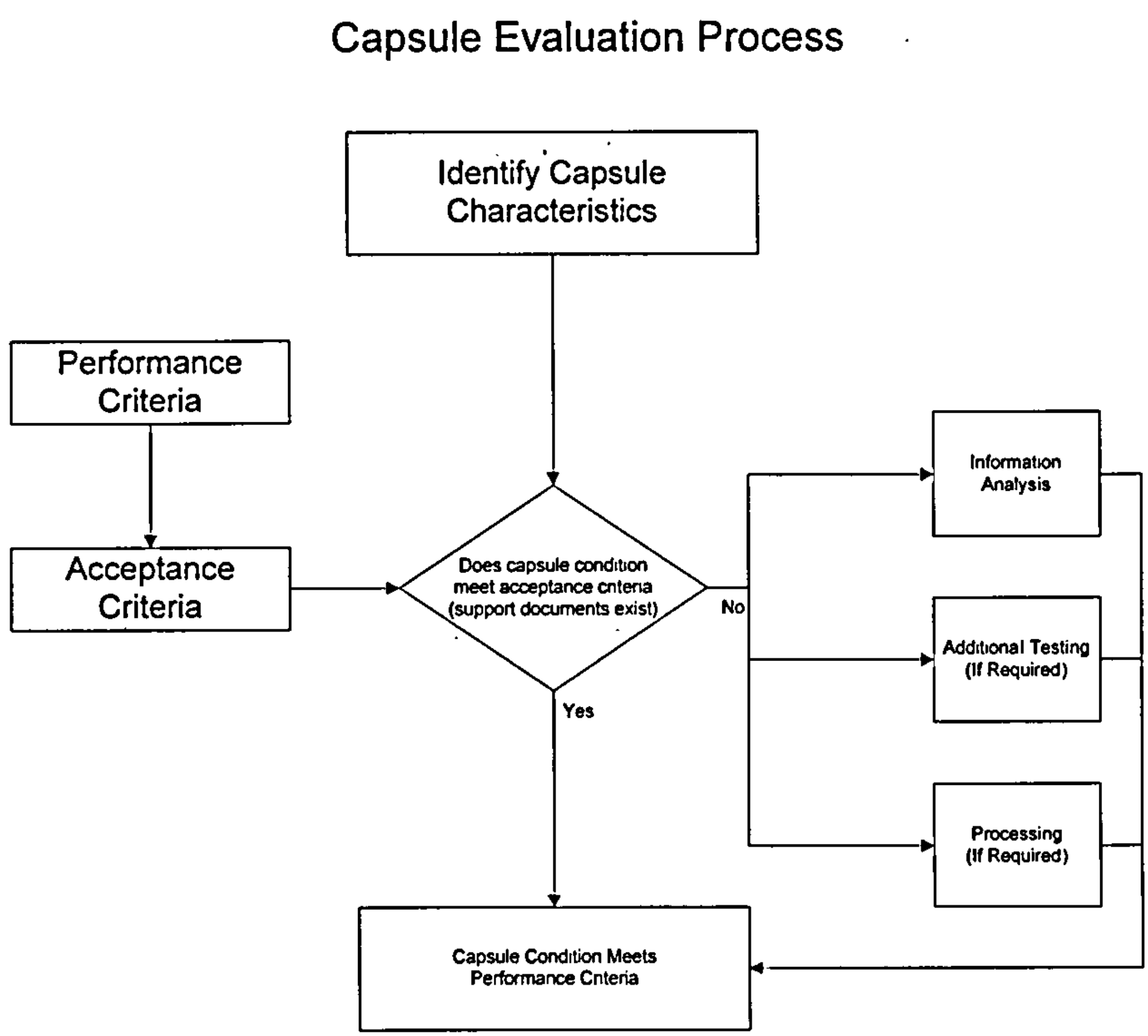

Figure 5.1. Capsule Attribute Evaluation Process.

The first step in the evaluation process is to determine whether the capsule can meet the acceptance criteria in its current condition. Historical information, results from previous inspections and tests, as well as new corrosion studies will be reviewed to assist in this assessment. If it is determined that the capsule condition meets the acceptance criteria, the capsule condition is considered acceptable for overpacking and transfer to dry storage with respect to that acceptance criteria.

If the capsule condition does not meet the acceptance criteria, then additional information analysis, testing, and/or processing may be required to satisfy the criteria before the capsule can be overpacked. Any additional analysis and/or testing that need to be performed will be identified. Results of the analysis and/or testing will be documented and accepted before the capsule can be overpacked. For capsules that cannot be shown to meet the acceptance criteria, and additional analysis or testing is not beneficial, then processing may be required. These options are discussed further in Section 7.0.

6.0 CAPSULE CHARACTERISTICS COMPARISON WITH ACCEPTANCE CRITERIA

The known characteristics of the capsules were compared with the acceptance criteria. The following sections provide the findings of these comparisons:

6.1. Acceptance Criterion 4.1.1: The inner and outer capsules were fabricated and inspected to documented fabrication requirements when they were constructed.

Evaluation: The inner and outer capsules were fabricated in accordance with specified requirements to be described in WMP-16878 and referenced drawings and specifications (see Section 9.0). Materials specifications and dimensional tolerances were specified in the fabrication drawings. All the material and fabrication records were inspected in accordance with established quality assurance (QA) procedures (see fabrication drawings, Section 9.0). Information on the fabrication and inspection of the capsules is also available in the production run books.

Results: Strict adherence to the operating and QA procedures satisfied this criterion.

6.2. Acceptance Criterion 4.1.2: The inner and outer capsule welds met the documented weld inspection criteria when they were originally fabricated.

All welding was performed in accordance with a systemic, quality controlled program, which included qualification of the welding operators, welding process, and procedures and materials in accordance with Section IX of the *American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code*. According to facility records, all welds accepted into the WESF system met specified quality and weld inspection requirements. Capsules welds that did not meet the strict QA requirements were rejected and welds were repaired or redone. The capsules were fabricated according to the referenced drawings. Section 3.4 discusses the difficulties and challenges faced in the welding program. Information on the fabrication and inspection of the capsules is also available in the production run books (WESF Run Books 74-0` to 83-32).

It is recognized that the original inspection system was not designed to detect all weld flaws. The inspection strategy, coupled with requirements for materials, design and fabrication, was considered adequate for the intended service. These undetected flaws however, have the potential to affect capsule service when the service exceeds the design criteria, as was apparently the case for C-1592 (see 3.4.2.1). It is also possible that others were not detected. C-287 is an example of this (see 3.4.2.1).

Results: Adherence to established welding standards and procedures satisfied this criterion. However a few weld defects have been detected in subsequent examinations. Weld failures are not expected, but can not be precluded. Handling in a hot cell facility (WESF) will protect against release from any failures.

6.3. Acceptance Criterion 4.1.3: The inner capsule is capable of sliding inside the outer capsule while submerged in water to verify that:

- **The inner capsule has not corroded through the wall and leaked a significant quantity of radioactive material to the annulus between the inner and outer capsules.**
- **The outer capsule has not leaked a significant amount of water into the annulus between the inner and outer capsules.**
- **The inner capsule has not bulged to a point that it presses against the outer capsule.**

Evaluation: The ICM test described in Appendix A determines whether the inner capsule is free to move within the outer capsule. All Cs capsules are ICM tested on a yearly basis. Sr capsules were ICM tested last in 1992, and since they have never left the WESF pool cells, no further testing has been conducted. Operational records show that all the capsules in the pool cells passed the last ICM test performed. As a measure to add additional assurance, all capsules, including Sr capsules, will be ICM tested again before overpacking for dry storage begins. The ICM test sheets and WESF logbooks, located in the WESF facility provide the information on the test results.

Results: Completion of the ICM test on all the capsules in the pool cells prior to overpacking will satisfy the requirements of this criterion.

6.4. Acceptance Criterion 4.1.4: The outer capsule exterior is free of smearable contamination.

Evaluation: Inner capsules were cleaned and tested for smearable contamination before being placed in the outer capsule. The inner capsule was transferred to a clean cell for encapsulation in the outer capsule. The outer capsules were smear tested after fabrication before placing them in the pool cells (see WESF Run Books 74-0' to 83-32). The water in the pool cells has been monitored and maintained contamination free. G Cell has been maintained to be free of contamination and will be inspected again, cleaned if necessary, prior to the start of loading operations.

Capsules received from RSI, Ohio, have surface coating of foreign material. The composition of the coating material is unknown but it can be easily scrubbed. These capsules will be scrubbed to remove the coating before placing them in dry storage overpack.

Results: All the capsules in the pool cells are and will be maintained free of smearable contamination to satisfy this criterion.

6.5. Acceptance Criterion 4.1.5: The capsule has not deformed to a point that it will bind or stick while being placed into an overpack.

Evaluation: The capsules were visually inspected for deformation before placing them in the pool cells. Any capsules that were bulged or deformed were placed in Type W overpacks. The visual examination planned prior to placing the capsules into the dry storage overpacks will verify this condition.

Results: The operational records show that none of the capsules stored in the pool cells are deformed to cause sticking or binding in the overpack. As the consequences of a stuck or bound capsules are severe, a method will be developed to inspect a suspect capsule to assure compliance with this criterion.

6.6. Acceptance Criterion 4.1.6: The outer capsule is of visible cracking and surface pits/dents greater than 1/16 inch.

Evaluation: All capsules were visually examined previously before placing them in the pool cells. Visual examination of the capsules will be repeated prior to loading into overpacks in accordance with ASME Section V requirements. The system will consist of a relatively high-magnification video system installed in the hot cell. The examination will be able to detect pits, cracks, flaws, and undercuts on the surface of welds, but may not be able to detect fine or "micro-cracks". Capsules will be accepted if there are no visible cracks."

Note: It is recognized that the sensitivity of VT may not disclose fine or micro cracking – see Section 6.8 for a discussion of this issue.

