

TEST PROGRAMS CONDUCTED IN SUPPORT OF HIGH-LEVEL WASTE  
CANISTER FABRICATION USING RADIOACTIVELY CONTAMINATED STEEL<sup>a</sup>

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ABSTRACT

The Canister Fabrication Development Activity (CFDA) was developed at the INEL to investigate the potential of fabricating high-level waste (HLW) canisters from radioactively contaminated stainless steel. Metal melting and forming processes were evaluated, and centrifugal casting was the method ultimately chosen for the process to fabricate the cylindrical portion of the HLW canister. Test programs were conducted to determine if a centrifugally cast (CF-3) stainless steel canister is equivalent to a wrought 304L stainless steel canister and to determine what problems might result from melting, casting, machining, and utilizing canisters fabricated from radioactively contaminated steel.

A survey was also made of the radioactively contaminated stainless steel volumes in the United States to determine a source of steel for fabrication of the canisters. The results of the survey showed that there are up to 30,000 tons of radioactively contaminated stainless steel that could be available over the next 25 years.

The results of these tests showed that centrifugally cast canisters are an acceptable alternative to wrought canisters and that HLW canisters can be successfully fabricated from radioactively contaminated steel.

INTRODUCTION

The Canister Fabrication Development Activity (CFDA) was a program conducted by EG&G Idaho, Inc. for the Department of Energy (DOE) at the Idaho National Engineering Laboratory (INEL) to evaluate the feasibility of fabricating high-level waste (HLW) canisters for the Defense Waste Processing Facility (DWPF) (operated by DuPont) from beta/gamma contaminated stainless steel.

Type 304L stainless steel was specified by DuPont for the DWPF canister. This choice was based on the fact that there currently is no existing geologic repository for HLW, and it appears that it will be many years before one can begin to receive the canisters filled with HLW from the DWPF. It has been estimated that the canisters will require storage for up to 20 years before they are shipped to a repository. Stainless steel Type 304L was chosen to minimize corrosion during the time of storage.

Fabrication of HLW canisters from radioactively contaminated stainless steel would provide an environmentally acceptable method for recycling this metal. Not only would it provide an acceptable use for metal which must be disposed of anyway, but it would eliminate the need to contaminate additional volumes of stainless, which would be the case if the canisters are made from noncontaminated stainless steel.

The CFDA program consisted of the following activities:

1. Evaluation of the volumes of beta/gamma contaminated stainless steel in the United States.<sup>1</sup>

2. Canister fabrication process evaluation and decision analysis.<sup>2</sup>
3. Test program to determine if the chosen process of centrifugal casting of the cylindrical section would produce a canister equivalent to the DWPF reference design.<sup>3</sup>
4. Centrifugal casting thickness and machining tests to determine the minimum as-cast wall thickness that would result in an acceptable canister body and to determine the best machining methods, equipment, and costs.<sup>4</sup>
5. Spiked melt tests to evaluate nuclide migration during melting of contaminated steel, contamination control problems, and homogeneity of isotopes in melted steel.<sup>5</sup>
6. Centrifugal castings made with contaminated stainless steel to evaluate nuclide migration due to centrifugal forces and contamination control problems resulting from machining steel cast from radioactively contaminated metal.<sup>6</sup>

This report provides a summation of CFDA development activities.

RADIOACTIVELY CONTAMINATED STEEL VOLUMES

An important consideration for the proposal to fabricate HLW canisters from contaminated steel was to determine the inventory of low-level beta/gamma contaminated stainless steel available in the U.S. The DWPF had estimated that the throughput at the facility would be 500 canisters per year for about 14 years to process existing waste and 200 per year thereafter to process the annual waste stream. For the first 20 years of operation of the DWPF, approximately 8000 canisters would be needed. Each canister requires about 1000 lbs of stainless steel or 1/2 ton;

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8,000 canisters would therefore require 4,000 tons of stainless steel. An inventory of contaminated stainless steel in the U.S. was required to verify that there is enough contaminated stainless steel available to satisfy DWPF canister requirements. DOE, DOD, and commercial sources of radioactively contaminated stainless steel were included in this inventory.<sup>1</sup>

#### DOE Sources

The DOE maintains sites in various areas of the U.S. where nuclear and/or energy research is conducted. All of these research sites have facilities considered to be surplus, which are controlled by the Surplus Facilities Management Program (SFMP). Some of these surplus facilities are scheduled for decontamination and decommissioning (D&D). These surplus facilities and those expected to be declared surplus by the year 2000 at the following DOE sites were included in the inventory: Hanford, Oak Ridge National Laboratory (including Paducah and Portsmouth), Idaho National Engineering Laboratory, Nevada, Savannah River, Shippingport, and some additional sites with small inventories.

All of the DOE sites except Savannah River and the Shippingport Atomic Power Station were visited to obtain as accurate an inventory as possible. Written correspondence provided inventories for Savannah River, and decontamination and decommissioning manuals provided the inventories for the Shippingport Atomic Power Station. The DOE volumes of contaminated stainless steel (shown in Table I) are approximately 4800 tons.

#### DOD Sources

Availability of contaminated stainless steel from sources within the Department of Defense has not been explored. The principal source will be from decontamination and decommissioning of nuclear navy vessels, such as submarines, seven of which are now retired from service and awaiting disposition. Approximately 100 will reach retired status between now and the year 2000; the reactor system in each vessel is

believed to contain about 100 tons of recyclable contaminated stainless steel. Present Navy plans for the 100 submarines include burial of the reactor components at the Hanford DOE burial site.

