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Characterization of an Aged WESF Capsule

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Bernard T. Kenna, Fred J. Schultz

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
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CHARACTERIZATION OF AN AGED WESF CAPSULE

by

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CONTENTS

	<u>Page</u>
Abstract.....	1
1.0 Introduction.....	2
2.0 Capsule History.....	4
3.0 Capsule Characterization.....	7
3.1 Source Pin Openings.....	7
3.1.1 Outer Capsule.....	7
3.1.2 Inner Capsule.....	7
3.2 Residual Gas Analysis.....	11
3.2.1 Outer Capsule.....	11
3.2.2 Inner Capsule.....	11
3.3 Analysis of Inner and Outer Capsules.....	12
3.3.1 Longitudinal Tensile Properties.....	12
3.3.2 Metallography.....	17
3.3.3 Electron Microprobe Analysis.....	18
3.3.4 Scanning Electron Microscopy.....	18
3.4 Cesium Chloride (CsCl).....	22
3.4.1 Impurities.....	22
3.4.2 Cesium Isotopes.....	24
4.0 Conclusions.....	26
5.0 References.....	27

TABLES

<u>Table</u>	<u>Title</u>	<u>Page</u>
I	Historical Calendar of Events for WESF Source C-117.....	6
II	Residual Gas Analysis for C-117 Inner and Outer Capsules.....	15
III	Summary of Tensile Properties of Capsules At Room Temperature.....	16
IV	Semi-Quantitative Analysis of CsCl and Dark-Colored Powder.....	23
V	Qualitative Dissimilarities Between CsCl And Dark-Colored Powder.....	25
VI	Isotopic Analysis of Cs and ⁹⁰ Sr (Nov. 20, 1981).....	25

FIGURES

<u>Figure</u>	<u>Title</u>	<u>Page</u>
1	Decay Scheme for ^{137}Cs	3
2	Sandia Irradiator for Dried Sewage Sludge.....	5
3	Detail of WESF ^{137}Cs Source Capsule.....	8
4	Partial View of WESF Capsule Prior to Studies.....	9
5a	Outer Capsule With Milled Flat Area.....	9
5b	Close-Up of Flat Area Milled on Outer Capsule.....	10
6	Inner Capsule With Flat Area Milled on the End With Void Space.....	10
7	View of Inner Capsule End Plug and Ring.....	13
8	Cutaway View of Inner Capsule Plug.....	13
9a	Inner Capsule Interior After Opening, Exposing CsCl In Interior.....	14
9b	Close-Up of CsCl In Inner Capsule (center in focus)...	19
10a	Photomicrograph of Sample from CsCl-Inner Capsule Interface (100x).....	19
10b	Photomicrograph of Sample from CsCl-Inner Capsule Interface (500x). (A) Slag stringer, (B) slag stringer illustrating two-phases, (C) grain boundary inclusions.....	20
10c	Photomicrograph of Inner Capsule Sample Above CsCl Interface (500x). (A) Slag stringer, (B) slag stringer illustrating two-phases, (C) grain boundary inclusions, (D) possible grain boundary inclusion.....	21

ABSTRACT

A joint effort by SNLA and ORNL was initiated for a detailed characterization of an 18-year-old WESF ^{137}Cs source which has been used in the Sandia Irradiator for Dried Sewage Solids. The study included evaluation of the inner and outer stainless steel capsules by optical metallography, electron microprobe, and physical testing. Analysis of the residual atmospheres within the two containers was also done. The CsCl was analyzed for isotopic content and impurities. No potential problem areas, including corrosion, were found.

1.0 INTRODUCTION

The chemical reprocessing of irradiated nuclear fuels in the Hanford Chemical Separations areas since 1945 has resulted in generation of significant volumes of high-level liquid radioactive wastes [1-3]. These wastes have been contained as alkaline slurries in underground, carbon steel-lined, reinforced concrete tanks. A program has been undertaken with the main goal being the ensured isolation of hazardous radioisotopes from life forms. One part of this program is the B-Plant Waste Encapsulation and Storage Facility (WESF) in Hanford, Washington, which reprocesses the liquid portion of the stored wastes to remove cesium and strontium individually, followed by conversion to and separate encapsulation of the solid forms, CsCl and SrF_2 [4-6]. The remaining wastes are converted to salt cake in the underground waste storage tanks for an indefinite storage period.