Results: Capsules meeting the criteria noted above will be deemed acceptable with regard to this criterion.

6.7. Acceptance Criterion 4.1.7: The capsule is capable of maintaining containment during normal handling, including minor collisions and drops, during overpacking. These requirements are:

- **Capsules survive normal manipulator gripping force (50 lb) without the release of any capsule contents.**
- **Capsules survive a drop of 4 ft without the release of any capsule contents.**

Evaluation: Drop testing of the surrogate capsules performed several times showed that the capsules were built to withstand 30-ft drop without suffering structural damage that will compromise the integrity of the capsules. As discussed in the following section, the material properties of the outer capsule (structural member of the capsule) have not degraded appreciably from the original material of construction. Capsule integrity will not be compromised (suffer catastrophic failure) under normal handling loads. A cursory evaluation of thermal aging of the capsule materials under worst historical conditions and structural performance of outer capsules (Appendix B) showed that failure of the capsule during normal handling conditions including manipulator gripping and minor collisions and drops (4 ft) is not predicted.

Results: The capsules are capable of maintaining containment during normal handling, including minor collisions and drops, during overpacking operations.

6.8. Acceptance Criterion 4.1.8: Material properties of the outer capsule (structural member of the double encapsulation) have not degraded to a point where capsule integrity would be severely compromised (suffer catastrophic failure) under normal handling loads.

Evaluation: The following environmental degradation processes were evaluated for their potential effect on the capsule:

Thermal Aging: Thermal aging, exposure of the capsule material to a given thermal condition (elevated temperature) for a prolonged period of time, may have a deleterious effect on mechanical properties of the capsules. Of particular concern is the loss of material fracture toughness and its potential impact on capsule handling.

The time-at-temperature exposure considered for this evaluation is conservatively estimated at 20,000 hours at temperature between 300 °C and 400 °C for the outer capsule walls. This represents a postulated condition of keeping the capsules in service at elevated temperatures at all times for 26 months, the worst-case condition that a capsule may have been subjected to at one of the commercial irradiator facilities. It is likely however, that the capsules were in service for less than 50% of the time.

An extensive study of the effects of long-term thermal aging on the fracture toughness of austenitic stainless steel base and weld materials was reported in *Effect of Long Term Thermal Aging on the Fracture Toughness of Austenitic Stainless Steel Base and Weld Metals* (Huang 1995). Specifically, it was concluded that no significant loss of fracture toughness (with regard to service requirements) will occur in Type 316 base and weld materials at less than 50,000 hours at 482 °C. Data reported in "Fracture Toughness Of Type 304 and 316 Stainless Steels and Their Welds" (Mills 1997); "The Fracture Toughness Behaviour of Austenitic Steels and Weld Metal Including the Effects of Thermal Aging and Irradiation" (O'Donnell et al. 1996); and "Effect of Long Term Aging on the Mechanical Properties of Stainless Steel Welds in PWR" (Faure et al. 1992) supports this conclusion with the following finding: "Below 450 °C, long-term thermal aging has minimal effect on J_{Ic} (a measure of resistance to fracture) of unirradiated wrought austenitic stainless steels."

In addition, one of the capsules that had been exposed to the Irradiator service (Capsule C1592 – one of two capsule failures considered to have experienced "worst-case" conditions) was evaluated by hardness testing (74A40-96-JHH-003). Results from this capsule were compared to hardness values from a capsule fabricated from a similar lot of material that had not been put into service (C-1835). No significant difference in hardness values between the two capsules was noted. A strong correlation between the fracture toughness and hardness properties of austenitic stainless steel, i.e., generally, as fracture toughness decreases, hardness increases (No. 9014, NiDI "Design Guidelines for the Selection and Use of Stainless Steel), exists. The information from this testing provides an additional data point supporting the studies noted above.

It is concluded from the above, that fracture toughness properties of the outer capsule weldments, at the time of overpacking, will not vary significantly from the original capsule properties (time of fabrication). However, exposure of the outer capsule walls to temperatures above 450 ^{0}C can result in loss of fracture toughness.

Stress Corrosion Cracking: Stress corrosion cracking (SCC), a process that requires the simultaneous action of a corrodent and a sustained tensile stress, would impact capsule weld soundness. Of primary concern would be the presence of gross cracking and its potential impact on capsule handling. There is reason to believe some of the capsules may have been subjected to conditions conducive to SCC. Capsule weldments were not annealed (source of residual tensile stress) and exposure to aggressive corrodents cannot be ruled out due to suspect water chemistry control at some of the irradiator facilities.

Visual examination, per Section 6.6, prior to overpacking should disclose gross cracking but cannot be relied upon to detect micro-cracking. Inspection for this type of flaw is not practical, and thus there is the possibility that some of the capsule weldments contain micro-cracking. The likelihood of this being the case appears to be small however given the capsule history.

A relatively small number of the capsules were subjected to conditions conducive to SCC (those sent to the RSI irradiator facility). Since then, capsule handling experience would indicate that such flaws, if present, have not impacted the performance of the capsules. These capsules have been subjected to shipping, handling, processing operations at both WESF and the irradiator facilities, and testing (including the ICM test) without incidence, i.e., catastrophic failure. This is a strong indicator that the capsules are suitable for dry storage handling and processing and that failure should not be expected. However, micro-cracking cannot be completely ruled out and as such one final measure of protection is afforded: The WESF facility is designed to accommodate leakage from a capsule should a weld fail during processing and handling.

It is noted that one of the reasons for the good performance may be due to the fact that austenitic stainless steels are generally not sensitive to notches, i.e., these materials are not susceptible to brittle failure. It was shown above, under the thermal aging discussion, that the capsules have retained these "good" properties (fracture toughness). If capsules are exposed to temperatures above 500 ^{0}C in dry storage, loss of fracture toughness can occur. Were small areas of micro-cracking to exist, it is likely that they would arrest under normal handling loads and avoid catastrophic failure.

Intergranular Attack: Intergranular attack (IGA), corrosion occurring preferentially at grain boundaries, usually with slight or negligible attack on adjacent grains, would impact capsule weld soundness. Of potential concern would be the presence of significant cracking or loss of weld cross-sectional area. IGA occurs in austenitic stainless steels as a result of carbide precipitation at the grain boundaries, referred to as sensitization. Sensitization is generally considered to occur between the temperatures of 540 °C and 845 °C (*ASM Handbook* [1987]).

It is concluded that sensitization has not occurred because the maximum service temperature experienced by the capsule outer walls is 200 °C to 300 °C, well below the minimum threshold where significant sensitization begins.

With regard to the weldments, which do encounter temperatures in the sensitization range, grain boundary precipitation of 316L (carbon content ≤ 0.030%) is not a concern due to the short-time exposure associated with welding (NiDi Handbook, No. 9014, *Design Guidelines for the Selection and Use of Stainless Steel*).

Hydrogen Embrittlement: Hydrogen embrittlement, a process resulting in a decrease of toughness or ductility due to the presence of atomic hydrogen, could potentially contribute to the loss of fracture toughness in the capsule. Welding was performed using a shielding gas, which included hydrogen, thus providing a potential source of hydrogen.

The capsules are considered to have been unaffected by exposure to hydrogen. Austenitic stainless steels, with "good" material properties are "...basically immune to hydrogen induced cracking (HIC)..." or hydrogen embrittlement (WSRC-TR-2002-00290, "Effect of Minor Additions of Hydrogen to Argon Shielding Gas When Welding Austenitic Stainless Steels with the GTAW Process (U)").

The as-fabricated capsule material condition is considered "good" and, as noted above in the discussion on thermal aging, were not degraded as a result of service since the time of fabrication.

Radiation Embrittlement: High radiation, specifically neutron radiation, causes microscopic nucleation of defect aggregates such as voids and precipitates in the austenitic stainless steel and change mechanical property transients. The capsules contain radioactive isotopes of ^{137}Cs and ^{90}Sr that are emitters of beta and gamma radiation. The approximate particle flux and particle fluence values for the Cs and Sr capsules are:

Sr-90 Flux / Fluence:

	Max energy (keV)	Intensity (per decay)	Avg energy (keV)	Flux @ t=0 yr (γ/cm^2)	Flux @ t=60 yr (γ/cm^2)	Fluence 60 yrs
Beta	546.00	100.0%	195.8	2.110E+11	4.978E+10	2.114E+20
Beta	93.83	1.40E-08	25.0	2.955E+03	6.970E+02	2.959E+12
Beta	519.39	0.0115%	185.6	2.427E+07	5.725E+06	2.431E+16
Beta	2280.1	99.9885%	933.7	2.110E+11	4.978E+10	2.114E+20
Photon	2186.242	1.40E-08	2186.242	4.463E+04	1.053E+04	4.470E+13

Cs-137 Flux / Fluence:

	Max energy (keV)	Intensity (per decay)	Avg energy (keV)	Flux @ t=0 yr (γ/cm^2)	Flux @ t=60 yr (γ/cm^2)	Fluence 60 yrs
Beta	513.97	94.4%	174.32	1.550E+11	3.887E+10	1.589E+20
Beta	892.22	0.00058%	300.57	9.522E+05	2.388E+05	9.764E+14
Beta	1175.63	5.6%	416.264	9.194E+09	2.306E+09	9.427E+18
IC Electron	661.657	9.89%	661.657	1.624E+10	4.072E+09	1.665E+19
Gamma	283.53	0.00058%	283.53	1.438E+07	3.608E+06	1.475E+16
Gamma	661.657	85.1%	661.657	2.110E+12	5.293E+11	2.164E+21

The only affect of concern is the beta flux hardening of the inner surface layer of the inner stainless steel capsule ("Dose dependence of the microstructural evolution in neutron irradiated austenitic stainless steel" [Zinkle et al. 1993]). This is a result of the beta particles producing atomic displacements. The penetration depth even for the 500 keV electrons is shallow on the order of a few tenths of a micrometer. The gammas do not produce damage in metals.