#### Commercial Sources

There are three main sources of contaminated stainless steel from commercial nuclear applications: (a) cracked piping from BWRs, (b) water-spaced fuel racks, and (c) D&D of commercial reactors.

Stress corrosion cracking of the main reactor coolant piping (and other systems, i.e., core spray system and reactor cleanup system) has caused problems in the operation of BWR plants. The solution to the cracking is either to repair the piping or replace it. There are about 30 BWRs in operation; in twelve, the piping is being replaced; in the remainder, the piping is being repaired or no decision has been made. The replacement of piping in each reactor results in about 50 tons of contaminated stainless steel.

Another source of commercial contaminated stainless steel is found in the replacement of water-spaced fuel racks used for storage of spent reactor fuel. At the present time, spent reactor fuel is stored in the racks placed in canals, but because of the necessary physical separation of the fuel elements, the number that can be stored is small. Use of fuel racks which use neutron absorbers (instead of physical separation) for criticality control almost doubles the number of elements that can be stored, so the water-spaced racks are being replaced. There remain twenty reactors that have not replaced the water-spaced fuel racks. Each reactor will generate about 200 tons of stainless steel when the water-spaced racks are replaced, resulting in a total of 4,000 tons.

Decontamination and decommissioning of commercial nuclear power plants will result in large quantities of contaminated stainless steel. Approximately 76 commercial nuclear power plants are operational in the United States (or have been operational--a few have already been retired from operation). Based on

TABLE I  
DOE Sources of Contaminated Metal (in tons)

Facility	SST < 10 mR/hr	10 mR/hr < SST ≤ 100 mR/hr	SST > 100 mR/hr	Carbon Steel <sup>a</sup>	Nickel <sup>a</sup>
Hanford	1060	40			
ORNL	370	910	65	25,000	5340
INEL	570	135	90	1,450	
Nevada	100				
Savannah River	380	350	540		
Shippingport	80	20			
Other	115	20			
TOTAL	2675	1465	695	26,450	5340

Total SST = 4835

a. These metals could be alloyed with chromium to form stainless steel.

an average life of 30 years, these plants will be ready for D&D commencing in the 1990's at an average rate of four per year. Each facility is estimated to generate at least 150 tons of stainless steel.

Table 2 shows the total potential stainless steel inventory from DOE, DOD, and commercial sources to be over 30,000 tons. This is more than adequate to supply DWPF with 8,000 canisters for the next 20 years.

#### CANISTER FABRICATION PROCESS DESCRIPTION

The DWPF reference canister design is shown in Fig. 1 and Type 304L stainless steel has been designated as an accepted material of construction. This canister has a length of approximately 9 ft 10 in., with an outside diameter of 24 in. and a wall thickness of 3/8 in. The cylindrical body of the canister is fabricated from 304L plate which is roll formed and

TABLE II

#### Potential Stainless Steel Inventory From All Sources

DOE	~ 4,800 tons
DOD	~10,000 tons
COMMERCIAL	
Pipe Replacement	~ 600 tons
Fuel Racks	~ 4,000 tons
D&D	~11,400 tons (from 76 presently operating)
<b>Total</b>	<b>30,800 tons</b>

welded along the longitudinal seam. Forged top and bottom heads are welded to the cylindrical body and a nozzle section welded to the top head to complete the canister.

An evaluation was made of steel fabrication methods to determine the most practical and economical method for the fabrication of DWPF canisters from contaminated steel. This evaluation resulted in the choice of centrifugal casting for the cylindrical portion. The top and bottom would be made from noncontaminated steel and welded to the cylindrical section. Fig. 2 shows the steps required to fabricate canisters. Low-level beta/gamma-contaminated metal will be size-reduced to fit into an induction furnace for melting. After the metal has been melted in the induction furnace, it will be transferred to an Argon-Oxygen-Decarburizer (AOD) using a ladle.

An AOD (Fig. 3) is a device used to remove the carbon from steel [to produce the low-carbon stainless steel required for the canisters (0.03%)] and to provide additional refining capability. The AOD removes the carbon and other impurities by passing a mixture of argon and oxygen through the molten metal. The AOD is capable of reducing the carbon to very low levels and removing other undesirable elements resulting in an improved grade of stainless steel.

When the AOD processing is complete, the molten metal is transferred to a ladle which is used to pour the molten metal into the spinning mold on the centrifugal casting machine (see Fig. 4). The mold rotates about 600 rpm and generates a force of about 100 G's. The centrifugal action forces the metal against the wall of the mold and the impurities therefore migrate