The initial impetus for the separation of cesium and strontium from the liquid waste was to reduce heat generation (from the radioactive decay of ^{90}Sr and ^{137}Cs) within the defense waste and to provide physical systems suitable for long-term storage of ^{90}Sr and ^{137}Cs [7, 8]. However, these encapsulated materials recently have been recognized to have possible utility which could delay their immediate disposal. For example, the encapsulated SrF_2 has proven to be an effective heat source for use in thermo-electric systems [9-11].

To investigate additional possibilities, the By-product Utilization Program (BUP) was initiated with the mission to develop the means for application of radioactive fission products for the benefit of society [12-14]. At the present time, effort is being focused on ^{137}Cs . About one-third of the cesium recovered in WESF processing is radioactive ^{137}Cs

(30-year half-life) which decays by beta emission in conjunction with 0.662 MeV gamma rays (see Figure 1) [15, 16]. The remainder of the cesium is stable ^{133}Cs with less than 1% of 2.06-year ^{134}Cs and about 10% of 2.3×10^6 -year ^{135}Cs . The gamma ray emission rate (1.6×10^4 gamma rays/min-g ^{137}Cs) and energy (0.662 MeV) from ^{137}Cs indicate that a WESF Cs capsule could serve as a gamma-radiation source ($0.9\text{--}1.5 \times 10^{17}$ gamma rays/min-capsule). One possible use is the gamma irradiation of sewage sludge to disinfect it sufficiently so that it can be used legally as an unrestricted soil amendment or fertilizer [14,17]. This has shown sufficient promise so that a pilot plant has been built by SNLA (Figure 2) and used for several years [18]. This technology is being made available to municipalities who would want to include it in their sewage treatment plants.

However, the WESF Cs capsules were designed for waste storage and disposal, not as gamma radiation sources [4-8], and have not been registered by the NRC for use as sealed radiation sources. Although DOE facilities are exempt from NRC licensing requirements, this registration would facilitate the licensing for non-DOE operation of ^{137}Cs irradiators which could use these sources [19].

Figure 1. Decay Scheme for ^{137}Cs .

The information required by NRC for WESF capsule registration pertains to the WESF capsule integrity under normal and adverse conditions and has been compiled by Kenna [20]. In perusing the literature, it was noted that there have been only cursory examinations of aged WESF capsules. Therefore, a joint effort by SNLA and ORNL was initiated for detailed characterization of a WESF capsule used in the Sandia Irradiator for Dried Sewage Solids (SIDSS). This report is a summary of the studies completed and the results obtained.

2.0 CAPSULE HISTORY

On September 25-26, 1975, the Waste Encapsulation and Storage Facility (WESF) at the Hanford site, Washington, assembled the WESF ^{137}Cs capsule used in this study. It was manufactured and inspected according to prescribed procedures [20] and given the unique capsule identification number C-117. Since that time, it has been stored in the WESF water storage pool, shipped to and stored at SNLA, used in SIDSS and sent to ORNL to be opened for characterization. Table I gives a historical calendar for WESF capsule C-117.

FIGURE 2. SANDIA IRRADIATOR FOR DRIED SEWAGE SOLIDS.

TABLE I

HISTORICAL CALENDAR OF EVENTS FOR WESF SOURCE C-117

<u>Event</u>	<u>Date</u>
Manufacture at WESF*	Sept. 25-26, 1975
Stored in WESF Pool	Sept. 26, 1975 - Aug. 15, 1978
Shipped to SNLA in NRBK-43 Cask	Aug. 18, 1978
Stored in SNLA Pool	Aug. 1978 - May 1979
Placed in SIDSS	May 1979 - Aug. 1981
Shipped to ORNL in NRBK-43 Cask	Aug. 1981
Opened at ORNL	Sept. 11, 1981
Characterization Studies by ORNL and SNLA	Sept. 11, 1981 - March 1983

*

<u>Capsule SN</u>		<u>Gross Mass</u>	<u>Net Mass</u>	<u>Approx</u>	<u>Approx</u>
<u>Outer</u>	<u>Inner</u>	<u>(kg)</u>	<u>(kg)</u>	<u>kCi ¹³⁷Cs</u>	<u>Watts</u>
C-117	C-117	7.660 (16.89 lb)	2.708 (5.97 lb)	63.7 [as of 8/18/78]	306

3.0 CAPSULE CHARACTERIZATION

Details of a WESF ^{137}Cs gamma source pin are depicted in Figure 3. The characterization study included evaluation of (1) the inner and outer capsules in terms of physical strength and corrosion, (2) residual gases within the two containers, and (3) the cesium chloride in terms of purity and ^{137}Cs content. The investigations and results are delineated below.