Cyclic Fatigue: Cyclic fatigue, a process leading to fracture under repeated or fluctuating stresses having a maximum value less than the ultimate tensile strength of the material, would impact capsule weld soundness. Of potential concern would be the presence of significant cracking where catastrophic failure could initiate under the handling loads identified in Section 3.1. Some of the capsules sent to irradiator facilities were subjected to thermal cycling operations, which could possibly have caused cyclic fatigue.

In an effort to evaluate the effect of this thermal cycling on capsule weldment properties (it is the weldment that sees the greatest effect of thermal cycling due to the large difference in thermal mass between the end cap and the sidewall), finite-element analysis and testing was performed (*WESF Cesium Capsule Behavior at High Temperature or During Thermal Cycling*, [Tingey et al. 1985]). The analysis and test set up included routine conditions* representative of an irradiator facility using a wet/dry mode of operation. This work concluded that no significant cracking would occur (crack of $\leq$0.0001 in. after 3.5×10^4 cycles or 94 years if cycled once each day).

*It is recognized that some of the irradiator capsule processing parameters probably exceeded the routine conditions considered in this analysis. This is evidenced by the fact that a few of the capsules failed to pass the ICM test, indicating excessive swelling of the inner capsule. These capsules were placed in Type W overpacks or destructively examined.

The Cs capsules in the pool cells have been ICM tested that includes gripping the capsules with manipulator force (50 lb). None of the capsules have experienced any damage during the test.

Environmental degradation of the capsule materials evaluated to determine the effects of thermal aging, stress corrosion, radiation, hydrogen embrittlement, and cyclic fatigue. Thermal aging and structural performance of outer capsules (Appendix B) showed that failure of the capsule during normal handling conditions including manipulator gripping and minor collisions and drops (4 ft) is not predicted.

Liquid metal embrittlement: LME is a degradation mode that can result in cracking of ductile materials. Welds are the most susceptible regions for cracks to occur. Cracking could lower the fracture resistance of capsules during handling and accidents such as dropping. Lead chloride ($PbCl_2$) and lead fluoride (PbF_2) may be present as impurities in the cesium and strontium capsules and could be reduced to metallic lead by reaction with the stored salts or corrosion of the capsule walls. However, capsules examined after testing at elevated temperatures (450 °Cat the salt/metal interface) for up to six years have not exhibited the effects of liquid metal embrittlement. Handling, shipping, use at the irradiator facilities, and ICM testing have not resulted in capsule wall failures due to LME, also suggesting LME has not significantly affected the capsule welds. The possibility LME could occur cannot be precluded. However, all capsule handling will be performed in the WESF, which is designed to safely contain any leakage should it occur due to LME. Since the inner capsule wall is not expected to be breached by corrosion during the 50-year dry storage lifetime, the potential for LME of the outer capsule wall is minimal. Leakage through the inner wall, and potentially the outer wall, of one or more capsules is not anticipated, but cannot be precluded. The amount of material that could be released from a failed capsule is small based on the analyses in WMP-16939. Therefore, once the capsules are loaded in the overpacks, LME will not jeopardize the ability to handle and retrieve the capsules at the end of dry storage if necessary, nor will it jeopardize the overpack integrity.

Results: The evaluation of the capsule show that the capsule material properties of the capsule walls have not degraded due to environmental degradation processes. The capsule integrity would not be compromised under normal handling loads. The capsule is capable of maintaining containment during normal handling, including minor collisions and drops, during overpacking operations. However the potential for stress corrosion cracking can not be precluded. Handling within a hot cell facility (WESF) will protect against release from any failures.

6.9. Acceptance Criterion 4.1.9: The inner and outer capsule walls have not experienced gross bulk thinning due to corrosion prior to loading the capsules into an overpack based on corrosion predictions. Specifically:

- **Bulk corrosion of the inner capsule wall is predicted to not exceed 25% of the original wall thickness.**
- **Bulk corrosion of the outer capsule wall is predicted to not exceed 10% of the original wall thickness.**

Evaluation: Impurities in the CsCl and SrF_2 materials are known, and their impact to corrosion rates has been analyzed. A corrosion study (WMP-16937) has been performed to estimate the loss in inner and outer capsule wall thickness due to corrosion of the 316L SS material for Cs capsules and Sr outer capsules and the Hastelloy C-276 material for the Sr inner.

WMP-16937 states that the major cause of corrosion in the capsules is the impurities in the salt mixture. Corrosion rate decreases with time as the impurities are depleted and the temperature decreases with time as the isotopes decay. If all impurities were allowed to react with the metal wall, about less than 20% of the inner capsule wall of the Cs capsule will be corroded. ICM testing on the Cs capsules shows that Cs salt has not corroded through the inner capsule wall and leaked significant amount of material into the annulus. Similar corrosion results (less than 5-10%) are expected in the Sr capsules (WMP-16937).

Thermal cycling and higher temperatures experience at some of the irradiator facilities would have increased the corrosion rate above that for the capsules stored in the WESF pool cells. However the corrosion analysis is conservatively estimated based on total consumption of all impurities. Therefore, any corrosion experienced at the irradiation facilities is bounded by the conservative total corrosion estimate in WMP-16937.

The outer capsules will not experience corrosion for two reasons: (1) because it did not experience exposure to higher temperatures as the inner capsules, and (2) all the impurities will be consumed by the inner capsules. The details of the corrosion from the salts and potential for stress corrosion at the irradiators are provided in WMP-16937. Capsules returned from the irradiators that failed the ICM test could have failed primarily due to thermal cycling and salt expansion instead of corrosion. These capsules were placed in a Type W overpack to provide additional containment.

Results: Wall thickness has not been significantly compromised due to bulk corrosion. Maximum corrosion of the inner capsule wall is limited to less than 20% of the original wall thickness in Cs capsules and less than 10% in Sr capsules. These findings satisfy this criterion.

6.10. Acceptance Criterion 4.2.1: The capsules have satisfied the first criteria (3.2) for initial loading into the overpacks.

Evaluation: The results of the evaluation of capsules against the acceptance criteria from Section 4.1 show that all the capsules satisfy that criteria.

Results: All the capsules are suitable for initial loading into the overpacks for dry storage.

6.11. Acceptance Criterion 4.2.2: The outer capsule wall structure maintains sufficient physical integrity to contain the bulk Cs and Sr materials. Specifically corrosion predictions shall show that leakage of CsCl and SrF_2 through the outer capsule wall is limited to a small percentage (<1%) of the total contained salts.

Evaluation: Criterion 6.8 shows that under the storage environments the corrosion of the inner capsule wall is expected to be less than 10% of the original wall thickness for Cs capsules and less than 5% for the Sr capsules. The outer wall of the capsules is not expected to have any corrosion from the salts especially when the inner capsule has not leaked any material to the annulus. The overpack will be designed to provide containment of any material that may leak from the capsule. The detailed consequences of the capsule failure will be addressed in the hazard analysis.

Results: The capsules will maintain their integrity to contain the salt materials.

6.12. Acceptance Criterion 4.2.3: The capsule is capable of maintaining containment during normal handling, including minor collisions and drops, during retrieval of the capsules from the overpacks if needed. These requirements are:

- **Capsules will survive normal manipulator gripping force (50 lb) without the release of significant (~1%) amount of capsule contents.**
- **Capsules will survive a drop of 4 ft without the release of significant amount of capsule contents.**

Evaluation: Drop testing of the surrogate capsules performed several times showed that the capsules were built to withstand 30-ft drop without suffering structural damage that will compromise the integrity of the capsules. An evaluation of thermal aging of the capsule materials under worst historical conditions and structural performance of outer capsules (Appendix B) showed that failure of the capsule during normal handling conditions including manipulator gripping and minor collisions and drops (4 ft) is not predicted. Long term thermal aging at temperatures below 450 °C has minimal impact on austenitic stainless steels (WMP-16939). The outer capsules that provide the structural integrity will be maintained at temperatures between 200 °C and 300 °C, that is considerably less than 450 °C (WMP-16940).

Results: The capsules would be capable of maintaining containment during normal handling, including minor collisions and drops, during retrieval operations in case needed.

6.13. Acceptance Criterion 4.2.4: Material properties of the outer capsule (structural member of the double encapsulation) have not degraded to a point where capsule integrity would be severely compromised (suffer catastrophic failure) under normal handling loads

Degradation processes include:

- **Thermal aging**
- **Stress corrosion cracking**
- **Intergranular attack**
- **Hydrogen embrittlement**
- **Radiation embrittlement**
- **Cyclic fatigue**
- **Liquid metal embrittlement.**

Evaluation: The evaluation of the capsules in criterion 6.6 showed that the capsule material properties of the capsule walls have not degraded due to thermal aging, stress corrosion, radiation, hydrogen embrittlement, and cyclic fatigue to a point that the capsule integrity would be compromised under normal handling loads. The capsules are capable of maintaining containment during normal handling, including minor collisions and drops, during overpacking operations. Once the capsules are placed in the overpacks and stored in the dry storage system, the environment of the capsules will be controlled to minimize the impact of the degradation processes on the capsule walls. Long term thermal aging at temperatures below 450 °C has minimal impact on the structural integrity of the outer capsule materials (WMP-16939). The outer capsules will be maintained at temperatures between 200 °C and 300 °C (WMP-16940). The only degradation process will be corrosion due to chemicals. WMP-16937 showed that the corrosion during the 50-year dry storage will be limited and will not impact the structural integrity of the capsules.

Results: The capsules at the end of 50- year dry storage will have structural integrity for normal handling during retrieval operations.

6.14. Acceptance Criterion 4.2.5: The capsules have not deformed due to swelling or bulging (e.g., induced by CsCl phase changes) sufficiently to prevent meeting the leakage criteria.