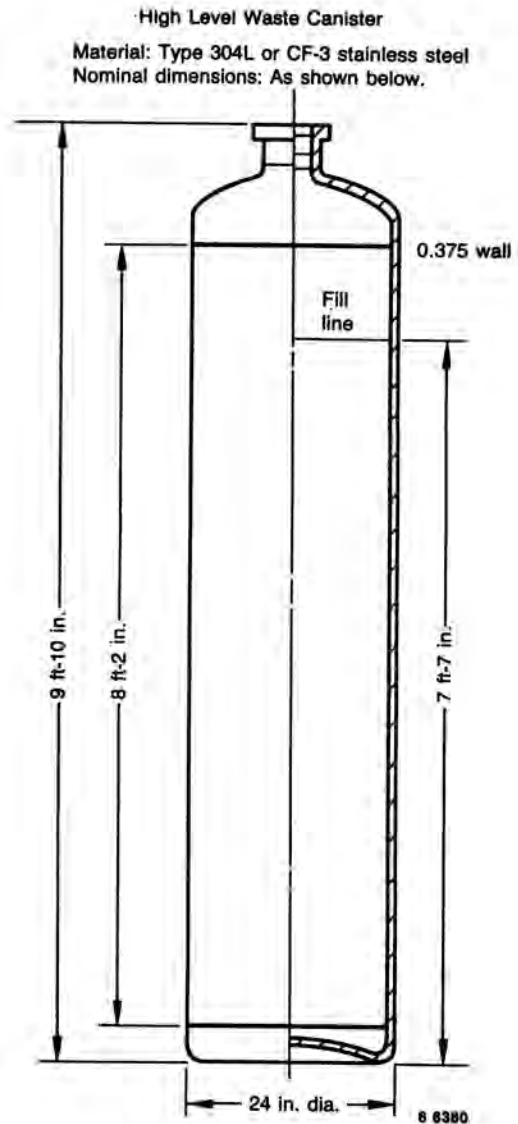


Fig. 1. High-Level Waste Canister.

to the inside of the casting. After the casting has cooled, it is removed from the mold and heat-treated in accordance with the appropriate ASTM specification.

The casting is then machined both inside and out and inspected dimensionally, radiographed, and liquid-penetrant-examined. End pieces are welded to the top and bottom and final testing performed. The canister is then sent to the DWPF for containment of the high-level waste.

#### TEST PROGRAMS IN SUPPORT OF CANISTER FABRICATION

After the fabrication process was chosen, it became necessary to conduct a test program to verify that a canister fabricated by centrifugal casting would have performance characteristics equivalent to the DWPF specified Type 304L canister.

Testing was also needed to determine what problems might result from the use of radioactively contaminated steel in centrifugal casting, machining, and welding processes. DuPont personnel expressed concern about handling the metal and radiation exposure which might result from the use of contaminated steel. The exterior of the canister must be completely free of surface contamination after it has

# DWPF Canister Fabrication Steps

- Metal sorting/sizing
- Decontamination
- Drying/preheating
- Melting
- Refining and alloy adjustment
- Centrifugal casting
- Cleaning
- Solution annealing
- Machining
- 100% liquid penetrant and x-ray exams
- Dimensional inspection
- Commercial procurement of 304L end pieces
- Welding of end pieces to cylinders
- LP and x-ray exam of welds
- Dimensional inspection
- Helium leak test
- Hydrostatic pressure test
- Final cleaning and inspection

Fig. 2. Canister Fabrication Steps.

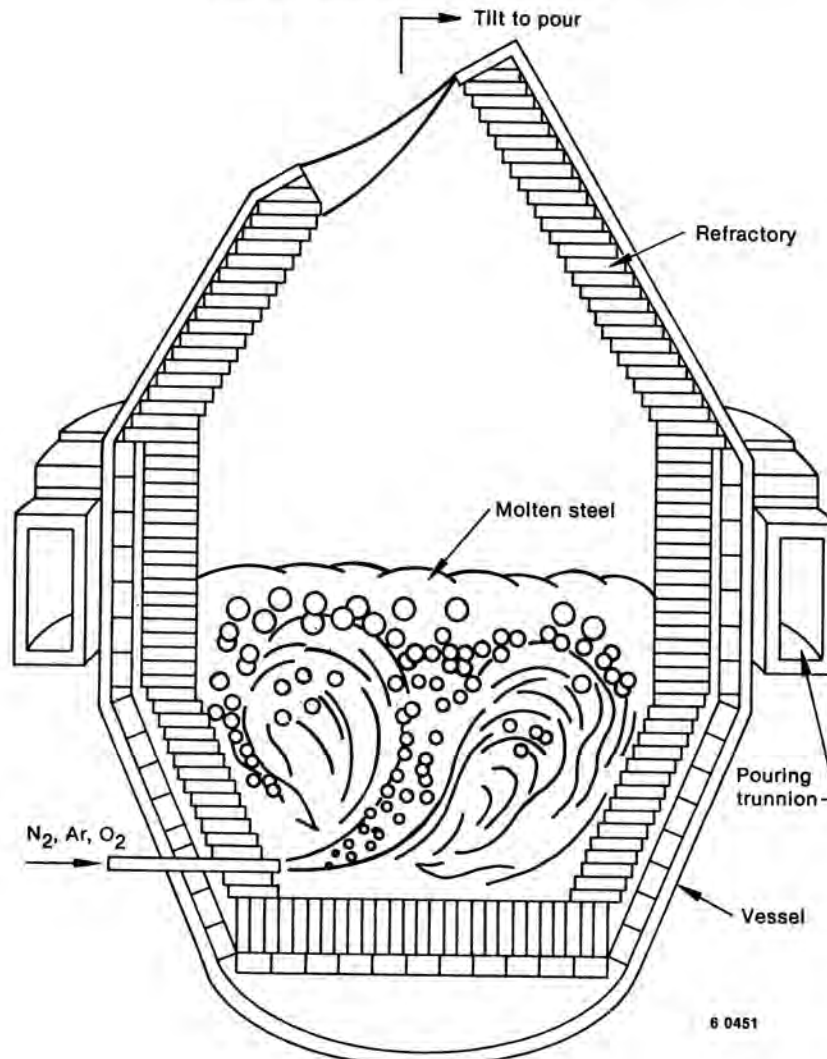


Fig. 3. Argon-oxygen Decarburizer.