3.1 Source Pin Openings

The C-117 source pin is shown in Figure 4 as it resided in a hot cell prior to opening.

3.1.1 Outer Capsule

The exterior surface temperature was estimated using a thermocouple in contact with the surface. A flat area approximately 2.54 cm x 1.27 cm was milled on the outer pin (Figure 5a and b), gas sampling equipment was mounted onto this surface, and a hole was made through the outer capsule by laser. The residual gas within the outer cylinder was removed for analysis and one end of the cylinder was cut off with a metal-cutting saw (ensuring the inner capsule was not in the way). After removing the inner capsule, the outer capsule was sectioned into samples for physical strength tests.

3.1.2 Inner Capsule

When first exposed to the atmosphere, the inner capsule surface appeared polished, but gained a very tarnished appearance within 30 minutes. The exterior surface temperature was estimated using a thermocouple in contact with the capsule surface. By placing the center of the cylinder on a wedge-shaped fulcrum, the capsule end containing the void space was determined (the void occurs because molten CsCl undergoes a phase change when solidifying with a concomittant decrease in volume). A flat area was milled (Figure 6) and the residual

Figure 3. Detail of WESF ^{137}Cs Source Capsule.

Figure 4. Partial View of WESF Capsule Prior to Studies.

Figure 5a. Outer Capsule With Milled Flat Area.

Figure 5b. Close-Up of Flat Area
Milled on Outer Capsule.

Figure 6. Inner Capsule with
Flat Area Milled on the End
With Void Space.

gas collected for analysis as was done with the outer capsule. The end of the capsule was cut off (Figures 7 and 8) exposing the CsCl (Figure 9) which exhibited an off-white to greyish color. There was a collection of dark colored, small particle size material on top of the solid CsCl. These "fines" were collected and the CsCl was subsequently removed, primarily by physical means, for later studies. The inner capsule was sectioned into samples for physical tests.

3.2 Residual Gas Analysis

A void volume exists in both inner and outer capsules. In the former, the void is a result of a phase change of CsCl with accompanying negative volume change (maximum of 17%) during solidification whereas the latter is due to a disparity in size between the two capsules.

3.2.1 Outer Capsule

Results of the outer capsule residual gas analysis by mass spectrometry are given in Table II. The end cap of the outer capsule is welded in place by a tungsten-inert gas (95% Ar-5% H₂) process (TIG) which explains the presence of Ar and H₂. Note that the internal pressure is calculated to be less than one atmosphere. This is probably due to the capsule and void volume being heated by the welding process which cools after the cap is sealed on.

3.2.2 Inner Capsule

After the CsCl solidifies, a helium-loaded metallic "sponge" is placed in the capsule to provide the means for performing a helium leak test after TIG welding the end cap in place. The internal pressure within the inner capsule also is calculated to be less than one atmosphere, the reason being the

same as for the outer capsule. Results from mass spectrometric analysis of the residual gas in the inner capsule are presented in Table II.

3.3 ANALYSIS OF INNER AND OUTER CAPSULES

The presence of heat, radiation and a salt (CsCl) conceivably could produce changes in physical strength and/or corrosion properties of the capsule material (316L stainless steel). Hence, analysis of the capsules focused on the extent of corrosion of the inner capsule and tensile strength of both inner and outer capsules.

3.3.1 Longitudinal Tensile Properties

Longitudinal tensile tests on both inner and outer capsules of the WESF source and on virgin (unused) capsules produced the results shown in Table III. Except for all Unused #1 and Used #1 samples, the testing was done according to the standard ASTM procedure [21]. The #1 samples were undersized which, judging from the data, had no effect on the results.

The yield and ultimate strengths appear to be lower for both outer and inner capsules which had experienced prolonged heating, i.e. the "Used samples". There is no indication that salt contact influences the decrease. These decreased values, however, closely approximate the literature values for tubular 316L stainless steel [22,23].

Figure 7. View of Inner Capsule
End Plug and Ring.

Figure 8. Cutaway View of
Inner Capsule Plug.