Evaluation: CsCl has two differing solid phases. The solid-solid phase transition occurs between 330 °C and 475 °C depending on the impurities present in the solids. This phase change results in an expansion of the CsCl volume by up to 18%.

One of the capsules failed at the RSI, Decatur, Georgia, irradiation facility due to expansion. Examination of the capsules showed that the expansion of the salt, due to thermal cycling of the capsule, caused the failure of the inner capsule. A thermal analysis of the Decatur irradiation system, performed by Eyler (1989), predicted a maximum centerline CsCl temperature of 468 °C and a maximum surface temperature of 289 ° for worst case conditions. It is postulated that continued thermal cycling (7,300 times) through the transition temperature, along with movement of the salt into the lower region of the capsule, would cause excessive annular stresses to the capsule resulting in possible rupture.

Twelve capsules experienced swelling due to thermal cycling at the irradiator facility; they did not pass the ICM test due to swelling. Those capsules were placed in the Type W overpacks.

Results: Even though partial solid-solid phase transformation of CsCl may occur during the early dry storage years, the capsules will not experience severe thermal cycling (see WMP-16939 for details).

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7.0 RECOVERY STRATEGY

Evaluation of the information and data available on the capsules indicated that all the capsules stored in the WESF pool cells can be shown to meet the performance criteria for overpacking and 50-year dry storage. To verify these results, all the capsules should be tested with the ICM test prior to moving the capsules to the G-cell and enhanced VT in the G-cell prior to overpacking. These tests may identify a suspect capsule. In addition, handling mishaps such as a minor collision or drop during overpacking operations may challenge the capsule integrity. New information may become available that could bring uncertainty to the integrity of the selected capsules.

A recovery strategy is outlined to disposition a capsule should its integrity become suspect for the overpacking operations due to any of the aforementioned reasons. The capsule evaluation process flow diagram (Figure 5.1) includes the following three options to ensure that the capsule in question will meet the performance criteria before it is placed in the overpack.

7.1 ANALYSIS

This option is used if new information supporting the capsule integrity is questioned. It includes modeling the capsule and further analysis of the existing information to satisfy the performance criteria that is in question. This is the first and preferred option.

7.2 TEST

This option is used if the existing information does not provide adequate support for the analytical evaluation. A simple test, like an ICM test or VT, is performed to verify the existing information or collect new information in order to comply with the performance criteria. The requirement for testing will be identified, test procedures will be prepared, and tests will be performed with test results documented and approved prior to capsule overpacking. A capsule that becomes a suspect for overpacking process due to minor collision or drop during normal overpacking operations can also be tested using this step.

7.3 PROCESSING

If a capsule becomes suspect and cannot be shown to meet the performance criteria by analysis, additional tests and processing may be required to resolve issues related to the capsule integrity. Two possible options can be considered by the project to handle a capsule that does not meet the performance criteria:

- Place the capsule in an overpack similar to the Type W overpack. In the past, if a capsule failed the ICM test or VT it was placed in a Type W overpack. However the capability to place the capsule in Type W overpack no longer exists at WESF.

- Place the capsule in the F-cell and handle it separately from the project.

As the schedule for the project is very aggressive, handling of a suspect capsule could become a major issue if not addressed during the design of the capsule overpacking system.

Based upon previous practices, placing the suspect capsule into another capsule (probably similar to the Type W capsule) is one of the most effective methods to meet the performance criteria.

If a new individual capsule overpack design is selected as the preferred method, certain options should be addressed. These options include:

- The previous welding system is no longer available. Other welding systems such as that used in welding of Plutonium Finishing Plant containers might be adopted for welding of a capsule overpack. A welded capsule overpack design has the advantage of potentially matching the geometry of the existing Type W overpack. This would allow the new overpack(s) to be used in the same type of insert as is planned for the Type W overpacks.

- A new mechanically sealed capsule overpack may also be possible to handle a suspect capsule. The overpack design would have to be shown to meet the integrity criteria, including corrosion resistance, to meet the performance criteria for the capsules for dry storage. Design of a new mechanically sealed overpack could result in a package design with a larger diameter than the current Type W overpacks. This larger diameter may be required to achieve the high sealing forces necessary for corrosion resistance seals such as those made of metal. However it may be possible to demonstrate that a completely leak tight seal is not mandatory. If the diameter of the new suspect capsule overpack is larger than that of the existing Type W overpacks, a new insert design will be required to load these new overpacks for dry storage.

These considerations indicate that providing a new suspect capsule overpack capability will take considerable effort and time. The project should address this in its overall schedule to ensure a suspect capsule can be addressed expeditiously during the relatively short time available for loading the capsules into the dry storage.

8.0 CONCLUSIONS

Table 8.1 summarizes the capsule characteristics against the performance criteria established to determine the acceptability of the capsules for overpacking and interim dry storage. The evaluation results in this report indicate that the current condition of the capsules meets the performance criteria for capsule overpacking. As a measure to provide additional assurance of the capsule conditions, ICM testing of all capsules and Type W overpacks, an enhanced visual inspection of the capsules, and verification of fit into an overpack for all capsules will be performed prior to capsule overpacking.

Table 8.1. Capsule Evaluation against Acceptance Criteria. (2 sheets)

Acceptance criteria	Capsule evaluation	Capsule meets criteria
4.1.1: Quality of capsule materials and fabrication was sound.	Capsules were fabricated by qualified operators in accordance with established and approved procedures and inspected by qualified inspectors.	Yes
4.1.2: Quality of welds was sound.	Welds were performed by qualified operators in accordance with ASME codes and accepted by qualified inspectors. However a few weld defects have been detected in subsequent examinations. Weld failures are not expected, but cannot be precluded. Handling in a hot cell facility (WESF) will protect against release from any failures.	Yes
4.1.3: Capsules are capable of passing the ICM test.	All capsules passed the latest ICM test. A verification ICM test on all capsules is planned prior to the overpack operations.	Yes – Final Verification needed.
4.1.4: Exterior of the capsule is free of smearable contamination.	All capsules were smear tested before placing them in the pool cells and G-cell will be maintained free of contamination.	Yes – Remove surface coating from RSI Wester-ville capsules.
4.1.5: Capsules are not deformed to cause binding in the overpack.	All capsules were inspected before placing them in the pool cells. Verification prior to loading into an overpack is needed.	Yes – Final Verification needed.
4.1.6: Capsules are free of surface damage.	All capsules were visually inspected before placing them in the pool cells. Enhanced visual examination is recommended before placing the capsules in the overpacks.	Yes – Final Verification needed.
4.1.7: Capsules have maintained structural and containment integrity.	Evaluation of the capsule wall materials showed they have not been degraded by the environment they have been exposed to. The capsules can withstand normal handling during overpacking operations.	Yes
4.1.8: The material properties of the capsule walls have not degraded to a	The evaluation shows the material properties of the capsule walls have not degraded due to environmental	Yes

Table 8.1. Capsule Evaluation against Acceptance Criteria. (2 sheets)

Acceptance criteria	Capsule evaluation	Capsule meets criteria
point that the capsule integrity would be compromised under normal handling loads. Degradation processes include: • Thermal aging • Stress corrosion cracking • Intergranular attack • Hydrogen embrittlement • Radiation embrittlement • Cyclic fatigue • Liquid metal embrittlement.	degradation processes. The capsule integrity would not be compromised under normal handling loads. The capsule is capable of maintaining containment during normal handling, including minor collisions and drops, during overpacking operations. However the potential for stress corrosion cracking cannot be precluded. Handling within a hot cell facility (WESF) will protect against release from any failures.	
4.1.9: Inner and outer capsule walls have not corroded to cause failure during overpacking operations.	Corrosion study on the Cs capsules has shown less than 20% of the inner wall in contact with the salt will be corroded. The outer wall is not expected to experience any corrosion. A less than 20% reduction in wall thickness is acceptable for structural strength. The corrosion of the Sr capsules is estimated at less than 5-10% of the inner capsule wall thickness.	Yes
4.2.1: Condition of all capsules is acceptable for dry storage overpack	Evaluation shows all the capsules are acceptable for dry storage overpack.	Yes – Assuming verification noted above is successful
4.2.2: The capsule will maintain its integrity after dry storage life to contain the salt materials.	The corrosion of the inner and outer walls is not expected to impact the integrity of the capsule to maintain containment of the salt materials.	Yes
4.2.3: Capsules will not fail during normal handling and minor collisions and drops during retrieval if needed.	The evaluation showed that the capsule walls will not experience environmental degradation to reduce the structural integrity of the capsules.	Yes
4.2.4: The material properties of the capsule walls have not degraded to a point that the capsule integrity would be compromised under normal handling loads.	The capsules at the end of 50-year dry storage will have sufficient structural integrity for normal handling during retrieval operations.	Yes
4.2.5: Capsules have not deformed due to expansion of the salts due to phase changes.	The temperature of the capsules will be maintained below the complete phase transformation temperature. Also the capsules will not see severe thermal cycling.	Yes

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APPENDIX A. DISCUSSION OF TEST METHODS

A1.1 CALORIMETRIC TEST

The purpose of this test was to determine the heat generation rate by the decay of the materials in the capsule. Heat generation rate was then converted into power (watts).

The Waste Encapsulation and Storage Facility (WESF) calorimeter consisted of two vessels, one inside the other with a water coil in the annulus. During the normal operation, water bath was confined to the inner vessel, which also contained a wire mesh basket holding the capsule and a lead annulus surrounding the basket for radiation absorption. The volume of the bath, which was agitated by an air sparger, varied between 20 and 22 liters. Bath temperature was monitored by thermocouples, which read out in the WESF operating gallery.

The temperature increase of the un-cooled bath was measured as a function of time. The standard operating mode was to establish a steady state temperature differential from the center of the capsule core to the agitated water bath. The bath temperature rise was recorded as a function of time. The resulting data was fitted to a straight line by least squares calculations. The slope of this line then permitted calculation of the capsule heat generation rate.