# Centrifugal Casting Machine

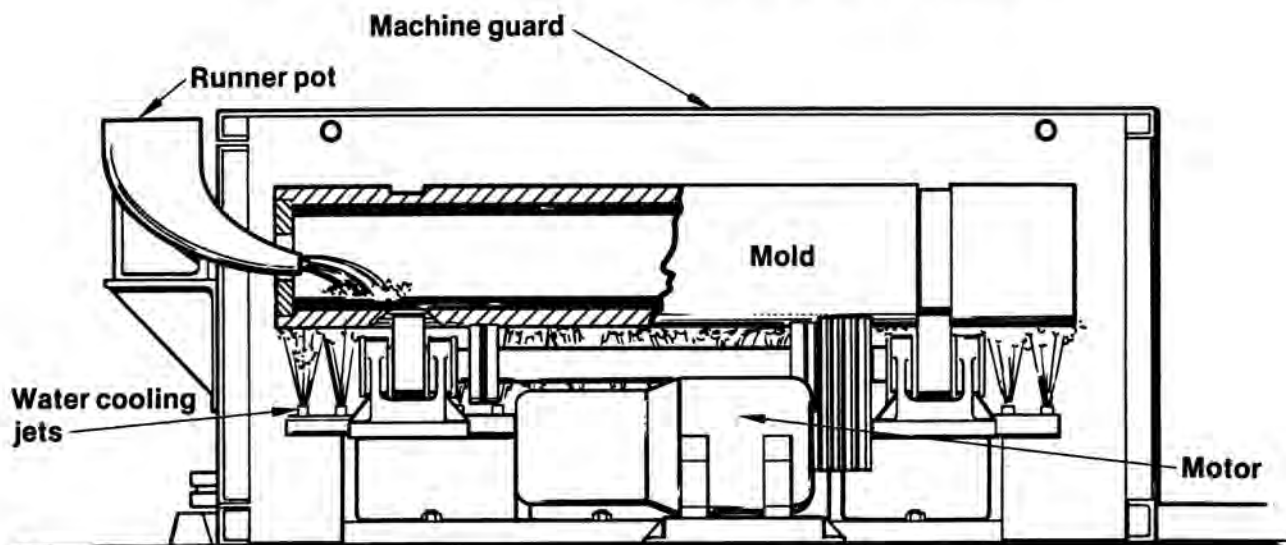


Fig. 4. Centrifugal Casting Machine.

been filled with HLW before it can be shipped to the repository. DuPont also expressed concern that the heat generated while filling the canister with molten glass may cause contamination from the steel to migrate to the surface so that the canister could not be decontaminated.

The following test programs were conducted to resolve all concerns and to verify that canisters could be successfully fabricated by centrifugal casting.

## Evaluation of Centrifugal Casting vs Wrought as a Fabrication Method

CF-3 stainless steel is the cast equivalent of wrought 304L. The viability of the substitution of CF-3 requires that its relevant properties be equivalent to 304L for the canister application. A literature review was conducted which suggested that when produced to a controlled ferrite content, CF-3 has equivalent mechanical properties to Type 304L stainless steel and can in fact provide improved resistance to corrosion.

A test program was conducted to determine if CF-3 has mechanical and corrosion properties equivalent to 304L for the canister application. DWPF reference design canisters were fabricated from CF-3 and wrought 304L for this purpose. These canisters were filled with nonradioactive borosilicate glass at Savannah River Laboratory (SRL) in order to expose the canisters to the thermal history and processing conditions expected from high-level waste glass. The relevant mechanical and corrosion properties of the canister materials were measured and several of the canisters were drop-tested.

The canister material test program consisted of three separate studies conducted by three independent laboratories. Each study investigated a portion of the subject matter of interest. The overall program was designed such that there was overlap between each of the three studies to provide additional confirmation of the conclusions reached.

Battelle Pacific Northwest Laboratories conducted canister drop tests to determine if glass-filled canisters of the DPWF reference design would pass Appendix B hypothetical accident conditions contained in 10 CFR 71. This testing also provided information directly related to the mechanical properties of the canisters. EG&G Idaho, Inc. performed mechanical property testing and corrosion testing of canister materials. Battelle Columbus Laboratories conducted metallurgical examinations and corrosion testing of canister materials. The reports from these three independent studies are included as appendixes to Reference 3. EG&G Idaho coordinated this work and was responsible for canister fabrication and sectioning to provide test materials for these studies.

SRL also conducted an independent study to verify the results of the canister material test program. EG&G Idaho, Inc. supplied sections from the test canisters for this purpose.

Ten canisters were fabricated in accordance with ASME Section III Division I Class III for the material test program. Two of these were Type 304L canisters constructed by Bingham Mechanical and Metal Products, Inc. (Idaho Falls, ID). These canisters were fabricated by the method described previously. Eight CF-3 canisters were produced by Wisconsin Centrifugal, Inc. (Waukesha, WI). Two of the CF-3 canisters (Canisters 001 and 006) were not used in the experimental program because of machining errors made during their fabrication.

While the CF-3 canisters were to be fabricated from one-piece castings for the cylinder body, Wisconsin Centrifugal, Inc. (WISCO) did not have a die available with sufficient length to form the casting. Instead, WISCO centrifugally cast two half-length castings which were welded to form the cylindrical body of the canister. The flanged heads and the nozzle for each CF-3 canister were fabricated from 304L (in the same manner as used in the 304L canisters).

CF-3 castings were prepared to provide two canisters each to three ferrite levels. This was accomplished by minor variations in the composition of the alloy heats.