Figure 9a. Inner Capsule Interior
After Opening, Exposing CsCl in
Interior.

Figure 9b. Close-Up of CsCl in
Inner Capsule (Center in Focus).

TABLE II

RESIDUAL GAS ANALYSES FOR C-117 INNER AND OUTER CAPSULES

Gas	Outer Capsule		Inner Capsule	
	STP cm ³	Mole %	STP cm ³	Mole %
H ₂	1.36	2.1	0.023	0.041
He	<0.046	<0.070	25.9	46.1
CH ₄	0.033	0.050	0.006	0.011
H ₂ O	<0.001	<0.0015	0.07	0.12
N ₂ +CO*	58.1	88.5	11.4	20.3
O ₂	0.020	0.030	0.002	0.0036
Ar	5.38	8.19	18.8	33.4
CO ₂	0.72	1.10	0.028	0.050
Void Vol (cm ³)		134		245
Vol. of Gas Removed (STP cm ³)		65.7		56.3
Internal Pressure, calculated (atm)		0.68		0.34
Surface Temp. (°C)**		104		127

* Mass spectrometric analysis was unable to resolve these two gases at mass 28, but the primary component is probably N₂.

** Measured before opening each capsule.

TABLE III

SUMMARY OF TENSILE PROPERTIES OF CAPSULES AT ROOM TEMPERATURE

Sample Source/Location	Yield Strength (MPa) *	Ultimate Strength (MPa) *	% Total Elongation	Reduction in Area
LITERATURE (Tubular)	267 $\pm$ 37	558 $\pm$ 48	57 $\pm$ 6	----
OUTER CAPSULE				
Unused #1				
Upper end	336.8 $\pm$ 16.3	670.5 $\pm$ 4.9	55.6 $\pm$ 2.8	63.1 $\pm$ 1.5
Lower end	346.5 $\pm$ 29.3	680.6 $\pm$ 11.3	53.6 $\pm$ 1.3	63.0 $\pm$ 0.7
Unused #2				
Upper end	321.5 $\pm$ 16.3	661.4 $\pm$ 2.9	53.0 $\pm$ 1.8	66.2 $\pm$ 1.1
Lower end	352.3 $\pm$ 4.5	665.7 $\pm$ 3.2	54.2 $\pm$ 2.4	65.8 $\pm$ 0.8
Unused #3	307.6 $\pm$ 30.0	655.8 $\pm$ 28.2	54.5 $\pm$ 5.3	65.5 $\pm$ 6.8
Unused #4	306.1 $\pm$ 31.4	643.9 $\pm$ 27.4	52.0 $\pm$ 1.4	62.0 $\pm$ 5.0
AVERAGE:	328.5 $\pm$ 23.4	663.0 $\pm$ 16.9	53.8 $\pm$ 2.8	64.3 $\pm$ 3.6
Used #1				
Upper end	262.4 $\pm$ 13.1	569.7 $\pm$ 28.5	68.1 $\pm$ 1.8	73.7 $\pm$ 0.8
Lower end	260.7 $\pm$ 13.0	569.1 $\pm$ 26.3	67.2 $\pm$ 1.1	73.8 $\pm$ 0.9
Used #2	264.0 $\pm$ 7.0	560.3 $\pm$ 13.0	61.5 $\pm$ 5.7	68.0 $\pm$ 3.7
INNER CAPSULE				
Used #1				
[Limited Salt Contact]**				
Upper end	263.3 $\pm$ 13.1	572.9 $\pm$ 28.7	65.2 $\pm$ 2.1	69.7 $\pm$ 1.4
Lower end	281.0 $\pm$ 23.0	575.0 $\pm$ 2.3	62.1 $\pm$ 6.4	70.2 $\pm$ 1.3
Used #2				
[Continuous Salt Contact]**				
Upper end	259.4 $\pm$ 20.8	545.1 $\pm$ 45.1	60.2 $\pm$ 4.8	74.0 $\pm$ 6.0
Lower end	325.7 $\pm$ 32.9	570.8 $\pm$ 32.5	49.8 $\pm$ 5.3	75.0 $\pm$ 2.0
AVERAGE	273.8 $\pm$ 19.3	566.1 $\pm$ 28.3	62.0 $\pm$ 6.1	72.1 $\pm$ 2.9

* 1 ksi = 6.895 MPa

** There is initial salt contact in the upper portion at the time when the capsule is filled with molten CsCl. There is contraction of the salt on solidification and the top end does not maintain continuous contact with the CsCl mass.