A1.2 INNER CAPSULE MOVEMENT TEST

The purpose of the inner capsule movement (ICM) test is to detect an increase in the diameter of the inner capsule caused by the swelling of cesium chloride (CsCl) and strontium fluoride (SrF_2) salt and presence of water or salt between the inner and outer capsule. Using underwater tongs, the capsule was quickly lifted in the vertical position approximately 6 in. This could cause the inner capsule to slide inside the outer capsule and produce a "clunk" sound. The capsule identification number is read using an underwater video camera.

Details of the ICM Test procedure are provided in Operating Procedure # EO-905-030, "Perform Inner Capsule Movement Test and Visual Inspection."

A1.3 WELD QUALITY TESTS

A1.3.1 Visual Test

The purpose of visually testing (VT) the completed capsule welds is to determine weld integrity or weld soundness. In addition to disclosure of discontinuities open to the weld surface, such as cracks, porosity, undercut, etc., VT can provide much information about the operation of the welding process. VT is an integral part of assessing the overall quality of the fabrication process. VT was applied to all capsule welds.

A1.3.2 Bubble Leak Test

The purpose of bubble leak testing is to detect gross leaks. The capsules were submersed into a tank of water for 15 minutes -- the appearance of bubbles indicates presence of a gross leak. Bubble leak testing was applied to all inner capsule welds.

A1.3.3 Penetrant Test

The purpose of liquid penetrant testing was to detect small and tight discontinuities open to the weld surface; those not readily disclosed by visual testing. Penetrant testing was applied only to the capsule end welds made in the shop, those made prior to loading of product into the capsule. This included both inner and outer capsules.

A1.3.4 Helium Leak Test

The purpose of the helium (He) leak test was to detect fine leaks. A sintered disk, saturated with He, was positioned between the product and the end cap closure. After the closure weld was made, the capsule was placed into a vacuum bell jar and sniffed for the presence of He. Detection of He, at a defined leak rate, indicates presence of a fine leak. He leak testing was applied to the closure weld of the inner capsule only.

A1.3.5 Ultrasonic Test

The purpose of ultrasonic testing was to determine the level of weld penetration into the weld joint. Ultrasonic testing is performed by directing a high-frequency sound beam into a test part, and evaluating any reflected signal. Testing of the capsule welds included pre-calibration of the equipment by scanning a standard (capsule end with known reflectors), scanning a capsule weld mockup (weld with known penetration), scanning the production capsule weld, and post-calibration verification by re-scanning the standard. Traces from each of the scans were evaluated for accuracy and comparative analysis to assess weld penetration levels of the production capsule weld. Ultrasonic testing was applied to all capsule welds except for the closure weld of inner capsules. A variation of the above was also employed in which the standard, the weld mockup and production capsule were scanned producing a single trace. Results from this trace were evaluated and analyzed as noted above.

A1.4 SMEAR TEST

This test was performed to assure that the capsules are free of smearable contamination before they are placed in the pool cells.

The capsule was cleaned and a swab was rubbed against the capsule area that was being tested. The swab was removed from the cell into an area where background radiation is below 200 counts. The swab was tested using a Geiger Counter. The capsule was considered free of smearable contamination if the count was below 200.

A1.5 DROP TEST

This test was performed to determine the impact of accidental drop of the capsule on the structural integrity of the capsule. The test capsules were fabricated to the same specifications as the production capsules. The only difference between the test capsule and the real production capsule was the material in the inner capsule. The test capsules contain nonradioactive CsCl and the real capsule contains radioactive CsCl.

The test capsule was dropped from a height of 30 ft at different angles onto a flat, horizontal, and essentially unyielding surface. The capsule was then tested to determine the impact of drops on the physical appearance, weld, and leak tightness.

The tested capsules showed no significant physical or structural damage to the capsules.

A1.6 RING GAUGE TEST

The Ring Gauge Test was designed to determine how much a capsule may have bulged due to thermal cycling and salt expansion at the irradiators.

Exposure to extensive thermal cycling at elevated temperatures at one of the irradiator facilities caused expansion of the cesium salt due to repeated crystalline phase transitions and expanded the inner capsule. The inner capsule pressed against the outer capsule and made the outer capsule bulge. The ICM test determines if the inner capsule had bulged to press against the outer capsule. The ring gauge test was performed on the capsules to determine if the outer capsule had bulged.

The capsule was passed through a heavy metal ring of 2.75 in. or 2.825 in. diameter that was a loose fit over the normal capsule. If the capsule did not pass through these ring gauges, the capsule had bulged.

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APPENDIX B. CURSORY EVALUATION OF EFFECTS OF THERMAL AGING ON STRUCTURAL PERFORMANCE OF CSCL OUTER CAPSULE

B1.1 PROBLEM DESCRIPTION

The cesium chloride (CsCl) capsules are planned to be removed from Waste Encapsulation and Storage Facility (WESF) and be placed in dry storage overpack. In the process, the capsules will be handled using manipulators, which introduces the potential for damage. The postulated handling and associated accident loading conditions include a 4-ft drop, and a 50 lb manipulator gripping force. A concern is that these handling conditions will cause the capsule to fail (breach containment of outer capsule). A particular concern is the effect of thermal aging on the capsule material, which is postulated to cause a loss of fracture resistance and ductility. The outer capsule is made from 316L stainless steel (SS). The temperature and time, from past exposure, used in the evaluation is 500 °C or less for 20,000 hours.

B1.2 THERMAL AGING AFFECT ON MATERIAL PROPERTIES OF INTEREST

Several sources (Effect of Long Term Thermal Aging on the Fracture Toughness of Austenitic Stainless Steel Base and Weld Metals [Huang 1995]; "Fracture Toughness of Type 304 and 316 Stainless Steels and Their Welds" [Mills 1997]; "The Fracture Toughness Behaviour of Austenitic Steels and Weld Metal Including the Effects of Thermal Aging and Irradiation" [O'Donnell et al. 1996]; "Effect of Long Term Aging on the Mechanical Properties of Stainless Steel Welds in PWR" [Faure et al. 1992]; and *The Effects of Thermal Exposure at 566° C on FFTF Primary Outlet Piping* [Greenslade 1980]) were reviewed for relevant data for thermal aging of 316 SST base metal and weld material. The two mechanical properties evaluated herein are ductility and fracture toughness. Thermal aging has been shown to result in reductions in both ductility and fracture toughness. 316 SS is a material known for it generally high ductility and fracture toughness characteristics.

B1.2.1 Ductility

Material ductility is a concern because it is expected that plastic deformation will occur during the 4-ft drop, particularly for a corner drop condition. Hence, ductile failure needs to be evaluated. Greenslade (1980) has measured the tensile properties for thermally aged Fast Flux Test Facility (FFTF) primary piping material (316 SS) at both room and elevated temperature after being held at 566 °C for up to 100,000 hours.

Both Uniform elongation (e_u) and Total Elongation (e_t) for 316 SS show about a 20% reduction in ductility value at 20,000 hours at elevated temperature exposure. However, the ductility is still very high ($e_t = 38\%$, $e_u = 30\%$).

In general, the high ductility observed, would indicate a very robust material that could accommodate a considerable amount of plastic straining before failure. It is recommended that for design evaluation the ductility values normally used (e.g., minimum or from certification) be reduced by 20%.

B1.2.2 Fracture Toughness

Huang (1995) has shown an approximate 30% reduction in fracture toughness (J_c) for 316 SS when aged at 482 °C for 100,000 hours. However, the fracture toughness value is still quite high (395 kJ/m^2). Mills (1997), O'Donnell et al. (1996), and Faure et al. (1992) report that for aging below 450 °C, there is a minimal effect on J_{IC}, but also report a 35% reduction for aging at ~ 550 °C for 50,000 hours.

For weld sections of 316 SS, much lower values are reported (Mills 1997; O'Donnell et al. 1996; Faure et al. 1992), especially when tested at temperature below 300 °C. Here, values as low as 50 kJ/m^2 were reported. Data for 316 gas tungsten arc weld on base metal, which is most like the actual capsule weld, show values of about 150 kJ/m^2 at 10,000 hours of exposure. Because there is not any data for the 20,000 hour design condition, the most conservative value (50) will be used.

"Rule of thumb" screening criterion with respect to fracture potential is that for materials with J_{IC} greater than 140; "brittle" fracture is not a concern. Hence, it does not appear that the base metal is a concern. However, the welds when using the most conservative data, which may not be realistic, with fracture toughness of approximately 50 kJ/m^2, should require a fracture mechanics evaluation.

For additional evaluation, given below, using linear elastic fracture mechanics for weld regions the fracture toughness K_{IC} needs to be calculated. Here:

$$K_{IC} = (EJ_{IC} /(1-\upsilon^2)]^2$$

For a J_{IC} of 50 kJ/m^2; K_{IC} = 115 MPa-$m^{1/2}$ (104 ksi-$in^{1/2}$).

B1.3 FOUR-FOOT END DROP

The following is an approximate analysis to assess potential damage.

Assume capsule falls on end. Failure is at the bottom of the cylindrical section (at weld junction) that impacts surface. Assume surface is infinitely rigid. Hence the inertial force "seen" at this location is that from the upper end cap and the cylindrical shell.

B1.3.1 Assumed Geometry and Associated Properties

outer diameter (OD) = 2.625-in.

Wall thick (t) = .12-in.

Length tube (l)	= 20-in.
End cap thick	=0.4-in.
$V_{end\text{-}cap} = \pi D^2 t / 4$	$= \pi(2.63)^2(.4)/4 = 2.17$ in^3
$a_{tube} \approx \pi Dt$	$= \pi(2.63)(.12) = .991$ in^2
$V_{tube} = a_{tube} l$	$= (.991)(20) = 19.8$ in^3
Vtotal	= 22 in^3
Weight (w)	$= \rho V = (.293)(22) = 6.44$ lb
k (stiffness)	$= a_{tube}E / l = (.991)(30\text{x}10^6) / 20 = 1.49\text{x}10^6$ lb/in.