The 304L plate used in the wrought canisters and the flanged heads and nozzles for each canister were solution-annealed and pickled prior to forming. The cast CF-3 cylinder bodies were solution-annealed prior to machining. The CF-3 castings were solution-annealed by heating to a temperature between 2000°F and 2150°F for one hour per inch of maximum section thickness or one hour (whichever is greater) and then quenched in water. The centrifugal castings as cast had a wall thickness of approximately 1.25 in. The castings were machined to obtain the desired wall thickness. After machining, the cast cylinder sections were 100% radiographed and liquid-penetrant-tested.

CF-3 and 304L canisters were filled with non-radioactive borosilicate glass, simulating the borosilicate glass waste form. SRP 165 black frit was used for this purpose. The glass-filling operation was conducted using operating conditions representative of those anticipated for actual operations at the DWPF. As a result, the thermal histories of the test canisters corresponded to expected use. The pour temperature of the borosilicate glass was 1050°C (1920°F). The temperature of the canister wall never reached that level, however, due to the rapid dissipation of heat from the canister and the low glass-filling rate. A temperature profile for a typical canister is shown in Fig. 5.

The glass-fill rates averaged 200 lb/h. The duration of the glass-filling operation for each canister was approximately fifteen hours. During the

glass-filling operation, the canisters were filled with an average of 3,250 lb of glass.

Canisters 002, 004, 005, and 007 were sectioned for mechanical property and corrosion testing. (Canisters 003, 008, 011, and 012 were used for drop-testing and were not sectioned.)

The impact, mechanical, and corrosion properties of CF-3 and 304L canisters were measured and compared.

Impact testing (drop tests) conclusively demonstrated the integrity of both CF-3 and 304L canisters. No loss of integrity was determined by helium-leak testing and dye-penetrant testing. Deformation measurements indicated that a large margin existed between the drop test strains and the strains required to rupture the canister wall because of ductility exhaustion. This was further substantiated by subsequent mechanical property testing.

Mechanical property measurements, including tensile tests and charpy impact tests, indicated some differences in performance between CF-3 and 304L. The yield strength of 304L was slightly higher than CF-3. CF-3 is tougher (greater energy absorbed to fracture) than 304L. Both materials exhibit high strength, elongation to failure, and fracture toughness. The mechanical property data indicate that CF-3 is equivalent to 304L for the canister application.

Corrosion testing indicated that both CF-3 and 304L canisters were not attacked by the glass. They did not become susceptible to intergranular corrosion (sensitized) as a result of thermal history from the glass-filling operation. The ferric sulfate-sulfuric acid test and the nitric acid test suggested that CF-3

## Canister Glass-Filling Thermal Profile Canister #004

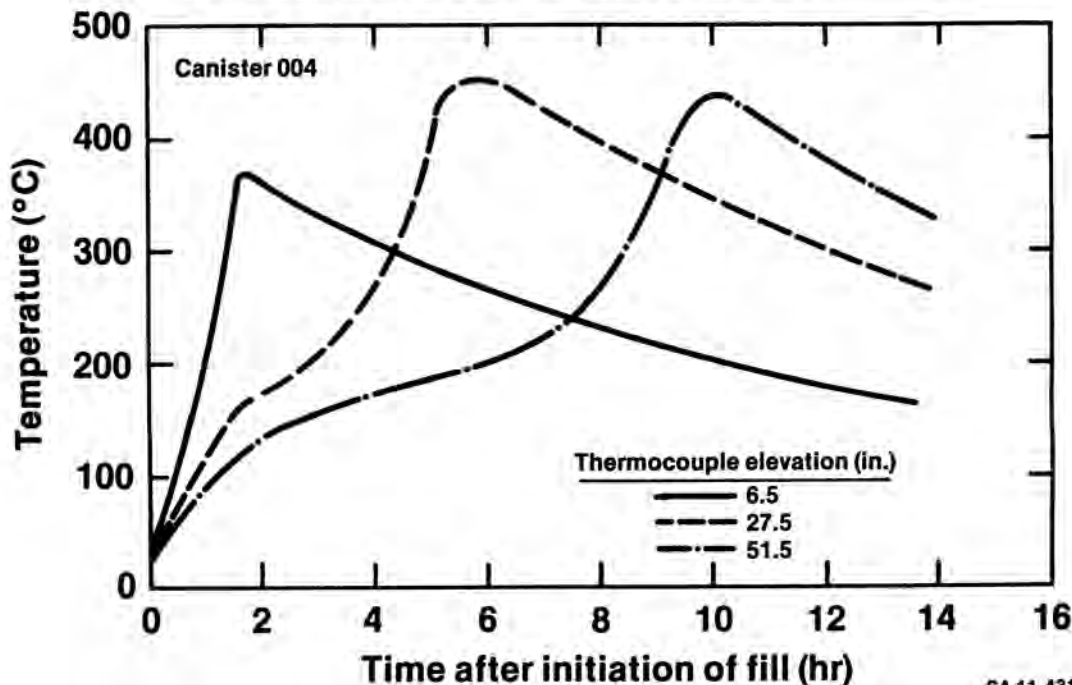


Fig. 5. Thermal Profile For Canister #004.

was slightly more susceptible to intergranular attack than 304L; however, the differences were small and the corrosion rates measured were well within DWPF acceptance levels for stainless steel. Both canister materials were resistant to stress corrosion cracking, although testing showed CF-3 to be slightly less susceptible than 304L. The pitting resistance of 304L is slightly higher than CF-3; the difference is small and not believed to be significant for the canister application. The pitting resistance of CF-3 could be improved by AOD refining prior to casting or by small increases in the alloy chromium content. Some of the differences observed could be due to the testing of only one 304L canister. The corrosion property data suggest that CF-3 is equivalent to 304L for the canister application.