3.3.2 Metallography

Metallographic examination of the inner surface of the inner capsule indicated a slight, general roughening of the surface (corrosion), the extent being no greater than 0.003 in. (Figure 10a). It is not known if the corrosion is a continuing process ($0.003 \text{ in}/8 \text{ years} = 0.00038 \text{ in/year}$) or if it occurred primarily when the capsule was filled with molten CsCl. This question is being addressed in a study being conducted by H. Fullam [24].

The area in Figure 10a is a section of the capsule which had been in continuous contact with the CsCl mass. Using higher magnification, Figure 10b shows a more detailed examination made of an area located between the arrows in Figure 10a. There are aligned stringers of slag due to a rolling process during manufacture of the stainless steel (A). It is a two-phase slag as indicated by the presence of both light and dark portions (B). Annealing was done after the rolling process as shown by the equiaxial, and random orientation of large grains with twinning. Some grain boundaries appear to have inclusions (C) and, although their true composition is unknown, it can be surmised that some are carbides. There does not appear to be any significant amount of CsCl diffusion into the grain boundaries.

Figure 10c represents a section of the inner capsule which was above the CsCl-capsule interface, i.e., it had not experienced continuous contact with the CsCl mass. There is essentially no difference between it and the area shown in Figure 10b. The aligned, two-phase slag stringers are apparent (A and B) and the large grains, with twinning, are equiaxial and randomly oriented. Although some grain boundaries appear to have inclusions (C), it is uncertain whether the ones represented by D are really inclusions. The uncertainty lies

in the unvarying dark coloration, i.e., the grain boundary at C in Figures 10b and 10c exhibit shaded variations in color and there is no doubt that this is due to inclusions. In any case, both the void area and the CsCl contact area of the inner capsule appear to be essentially the same.

3.3.3 Electron Microprobe Analysis

Cross-section samples of the inner capsule were studied by electron microprobe. A primary conclusion was that no cesium compound had migrated/diffused into the grain boundaries of the stainless steel capsule. No unusual phenomenon was observed either on the inner surface or the cross-sectional surface.

3.3.4 Scanning Electron Microscopy

An SEM study of both the inner surface and cross-sectional surface has been done at SNL. The results are in Appendix A.

Figure 10a. Photomicrograph of Sample from CsCl-Inner Capsule Interface Area (100x). Section between arrows used for Figure 10b. Note slight roughening of surface at the interface.

Figure 10b. Photomicrograph of Sample From CsCl-Inner Capsule Interface (500x). (A) Slag stringer, (B) slag stringer illustrating two-phases, (C) grain boundary inclusion. Note large, equiaxial grains in random orientation. Also note similarity to Figure 10c.

Figure 10c. Photomicrograph of Inner Capsule Sample Above CsCl Interface (500x). (A) Slag stringer, (B) slag stringer illustrating two-phases, (C) grain boundary inclusion, (D) possible grain boundary inclusion. Note large, equiaxial grains in random orientation. Also note similarity to Figure 10b.

3.4 Cesium Chloride (CsCl)

The mass of CsCl recovered from the capsule was 5.93 lb (2.69 kg). This can be compared to the reported loading of 5.97 lb (2.71 kg). Thus, less than 1% of the CsCl was lost during the operations. Examination of the CsCl was necessary since it is an integral part of the WESF gamma source. The gamma ray flux available depends directly on ^{137}Cs content; hence isotopic analysis of the cesium was done. Impurity analysis of CsCl was done because both the corrosive behavior and physical properties of the salt can be affected by impurities. Two separate samples were characterized: (a) the bulk CsCl, and (b) the dark-colored "fines" found on top of the CsCl.

3.4.1 Impurities

Analysis by spark source mass spectrometry (SSMS) provided the results given in Table IV. The values are semi-quantitative and should not be quoted as absolute values. They are useful for intercomparing the compositions of the bulk CsCl and the dark-colored powder. Using the arbitrary guideline that factors of three or four difference indicate compositional differences, Table V summarizes the dissimilarities of the two materials in qualitative terms. The concentration of iron and nickel in the powder are probably the cause of coloration. The presence of these elements do not necessarily suggest corrosion of the stainless steel capsule because iron and nickel are impurity elements in the original cesium solution used for making CsCl.