B1.3.2 Drop Analysis using Work (W)-Energy methods

PE (potential energy) = wh = (6.44 lb.)(48-in) = 309 in.-lb

The PE is converted to kinetic energy (KE) at impact, which strains the tube by doing work (elastic or elastic-plastic).

$$W = \int F \cdot ds \text{ and } F = kx \text{ (assumed elastic, x is deformation)}$$

Therefore: $W = \int kx \cdot dx = kx^2/2$ or

$$x = (2W/k)^{1/2} = [(2)(309)/ 1.49\text{x}10^6]^{1/2} = 0.0204\text{-in.}$$

$$\varepsilon \text{ (strain)} = x/l = .0204 / 20 = 0.00102$$

The corresponding elastic stress is:

$$\sigma = E\varepsilon = (30\text{x}10^6)(.00102) = 30{,}600 \text{ lb/in}^2$$

This is approximately the yield strength of the 316 SS at room temperature so the elastic assumption is valid; and ductile failure is not expected as this stress is well below the ultimate strength.

B1.3.3 Linear-Elastic Fracture Mechanics Evaluation

Evaluate for circumferential crack (size = a) in cylinder at the weld with uniform axial stress. Solution from "Stress Intensity Factors Solutions for Continuous Surface Flaws in Reactor Pressure Vessel," (Buchalet and Bamford 1976) for $t/R = 0.1$. K_I is the mode 1 stress intensity factor. The treatment given here is very conservative in that the compressive stresses at impact would in general tend to close the crack-tip and should not be a concern.

$K_I = \sigma (\pi a)^{1/2} F$; where F(a, t, R, stress distribution) is a factor determined from finite element results. Here the stress, σ, is 30.6 ksi as calculated above.

The results of the stress intensity factor calculation, along with the calculation of the net section stress as a result of the circumferential crack effectively removing cross-section area are given below.

a (in.)	F	K_I (ksi-in$^{1/2}$)	σ(net-section) (ksi)
.03	1.1	8.6	40.7
.06	1.6	21.3	61.2
.09	2.5	40.8	122.4

Even for a crack that is 75% through the wall, non-ductile failure is not expected as K_I (40.8 ksi-in$^{1/2}$) is less than K_{IC} (104 ksi-in$^{1/2}$). Additionally ductile failure is indicated at around crack size that is ~ 60% through the wall as the ultimate strength (75 ksi) is calculated for the net section.

B1.4 FOUR-FOOT CORNER AND SIDE DROPS

These evaluations are beyond the scope of this cursory evaluation as they would likely involve the used of elastic-plastic finite element analysis, possibly dynamic and maybe require a J-integral finite element analysis. These loading conditions, particularly the corner drop, would most likely produce some plastic deformation. If the plastic deformation is away from the weld, failure is unlikely because of the high ductility and fracture toughness of the base 316 SS material (most likely the case for the weld region too), and the small amount of kinetic energy at impact.

B1.5 50 LB. HANDLING (CLAMPING) LOAD

A design load is a 50 lb clamping force from manipulators or handling equipment. This pinching will load the capsule wall. To determine the stresses due to loading, a three-dimensional (3-D) elastic finite element analysis was preformed.

The analysis was done with the ALGOR commercial finite element program (*Accuracy Verification Examples Manual* [ALGOR 2001]). A 1/4 section of symmetry section was modeled using all plate-shell elements (see Figure B-1). Boundary conditions were set to give the conditions of symmetry and to simulate the end-caps (fixed). Two loading conditions were analyzed: (1) a 50 lb clamping force applied 3 in. from one end-cap, and (2) a 50 lb clamping force applied 3 in. at the center. The loading was distributed over two node points to simulate a line load 1/2-in. long.

The resulting Von Mises effective stresses were calculated at 3,890 lb/in^2 and 4,070 lb/in^{2}for the center and end load conditions, respectively. Resulting stress contour/ displaced plot is show below for Load Case 2. The stresses are well below the material yield stress of 30,000 lb/in^2, and hence failure is not anticipated.

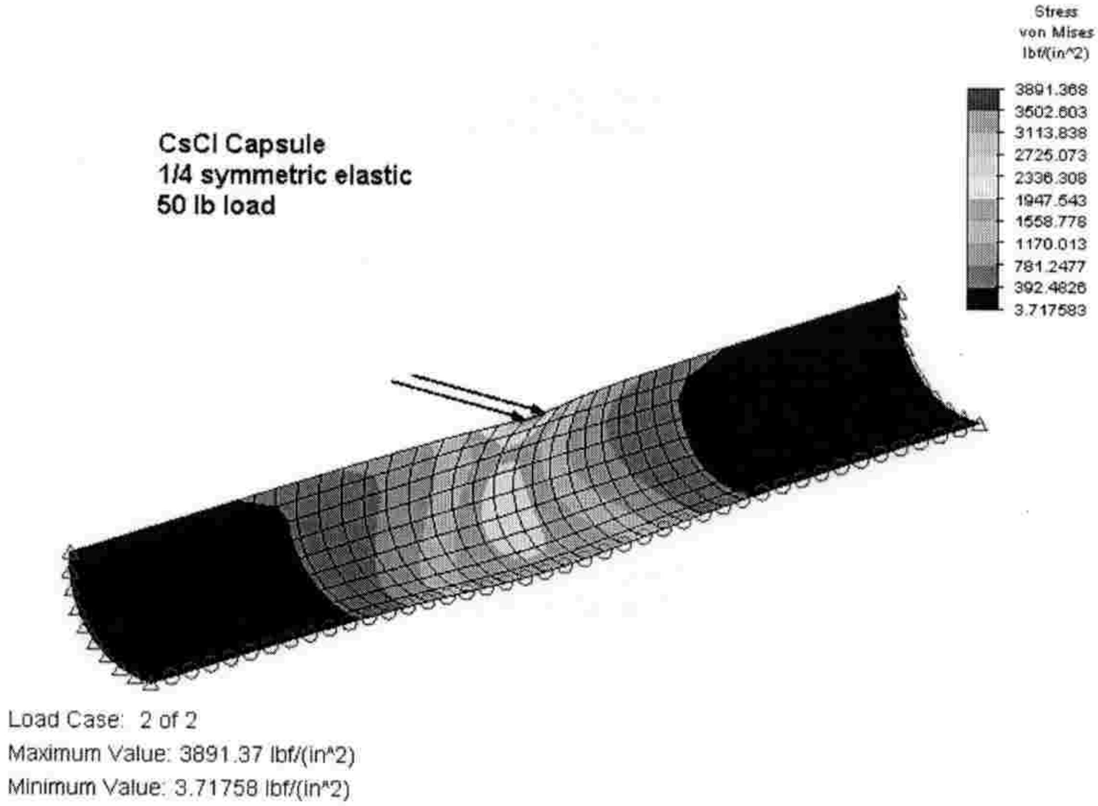

Figure B-1. Symmetry Section Modeled Using All Plate-Shell Elements.

B2.1 CONCLUSIONS

Based on the effect of thermal aging on the structural integrity of the outer capsule, the following conclusions are made:

1. Failure is not predicted and hence is highly unlikely for the loading conditions of a 4-ft end drop, and a 50 lb handling load.
2. Detail failure prediction for the 4-ft side load, and corner drop were not made in this evaluation. However, failure for these loading conditions is judged to be unlikely because of the low impact KE seen by the load path, and the general robustness in material properties.
3. The temperature of the capsules will be maintained below the threshold limit of thermal aging. Accident times will be kept short to minimize thermal degradation.

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APPENDIX C. ESTIMATION OF THE IMPURITIES IN STRONTIUM WASTE CAPSULES

C1.1 STRONTIUM WASTE CAPSULE PRODUCTION

Strontium-90 was transferred from the B-Plant to the Waste Encapsulation and Storage Facility (WESF) as strontium (Sr) nitrate solution. The strontium nitrate solution was treated with sodium fluoride (Na F_2) to produce strontium fluoride (SrF_2) precipitate. The SrF_2 solids were filtered through sintered stainless steel filters to separate the solids from the supernatant. The supernatant was collected in a tank and sampled for Sr analysis. The filtrate with significant quantity of Sr was mixed with fresh Sr nitrate solution and treated with Na F_2again. The supernatant with negligible Sr concentration was sent to the underground storage tanks as waste. The SrF_2 solids were washed with water to remove excess chemicals.

The SrF_2 solids were transferred from the filters to the drying pan (also called "boat") made of Inconel[3]-600 alloy. The drying pan was covered with a lid and placed in the furnace. The furnace was purged with argon gas at a rate of one liter per minute. The furnace was heated to 950 °C (later changed to 800 °C in 1982) in four hours, maintained at that temperature for eight hours, and then cooled to cell temperature in four hours. The drying pan was removed from the furnace and left on the deck (working platform) in the cell for some time before starting the transfer of the solids into an inner capsule made of Hastelloy[4] C-276.

After drying in the furnace at high temperature, the SrF_2 solids were stuck in the drying pan. An air chisel had to be used to remove the solids from the drying pan. The air chisel not only broke the solids into small pieces but also created dust and made the material fly out of the pan onto the deck and the cell floor. The SrF_2 dust, created by the air chisel, deposited on everything in the cell. The broken solids were transferred to the inner capsules using a stainless steel spatula and galvanized steel funnel. The funnel got corroded with SrF_2 and had to be replaced several times during the production campaign. The material transferred into the capsule was compacted using powered impact compactor that also created dust in the cell. Once all the material from the pan was transferred into the capsule, the end cap was clamped on the capsule. The capsule was wiped clean and transferred to D-cell for welding the end cap.