From the data obtained in the canister material test program, the conclusion is that CF-3 is an acceptable alternate for 304L for fabrication of DWPF canisters.

#### Casting Thickness and Machining Tests

The canisters used in the test program comparing wrought 304L with cast CF-3 were made from castings with an initial wall thickness of 1 1/4 in., which were subsequently machined to the required 0.375 wall thickness. The as-cast wall thickness obviously affects the quantity of steel which must be melted, cast, and machined and therefore influences the size of the process equipment needed if a canister fabrication facility were to be built. It also affects the processing time, especially the time required to machine a casting.

A casting thickness test was conducted to establish the minimum initial wall thickness of the 24 in. diameter, 110 in. long centrifugal casting which can be machined to a finished 3/8 in. cylinder without rejectable defects. The previous centrifugal casting studies indicated that a wall thickness of 3/4 in. was estimated to be the minimum possible. Three full-length castings were produced with wall thicknesses of 3/4 in., 7/8 in., and 1 in.

Each casting was machined in steps, and the casting was liquid-penetrant-examined after each step to determine the wall thickness at which no unacceptable defects were found. The 7/8 in. thick casting resulted in an acceptable cylinder when machining was complete.

The defects in the castings were principally shrinkage and porosity on the inside surface. To remove these defects requires the removal of about 1/4 in. of material from the inside surface. The defects on the outside surface are from the mold wash and a removal of 1/8 in. or less of material from the outside surface removes this crust.

The Conceptual Design Report<sup>2</sup> for the CFDA specified equipment sizes based on a 3/4 in. thick casting. The 7/8 in. thick casting fits within the envelope of the specified equipment sizes.

The second purpose of the test was to resolve questions about the time required to machine a casting and about the most suitable choice for a machining setup: (a) a setup composed of a lathe which can machine both the ID and OD or (b) a setup which requires a boring machine for the ID and a lathe for the OD. The choices obviously affect facility design and the final cost to fabricate canisters.

Each of the three centrifugal castings was machined at a different facility. One facility used a

lathe for machining both the ID and OD, and the other two used a lathe for the OD and a boring machine for the ID. The fastest machining time was logged on the 3/4 in. casting machined at Wisconsin Centrifugal using a lathe and boring machine. Based on this experience, the time required to machine a cast cylinder with a 7/8-in. wall thickness is estimated as 24 h. A facility which machined the same size casting continually could conceivably reduce the machining time.

#### Spiked Melt Tests

The contaminated metals which would be used for canister fabrication are surface contaminated only, with <sup>60</sup>Co, <sup>90</sup>Sr, and <sup>137</sup>Cs as the predominant isotopes, although lesser quantities of other isotopes may be present.

In order to address the questions of isotope distribution and possible changes in melting practice, and to demonstrate the suitability of this contaminated scrap for use in centrifugally cast HLW canisters, several melts were prepared using uncontaminated stainless steel to which were added known quantities of <sup>60</sup>Co, <sup>85</sup>Sr, and <sup>137</sup>Cs. Samples of ingot, slag, and fume were analyzed to determine the partitioning of isotopes among these constituents and smears were taken from tools, equipment, the exhaust system, and the vicinity of the operation to assess the spread of contamination as a consequence of these tests.

The spiked melt tests were performed at the Waste Experimental Reduction Facility (WERF) at the INEL. WERF has an induction furnace which was installed to develop the capability to melt radioactively contaminated ferrous metals for the purpose of volume reduction.

The procedure in the spiked melt tests was to place a sufficient, known quantity of radioactivity into the melt so that data could be obtained which would permit a determination of the final distribution of the contamination following the melting process. Three tests were performed for repeatability. The spiked melt tests were conducted using <sup>60</sup>Co, <sup>85</sup>Sr, and <sup>137</sup>Cs as the contaminants. These isotopes were chosen because they are the contaminants most likely to be found on metals that would be considered usable for metal recycling, such as canister fabrication. <sup>85</sup>Sr was used instead of <sup>90</sup>Sr because it is a gamma emitter and therefore easier to detect (<sup>90</sup>Sr is a beta emitter). The third test melt also included <sup>192</sup>Ir to represent heavy elements such as <sup>233</sup>U, etc. The <sup>192</sup>Ir will behave similarly to the <sup>60</sup>Co and will remain in the metal, whereas <sup>233</sup>U would oxidize and be removed in the slag.

The three test melts were made using noncontaminated 304L plate made from one heat at a steel mill. A sample of the plate was analyzed to provide a background activity measurement. In all three tests, the contaminants were mixed with a nitric acid solution, placed in steel bread pans, and evaporated. Nitric acid was used to etch the contaminants into the metal, simulating as closely as possible the oxidized condition of contamination found on normally contaminated metal.

Normal operation proceeds as follows: metal which has been sized (cut) to fit into the furnace is loaded into the furnace crucible. As the initial charge of metal melts and drops lower into the furnace, more material is added until all the metal is molten. A coagulant is then added to the top of the



molten metal to aid in removing the slag. The temperature is measured periodically using a submersible disposable thermocouple, and when the pour temperature is reached, the furnace is tilted and the metal poured into a mold. When an adequate skin has formed on the ingot, the mold is moved to the cooling room to complete the cooling process.