Table IV

SEMI-QUANTITATIVE ANALYSIS OF CsCl AND DARK-COLORED POWDER

<u>Element</u>	<u>g element/g sample (x10³)*</u>	
	<u>CsCl</u>	<u>Dark Powder</u>
Al	3	8
B	4	2
Ca	0.5	1
Co	≥ 0.2	0.1
Cr	1	2
Cs	530	150
Cu	2	0.3
Fe	5	20
K	1	2
Mn	0.5	0.2
Mo	-----	0.6
Na**	2	2
Ni	1	3
P	1	3
Pb	-----	≥ 0.2
Pd	0.2	≥ 0.5
Rb	0.2	0.03
S	50	20
Si	50	2
⁹⁰ Sr	0.01	0.04
Zn	0.8	0.3

* Precision estimated as +100% - 50%.

** Values probably high due to Na both in dilution water and leaching of glass containers.

3.4.2 Cesium Isotopes

The concentrations of the four cesium isotopes (stable ^{133}Cs , 2.06 year ^{134}Cs , 2.3×10^6 year ^{135}Cs , 30.1 year ^{137}Cs) and ^{90}Sr were estimated by SSMS in both bulk CsCl and the dark powder. Radiometric measurements were also made to accurately determine the concentrations of ^{134}Cs , ^{137}Cs and ^{90}Sr . These results are presented in Table VI.

From Table I, the approximate ^{137}Cs content of the capsule was 63.7 kCi as of August 18, 1978. On November 20, 1981, there were 22.2 Ci/g or $(22.2 \text{ Ci/g}) \times (2708 \text{ g})^* = 60.1 \text{ kCi}$ in the capsule (Table VI). The decrease is due to the radioactive decay of ^{137}Cs as described by the equation:**

$$A_t = \left[A_0 \exp -0.693t/t_{1/2} \right]$$

$$A_t = (63.7 \text{ kCi}) \exp \left[-(0.693)(1197)/(10986.5) \right]$$

and $A_t = 59.1 \text{ kCi}$.

This calculated value is in agreement with the measured ^{137}Cs content. Approximately 25% of the CsCl mass is ^{137}Cs and about 32% of the cesium is ^{137}Cs .

* From Table I

** A_0 is the initial activity of a radionuclide (63.7 kCi ^{137}Cs in this case) having a radioactive decay half-life of $t_{1/2}$ (30.1 y or 10986.5 days for ^{137}Cs) and A_t as the activity after passage of time, t (Aug. 18, 1978 - Nov. 20, 1981, or 1197 days), expressed in the same units as $t_{1/2}$.

Table V

QUALITATIVE DISSIMILARITIES BETWEEN
CsCl AND DARK-COLORED POWDER

<u>Element</u>	<u>CsCl</u>	<u>Dark Powder</u>
Al	low	high
Cs	high	low
Cu	high	low
Fe	low	high
Ni	low	high
Rb	high	low
Si	high	low
Zn	high	low

Table VI

ISOTOPIC ANALYSIS OF Cs AND ^{90}Sr (Nov. 20, 1981)

<u>SSMS</u>	<u>Bulk CsCl</u>		<u>Dark Powder</u>	
	<u>$\mu\text{g/g sample}$</u>	<u>Ci/g^*</u>	<u>$\mu\text{g/g sample}$</u>	<u>Ci/g^*</u>
^{90}Sr	10	1×10^{-3}	40	5×10^{-3}
^{133}Cs	300000	-----	85000	----
^{134}Cs	90	0.12	50	6×10^{-2}
^{135}Cs	50000	6×10^{-5}	20000	2×10^{-5}
^{137}Cs	180000	16	50000	4
<u>Radiometric**</u>	<u>$\mu\text{g/g sample}^*$</u>	<u>Ci/g</u>	<u>$\mu\text{g/g sample}^*$</u>	<u>Ci/g</u>
^{90}Sr	7	$< 1 \times 10^{-3}$	15	$< 2 \times 10^{-3}$
^{134}Cs	23	3.00×10^{-2}	27	3.50×10^{-2}
^{137}Cs	256000	22.2	254000	22.0

* Calculated from values reported

** Radiometric analysis should provide a more accurate appraisal than SSMS of the amount of a radionuclide present.

4.0 CONCLUSIONS

This document represents the first thorough characterization study of an aged WESF capsule which has been done. The results have not indicated the presence of any potential problems with either the inner or outer capsules. The cesium chloride appears to be a benign resident within the capsule to this point in time. It is recommended that similar characterization studies be done on older capsules to build a data base as a function of time.