Based upon visual observation, if considerable quantity of the SrF_2 material fell on the deck, the material was swept into the drying pan using a paintbrush and dustpan. The paintbrush disintegrated under the high heat and radiation and considerable number of bristles went into the pan. The dustpan also corroded and had to be changed several times during the production campaign. The drying pan with collected material was placed in the furnace and put through the 16-hour heating cycle as the original SrF_2 solids. The solids were transferred from the drying

[3] Inconel is a trademark of Inco Alloys International, Inc. Corporation Delaware, Huntington, West Virginia.

[4] Hastelloy is a trademark of Union Carbide and Carbon Corporation Corporation, New York, New York.

pan into a new inner capsule using the same process described above. As the material in this capsule was considered waste SrF_2, it was called a "strontium waste capsule."

The material that fell on the floor during the transfer from the drying pan into the capsule collected on the floor. The accumulation of the SrF_2 on the cell floor and other equipment caused the cell to become thermally and radiologically hot. Periodically the cell floor had to be cleaned to remove the SrF_2 material from the floor. The material on the floor was collected using a broom and dustpan and placed in the drying pan. This material collected from the floor also included everything that was left on the floor from the operations and maintenance activities. Big pieces of maintenance debris were picked up using the manipulators and placed in a waste drum. Effort was made to minimize the debris going into the drying pan. Equipment changes and wiring was performed in a manner to minimize small pieces of metal in the cell. Still there were metal pieces, rags, broom bristles, deteriorated plastics, and other materials that were collected and placed into the drying pan. The drying pan with collected material was placed in the furnace and put through the 16-hour heating cycle as the original SrF_2 solids. The solids were transferred from the drying pan into a new inner capsule using the same process described above. As the material in this capsule was also considered waste SrF_2, it was also called a Sr waste capsule.

At the end of the SrF_2 capsule production campaign, C-cell was cleaned with a high pressure water to clean the walls, ceiling, and equipment. The liquid waste was sent to B-Plant and the solids collected were placed in the pans for processing through the furnace. These pans were never processed through the furnace and are still in the C-cell.

A total of 640 SrF_2 capsules were produced at WESF, out of which 39 capsules were used for the U.S. Department of Energy beneficial use program. At present there are 601 SrF_2 capsules in the WESF pool cells, out of which approximately 190 capsules are Sr waste capsules. The impurities in the SrF_2 powder in the regular SrF_2 capsules were determined by analyses of samples. The material in the Sr waste capsules was never analyzed to determine the specific contents. A comparison of the specific power (watts/kg) showed that, except for few capsules, the Sr waste capsules have lower specific power in comparison the production capsules. When compared to the production capsules during the same period, some of the waste capsules had approximately 50% of the production capsule specific power, indicating that the "waste" material contained in some of the capsules was as much as 50%.

C1.2 WASTE MANAGEMENT PRACTICES IN THE HOT CELLS

As stated above, effort was made to minimize the amount of non-Sr debris that went into the drying pan to minimize the cost and operational problems caused by solid materials in the drying pan. Instructions to the operators were to pick all materials that could be picked up with the manipulators and separated from the SrF_2 powder and place them in a waste bucket. The operators could pick up ½-in. size pieces of debris using manipulators and place them in the bucket. The bucket was then moved from C-cell to A-cell where the debris was transferred to a waste drum. Once the drum was filled, it was sent to the waste management as low-level waste.

Small pieces of debris (less than ½-in. size) that could not be picked up with the manipulators and some slightly larger pieces of plastics that were covered with SrF_2 powder were swept with the broom and placed in the drying pan for re-heating.

C1.3 PROCESS FOR ESTIMATION OF IMPURITIES IN STRONTIUM WASTE CAPSULES

As mentioned above, the Sr waste capsule contents were not analyzed. In addition to separation process impurities that are also present in the production capsules, these capsules contain considerable quantities of other materials collected from the cell. Corrosion analysis showed that the impurities in the SrF_2 powder are the main contributors to corrosion of the capsule walls. Now as these capsules are planned for dry storage, the temperature inside the capsule will be higher and it will enhance the corrosion rate. The corrosion rate is dependant on the concentration of the impurities in the capsule contents.

WMP-16937, *Corrosion Report for Capsule Dry Storage Project*, stated that the corrosion is caused by the impurities present in the SrF_2 powder. It is therefore important to know what materials are present in Sr waste capsules. As this information is not available in any document, it was decided to estimate these impurities by interviewing the operations personnel on the operating procedures, problems, and operational practices. Several meetings were held with the operations people to estimate the impurities as described below.

- First meeting was held with representatives from WESF who were actively involved with the WESF operations during the Sr capsules production campaign. These representatives included one operations engineer, two operators, one operations supervisor, and one senior engineer. The purpose of the meeting was to prepare a list of the materials that would have been present in the cell and had a potential of getting in the drying pan. Every step of the production process and operations was discussed in detail to establish the following list of materials and qualitative estimate of quantities:
  - Mostly SrF_2 (same as production capsules)
  - Small pieces of plastics, rubber, wood, broom bristles, paper, cotton rags, tape, styrofoam, tygon tubing, and wire insulations (<1%)
  - Iron and stainless steel metal from nuts and bolts, screws, manipulator fingers (some capsules may have significant quantities)
  - Iron oxide from oxidized parts (very small quantity)
  - Tungsten welder tips (rarely)
  - Inconel 600 metal chips (rarely)
  - Glass from sample bottles and light bulbs (rarely)
  - Lead oxide from paint chips (negligible quantity)
  - Lead metal from storage of bricks in C-cell, and broken bulbs (negligible quantity)

- Ceramic materials from furnace (negligible quantity)
- Copper/brass metal from welder, sleeve, clips, and wire pieces (negligible quantity)
- Titanium block used during electro-polishing(very remote possibility)
- Asbestos (negligible quantity).

A comparison of the qualitative estimates of these materials with the capsule contents calculated from the specific power of the capsules, discussed above, revealed that a more structured estimate was needed to account for the large percentage of impurities present in some of the capsules.

- Second meeting was held to estimate the probability and quantity of each material listed above. The attendees included one operations engineer, two operators, one corrosion engineer, and two senior engineers. The purpose of the meeting was to discuss the materials list again and estimate quantity of each material to the best knowledge of the operators and the operations engineer that will help the corrosion engineer in performing corrosion analysis.

The following table shows the materials and best estimates of the probabilities and quantities that could be present in the feed to the Sr waste capsules prior to heating:

Material	Probability*	Quantity**
Strontium Fluoride • Always present • Generally more than 50% of content	C	H
Small pieces of plastics, rubber, wood, broom bristles, paper, cotton rags, tape, Styrofoam, tygon tubing, and wire insulation • Materials from plastic equipment used in the cells • Pieces larger than half inch normally put in solid waste	H	L
Iron and stainless steel metal from nuts and bolts, screws, manipulator fingers, Hastelloy, and other equipment parts • Parts from in-cell repairs of equipment • Typically smaller than half inch	H	M
Metallic oxide from oxidized parts • Rusted metal pieces smaller than half inch	H	L
Inconel 600 metal chips from drying pans • Chips created when removing SrF_2 from pans • Pans were replaced periodically due to damage	H	M
Hastelloy chips from capsule cutting for rejected welds • Rejected capsules were cut into 3 segments with abrasive saw to remove contents. • As many as one of every three capsules was rejected early in program	H	M
Abrasive cutting blade debris from cutting rejected capsules • See "Hastelloy chips" above • Could cut one capsules apart with one 14-in. blade	H	M
Tri Sodium Phosphate for cleaning • Periodically used to clean cells • Trace amounts remained on walls and floor after cleaning	H	L
Concrete (spalled pieces) and powder • From concrete cover block movement above cell • Spalling from the cell ceiling.	M	M
Glass pieces from light bulbs and sample bottles • Cell lights periodically broke, as well as sample bottles • Larger pieces placed in solid waste	M	L

Material	Probability*	Quantity**
Ceramics from furnace and glo-bars • Disintegration of the furnace bricks	M	L
Asbestos • Insulation of the pipes	M	L
Tungsten tips from welder • Tips left on the floor	L	L
Sodium fluoride • Left on the filter	L	L
Lead metal from shielding bricks and broken light bulbs • Mostly from corrosion of the bricks	L	N
Lead Oxide from paint chips • Chips from periodic cleaning of cell walls	L	N
Copper/brass from electrical connector pins, clips and welder sleeves • Corroded clips and connecter pins	L	N
Titanium from titanium block used for electropolishing • Corrosion of the titanium block	L	L

* Probability: C (certain) 100%
H (high) > 50%
M (Medium) 10-50%
L (low) <10%
** Quantity: H (high) > 20% of the capsule contents
M (medium) 1-20% of the capsule contents
L (low) <1% of the capsule contents
N (negligible) <0.1% of the capsule contents

These estimates were reviewed by three other operators who were involved in the SrF_2 capsules production campaign but could not participate in the process due to schedule conflicts.

APPENDIX D. PEER REVIEW RECORD

Note: This appendix provides a record of the peer review performed by Dr. Joe H. Payer of Case Western Reserve University.