Several changes were made to the normal operation for conducting the spiked melts: (a) the bread pans used to add the contaminants were placed in the bottom of the furnace prior to adding the charge material to ensure adequate mixing of the contaminants with the molten bath; (b) a sample of the molten metal was taken using a small dipping ladle; (c) four slagging tools were used to provide sequential slag samples to determine any differences between the first slag removed and the slag removed after the metal had been molten for awhile and stirred (by the induction currents); (d) metal and slag from the first test melt were analyzed prior to conducting the second and third test melts and results indicated that the slag coagulant may have an effect on removal of contaminants from the melt. Slag coagulant was therefore added to the second and third test melts and actually stirred into the molten metal to try to determine any effect it may have on decontamination of the molten metal.

The first spiked melt consisted of 510 lbs of metal and 50  $\mu$ Ci of  $^{60}\text{Co}$ , 5  $\mu$ Ci of  $^{137}\text{Cs}$ , and 5  $\mu$ Ci of  $^{85}\text{Sr}$ . The second melt had the same concentration as the first but was a 700 lb melt (i.e., 70  $\mu$ Ci of  $^{60}\text{Co}$ , 7  $\mu$ Ci of  $^{85}\text{Sr}$ , and 7  $\mu$ Ci of  $^{137}\text{Cs}$ ). The third test melt was identical to the first but also included 6  $\mu$ Ci of  $^{192}\text{Ir}$ .

Ingots #1 and #3 were sectioned for analysis as shown in Fig. 6. During the sectioning of these ingots, samples were taken from each cutting operation for analysis to determine if the ingots were homogeneous. Ingot #2 was also partially cut through in three

places to provide samples for analysis. The ingots were all sectioned with a cut off saw. Samples of the molten metal were also taken during the melting operation together with samples of the slag, and dust filtered from the off-gas.

The slag samples contained small pieces of metal which gave the slag false readings of  $^{60}\text{Co}$ . An effort was made to remove the metal from the slag, and each was analyzed separately.

Each sample was analyzed using a germanium-lithium detector. The metal filings from cutting the ingots were analyzed as 2 gram samples to minimize attenuation factors. As can be seen from Table III, essentially all of the  $^{60}\text{Co}$ , approximately 7% of the  $^{137}\text{Cs}$ , and less than 1% of the  $^{85}\text{Sr}$  remained in the ingot. These results were expected because cobalt is known to alloy with steel, cesium volatilizes, and strontium oxidizes. The percentages of  $^{137}\text{Cs}$  and  $^{85}\text{Sr}$  are not very accurate, because those isotopes were only added in a ratio of 10 to 1 as compared to the  $^{60}\text{Co}$ ; when such a small percentage remains in the ingot (less than 1% as much as the  $^{60}\text{Co}$ ), there is not a very significant amount to be detected by the counting system. The data showed that the  $^{60}\text{Co}$  is homogeneously distributed throughout the ingot.

Smears taken of the furnace room before and after each test showed that there was no measurable buildup from melting operations at these levels of contamination.

These spiked melt tests have shown that melting metals with contamination levels up to the present 10 mrem/h limit should not result in contamination control problems in the furnace room and off-gas system. These tests have also shown that contaminated metals can be successfully processed and used in making high-level waste canisters for use in the

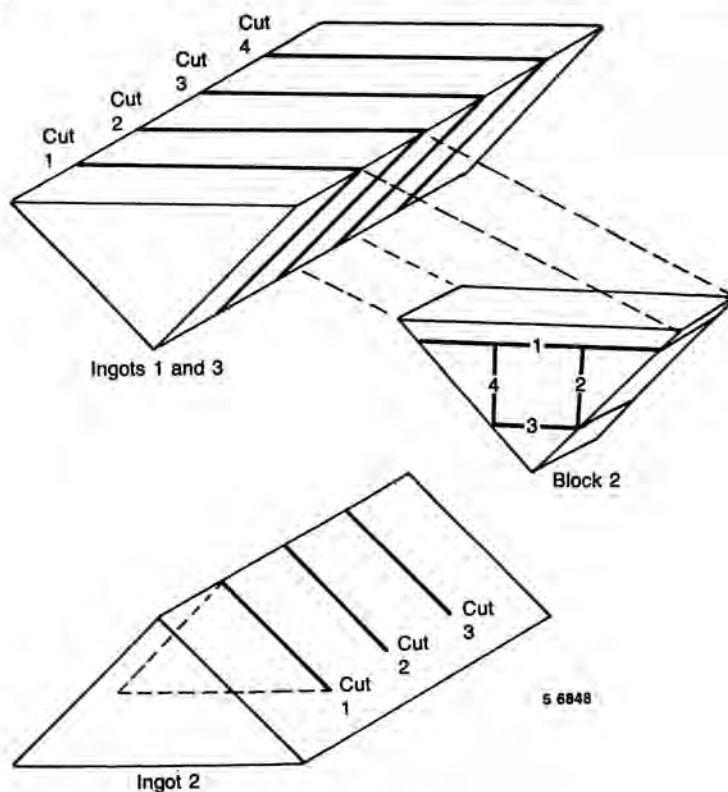


Fig. 6. Ingot Sectioning.