5.0 REFERENCES

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date: **April 13, 1983**

to: **B. T. Kenna, 9784**

from: *S. F. Duliere* *et al.*
S. F. Duliere and C. P. Fryer, 9453

subject: **Analysis of WESF Capsule (C-117)**

Optical and scanning electron microscopy were performed on fractured tensile specimens and blank strips cut from inner and outer cannisters of a WESF capsule (C-117) which had previously contained CsCl.

Fracture surfaces of tensile specimens cut from the upper and lower ends of the inner and outer cannisters were examined in the scanning electron microscope (SEM). All of the fractures had the dimpled surface typical of a ductile tensile failure (Fig. 1). No particles (excluding obvious debris) were found in the dimples. No unusual features were seen on any of the fracture surfaces. There were no deposits of Cs anywhere on the surfaces sufficiently concentrated for detection in the SEM. However, contamination levels of over 1 million dpm for Cs-137 were obtained from surface swipes.

Small samples were cut from the blank strips for SEM inspection of the inside surfaces. Samples were taken from the notched and unnotched ends of the strip from the inner cannister and from the unnotched end of the strip from the outer cannister. The inside surfaces of both the inner and outer cannister were deeply etched or attacked in the grain boundaries (Fig. 2,3). Machining marks were still distinguishable on the surfaces of some grains (Fig. 4), which indicates that the attack was primarily intergranular and that there was no gross grain removal. The total depth of attack from the original surface is estimated to be 10 μ m, or 20% of the average grain diameter.

In order to determine whether this attack was due to the CsCl or was a pre-existing condition, the outer surfaces of the cannisters were scanned. These surfaces had not been attacked and showed only machining marks from the cannister fabrication (Fig. 5 is typical). Presumably, then, an overly severe pickling or passivation treatment was given to the inside surfaces of both cannisters before the capsule was assembled. No Cs was detected on these surfaces by energy dispersive analysis in the SEM.

The samples from the unnotched ends of the blank strips were mounted and polished for optical inspection of the inside edges. No significant difference was found between the inner and outer cannisters (Fig. 6). A few stringers were seen; these were elongated in the axial direction of the cannisters and were distributed evenly throughout the cross-section. (Fig. 7) No second phase precipitates were found near the inner edges.

Conclusions

Storage of CsCl in this stainless steel capsule did not affect the steel microstructure. The fracture surfaces of tensile bars cut from the inner cannister appeared similar to those cut from the outer cannister. The surface topography of the walls and the microstructure of the cross-section of the inner cannister showed no significant differences from corresponding areas of the outer cannister. The only unusual structure found was the deep intergranular attack ($\sim 10\mu\text{m}$) of the inside walls of both cannisters. Because the outside walls of the inner cannister were not attacked and the structures on both inside surfaces were the same, we concluded that the inside surfaces of the cannisters underwent an intentional chemical treatment (that was more severe than that required for surface cleaning or passivation) prior to capsule assembly and that the attack was not caused by the CsCl.

If, assuming a constant reaction rate, the surface had been caused by CsCl attack, the reaction of only $10\mu\text{m}$ of the total 2.4mm wall thickness in 7 years is insignificant; hence, the capsule should safely contain the CsCl over its projected usage life.

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Figure 1. Tensile fracture surfaces, SEM. 400X.

A) Inner Container

B) Outer Container

Figure 2. Surface topography of inside surface of inner can,
unnotched end of sample. SEM. 400x

Figure 3. Surface topography of inside surface of outer can,
unnotched end of sample SEM. 2000x

Figure 4. Surface topography of inside surface of inner can,
notched end of sample.
Note machining marks on top surfaces. SEM. 400X.

Figure 5. Surface topography typical of outside surface.
Outer can, unnotched end of sample. SEM. 400X

Figure 6. Polished cross-sectional view of cannister walls
showing inside edge. Optical. 100X.
A) Inner Cannister

B) Outer Cannister

Figure 7. Polished section of outer cannister wall showing attacked edge and stringers. Optical. 500X.

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