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1	2.1.4.3 Metal Aging *Though aging processes are accelerated at higher temperatures, the short durations will limit deterioration of material properties to acceptable levels. Therefore, aging affects will be acceptable over the 50-year lifetime...* Statement is not supported by quantitative treatment (a) limit on deterioration is qualitative—what is level of deterioration (loss of fracture toughness for normal, upset and accident? (b) acceptable limit not quantitative—based on cursory analysis.		The design specifications require that the salt/wall interface temperature does not exceed 450 °C for Cs capsules and 540 °C for Sr capsules during the storage. Our assessment showed that thermal degradation of the outer capsule wall with the salt-metal interface below those temperatures would be minimal and will have minimal effect on capsule strength. The outer capsule wall, which provides the structural strength for the capsule, never saw temperatures above 350 to 400 °C at the irradiator facilities. The outer capsule walls will see temperatures below 300 °C at normal dry storage conditions and no more than 440 °C (for the high power Sr capsules) at processing conditions. These temperatures are not expected to produce damaging aging affects in the capsule outer wall. Data shows that the wall materials experience negligible long-term aging effects at temperatures below 450 °C. The material properties have not been significantly altered by use at the irradiators, nor will	Accpt'd

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			they be in dry storage. Quantitative analysis is not warranted based on the temperatures the capsules have experienced and will experience in dry storage.	
2	Appendix B-Cursory Analysis Fracture analysis here is well conceived. The methods and calculations are well defined. However, this cursory analysis does not provide a well defined, conservative and realistic lower limit for the materials properties required for handling and accidents (e.g. dropped capsule). Recommend a more rigorous, quantitative treatment of structural performance (fracture analysis). Analogous to thermal analysis for temperature issues, fracture analysis is needed to determine the fracture toughness requirements of welds and capsule walls. This analysis is the foundation for handling/loading issues as well as performance in storage and retrievability. Results provide criteria for many important issues: weld quality, flaw (crack) tolerance, thermal aging, SCC, etc.		Cursory analysis was performed to determine qualitatively if there was a serious problem that needs to be addressed by the project during the design phase. Rigorous drop test (30 feet) performed on the capsules showed that the capsule materials and welds survived the corner and side drops without any serious damage. The capsule materials have not degraded from the original condition. The cursory analysis was performed to determine if the deterioration of the material properties due to thermal degradation, while at the irradiators, is acceptable.	Accpt'd

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3	Appendix B-Cursory Analysis Recommend quantitative treatment of end caps and welds for realistic and conservative drop orientations. Without more thorough analysis, the 4-foot drop criteria can not be deemed realistic or conservative. Corner and side drops were not treated and are likely to be more severe.		See Comments #1 and 2.	Accpt'd
4	Raising of SrF2 capsule processing to 700C from 540C *Mentioned in 2.1.4.3 and elsewhere in reports.* Sound technical basis not presented for raising to 600 or 700C. This is not just a retrievability issue, but also affects handling and loading after processing. Need for quantitative analysis of fracture resistance noted in #1, 2 and 3 above		We agree that the report does not establish a technical basis for raising the processing temperature limit, nor does it indicate that it does. The report states that if the Project decides to raise the processing temperature, they will need to perform analysis to verify that the effects of aging will not be deleterious at the higher temperature. That analysis would need to be more definitive that what is presented in Appendix B. Retrievability encompasses all aspects of unloading and handling. However, the conditions associated with further packaging and loading or opening of the capsules are not defined and beyond the scope of the current project and CAP effort.	Accpt'd

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5	2.0 several sub-sections. *This report does not address this topic.* Recommend adding cross reference to the report(s) that do address the topic.		Section 2.0 indicates that the Summary Report discusses all of the findings and recommendations from the CAP. That section will be revised to note that the Summary Report also provides links to each of the topical reports for each finding and recommendation.	Accpt'd
6	3.4.2 Weld Inspection and Acceptance Recommend adding comment on ability of prior inspection to detect large voids in weld such as those associated with weld failure of capsule from Radiator Sterilizers service. Define consequences and ramifications if these types of defects are undetectable and possibly present in other capsule welds.		Due to the difficulties in the remote testing it is true that some of the defects may not have been detected. Experience has been that these types of defects have not caused leakage of the radioactive material from the capsules. Text will be added to discuss the potential for weld defects that have not been detected. The discussion will note that these potential defects will be treated in the same manner as potential lack of penetration of the welds and potential for stress corrosion cracking. Namely, other the few identified, these defects are not known to exist and not expected to be prevalent, but they cannot be precluded. Handling and shipping	Accpt'd

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			experience, plus operational service at the irradiator facilities gives confidence that these problems, if they exist, are not widespread and have not impacted the storage or handling of the capsules. Furthermore, all capsule handling will be performed in the WESF hot cell facility that is designed to accommodate potential capsule failures. Any detected capsule failures will be handled per the recovery strategy discussed in Section 7.0. Once in the overpacks, weld failure is not anticipated, and the consequences are not severe if a weld does fail.	
7	6.7 *Capsule survive 4-ft drop* Technical basis for this important criterion is not quantitative and strong. See comments above. Can not judge degree of conservatism.		Four feet drop criteria is CFR 71 requirement during loading and transportation operations. The original design basis and testing was based on a 30-foot drop. Capsule properties have not changed significantly from the basis for those tests.	Accpt'd
8	6.8 Thermal Aging *It is concluded from the above, that fracture toughness properties of the outer capsule weldments, at the time of overpacking, will not vary significantly from the original capsule properties (time of fabrication).*		The temperatures of the outer capsule wall for processing and upset conditions (up to 440 °C) are not significantly higher than normal operations (~200 – 300 °C) in dry storage, and are below 450 °C where long-term effects were identified. Therefore, the	Accpt'd

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	Recommend addition: However, exposure to high temperatures during processing and upsets can result in significant loss of fracture toughness.		effects on fracture toughness at these conditions will not be significant. The higher potential temperatures for accident conditions can result in loss of fracture toughness, depending on the actual temperature of the outer wall. However, the criterion for accident conditions is that the capsules survive the immediate accident condition without massive failure. Recovery actions are addressed after the accident, and any analyses that are deemed necessary for safe recovery will be performed only if the accident actually occurs. The text will be modified to reflect this.	
9	6.8 Stress corrosion cracking *It was shown above, under the thermal aging discussion, that the capsules have retained these "good" properties (fracture toughness).* Recommend addition: Unless the capsules are exposed to temperatures above 500C and greater where loss of fracture toughness can occur.		Accepted and recommended wording will be added.	Accpt'd

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10	6.8 last two paras. *Environmental degradation of the capsule materials evaluated to determine the effects of thermal aging, stress corrosion, radiation, hydrogen embrittlement, and cyclic fatigue. Thermal aging and structural performance of outer capsules (Appendix B) showed that failure of the capsule during normal handling conditions including manipulator gripping and minor collisions and drops (4 ft) is not predicted.* All of these findings are based upon the Cursory Analysis. See comments #1, 2, 3. Recommend a more rigorous analysis for technical basis.		See Comments # 1 and 2.	Accpt'd
11	6.12 These findings are based upon the Cursory Analysis. See comments #1, 2, 3. Recommend a more rigorous analysis for technical basis.		See Comments # 1 and 2.	Accpt'd

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12	6.13 Degradation Processes Recommend addition of Liquid Metal Embrittlement to the list. Analysis and discussion of LME should be added in appropriate sections.		LME will be added as a degradation process here. This is being addressed in the Corrosion Report. The results will be summarized in the Characterization Report.	Accpt'd
13	Liquid Metal Embrittlement Recommend revision of the discussion of LME along the lines that follow. Liquid metal embrittlement (LME) is a degradation mode that can result in cracking of ductile materials. Welds are the most susceptible region for LME cracks to occur. The cracking should it occur could result in penetrations of capsules, and any cracks would lower the fracture resistance of capsules during handling and accidents such as dropping. The likelihood and consequences of this degradation mode should be considered in the analysis. Liquid metals at dry storage temperatures can cause cracking of structural metals and welds. Lead chloride ($PbCl2$) and ($pbF2$) are present as an impurity in the cesium and strontium capsules. The thermodynamic analysis shows that the lead compound will be reduced and metallic lead will result. The		See Comment #12.	Accpt'd

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	vapor pressure of lead is substantial and can promote transport to capsule walls. Thin layers of liquid metals (sub-micron) have resulted in failures in susceptible systems.			
14	Table 8.1 Recommend revisions to capture any revisions made based on above comments.		Will incorporate any changes resulting from resolution of the above comments.	Accpt'd
15	It is recommended that a wider range of pre-loading tests and examinations be done for all capsules or in some cases for a statistical sampling. Objective is to better determine capsule condition and to identify any "special" capsules. Suggested additional tests include (a) weighing—particularly "heavy capsules" where high temps of accident risk rupture, (b) hardness of wall body and weld—statistical sampling of capsules from radiator service would validate the qualitative judgments regards prior aging, and (c) a convenient means to measure thermal load would provide useful information to guide loading sequences.		A recommendation to perform selected weighing of some of the overweight capsules will be moved from Section 7 to Section 2.3. This recommendation will be tied to the results of the validation of the capsule database for dry storage. Based on our evaluation, material properties were not significantly affected by use at the irradiator facility. Two capsules were tested for hardness after service at RSI and showed no significant change. This information will be added to the report. We believe the calorimetry measurements provide suitable accuracy for dry storage needs. New measurements would not appreciably improve on the	Accpt'd

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3. Choose Document Number/Title (Only 1 Document Review per RCR Form) []WMP-16937 Corrosion Report Draft C [X]WMP-16938 Capsule Characterization Draft C []WMP-16939 Capsule Integrity Draft C []WMP-16940 Thermal Analysis Draft C []WMP-16878 Data Book Draft C []WMP-17265 Summary Report Rev. C	4. Reviewer []Bath, Singh []Bryan, Garry []Cannell, Gary []Covey, Lori []Heard, Fred []Josephson, Walt	4. Reviewer []Kraemer, Laurie []Miller, Bill []Olander, Don [X]Payer, Joe []Plys, Marty []Robbins, Dewey	4. Reviewer []Swenson, Joe []Thomson, Jim []Tingey, Garth []Tingey, Joel [] [] []	5. CLOSED September 1, 2003 DATE Signature on File REVIEWER Signature on File AUTHOR/ORIGINATOR

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			10% uncertainty currently defined, and 10% is acceptable for planning capsule loading. Of greater importance will be the overweight capsules, as discussed above.	