TABLE III  
Percentages of Isotopes Remaining in the Metal

Test	Isotope	Activity ( $\mu\text{Ci/g}$ )			Ave. % of Isotope Remaining in Ingot
		High	Low	Average	
1	Co-60	$2.32 \times 10^{-4}$	$2.16 \times 10^{-4}$	$2.24 \times 10^{-4}$	96%
	Cs-137	$3.5 \times 10^{-6}$	0	$2.25 \times 10^{-6}$	10%
	Sr-85	$9 \times 10^{-7}$	0	$3.3 \times 10^{-7}$	1%
2	Co-60	$2.25 \times 10^{-4}$	$2.03 \times 10^{-4}$	$2.14 \times 10^{-4}$	96%
	Cs-137	$2 \times 10^{-6}$	0	$1.3 \times 10^{-6}$	8%
	Sr-85	0	0	0	0%
3	Co-60	$2.32 \times 10^{-4}$	$2.13 \times 10^{-4}$	$2.24 \times 10^{-4}$	97%
	Cs-137	$2 \times 10^{-6}$	$0.1 \times 10^{-6}$	$1.2 \times 10^{-6}$	5%
	Sr-85	$5 \times 10^{-7}$	0	$2 \times 10^{-7}$	1%
	Ir-192	$1.78 \times 10^{-5}$	$1.61 \times 10^{-5}$	$1.67 \times 10^{-5}$	60%
Average of all 3 Tests	Co-60	$2.30 \times 10^{-4}$	$2.11 \times 10^{-4}$	$2.19 \times 10^{-4}$	95%
	Cs-137	$2.5 \times 10^{-6}$	0	$1.7 \times 10^{-6}$	7%
	Sr-85	$5 \times 10^{-7}$	0	$1.8 \times 10^{-7}$	1%

DWPF. In addition, data gained have given an indication of the contamination level of metals that can be melted and still produce a casting for a canister that meets the acceptance limit of less than 0.5 mrem/h at near contact set by the DWPF.

#### Contaminated Centrifugal Casting Tests

DWPF canisters filled with HLW will be sent to a geologic repository. The geologic repositories have imposed a requirement that the outer surface of the canister be free of smearable contamination. The canisters used in the qualification test program were fabricated from noncontaminated steel, and it was decided that centrifugal castings should be made from contaminated steel to verify that the final machined casting does not result in surfaces with smearable contamination.

Two contaminated centrifugal castings were made at Battelle Columbus Laboratories (BCL). BCL has a small centrifugal casting machine ( $\sim 100$  lb capacity) which could be used with contaminated steel. Some of the metal resulting from the spiked melt tests was used as the feed metal for the contaminated centrifugal casting tests.

At BCL, pieces from each ingot were melted in an induction furnace and centrifugally cast (using a horizontal centrifugal casting machine) into a carbon steel mold. The mold was sized to produce a casting 10 in. outside diameter and 12 in. long. The mold was coated 1/8 in. thick with Type SF-99 Centrifugal mold wash. The coating was dried, and the mold preheated to 400°F prior to pouring the molten metal into the mold.

The mold speed was adjusted to 1,050 rpm before pouring to generate a centrifugal force of between 120 and 130 G's. A melting time of approximately 75 minutes was required to bring the bath temperature to 2900°F. The metal was tapped directly from the furnace through a tundish into the horizontal centrifugal casting machine. After pouring was completed, an external water spray was applied to the surface of the mold to provide cooling. The temperature of the casting was monitored with an optical pyrometer until

the temperature fell below 2000°F. At this time, the mold speed was reduced to 300 rpm, and the casting was permitted to cool below red heat. The casting was removed from the mold approximately 30 min. after pouring.

The castings were stripped from the mold and a 1 in. long cylindrical section was removed from each end of both castings to provide samples for microstructural studies. The castings were machined on the outside diameter until a clean surface was obtained with a final outside diameter of 9.575 in. Next, the castings were machined on the internal diameter until a wall thickness of 0.375 in. was obtained. After the O.D. and I.D. were machined, the cylinder was parted to produce two pieces 5 in. long. One 5 in. cylinder was sent to SRP to contamination analysis and the other was sent to the INEL.

Approximately 0.030 in. per machining pass was removed. The machine chips from each pass were collected in separate containers and labeled with the location of each sample. Slag samples from each melt also were obtained.

Thirteen samples from the centrifugal casting machining operation and two slag samples were analyzed by gamma ray spectroscopy, and the results are shown in Table IV. No  $^{137}\text{Cs}$  and no  $^{85}\text{Sr}$  were found in the steel chips or in the slag after the second melting with any probability greater than 2 sigma. The  $^{60}\text{Co}$  was homogeneous in the steel chips with about the same activity as the spiked melt ingots. The amount of  $^{60}\text{Co}$  in the slag was a small fraction of the original  $^{60}\text{Co}$ , so that the percent of  $^{60}\text{Co}$  in the machining chips was practically 100% of the original amount used. The slag sample from the second melt contained some cobalt and some  $^{192}\text{Ir}$ , apparently due to entrapment of some steel in the slag during removal of the slag.

The samples from the O.D., on the average, had a higher percent of  $^{192}\text{Ir}$  than the samples from the I.D. The ratio of the averages was 1.06. Although not large, there is some migration of the heavier isotope to the outer surface due to the centrifugal forces generated during the casting operation.

TABLE IV  
Gamma Ray Spectroscopy of Centrifugal Castings

Sample Number	Sample Description	Nuclide and Activity (mCi/g)				Percent of Original <sup>a</sup>			
		<sup>60</sup> Co	<sup>137</sup> Cs	<sup>85</sup> Sr	<sup>192</sup> Ir	<sup>60</sup> Co	<sup>137</sup> Cs	<sup>85</sup> Sr	<sup>192</sup> Ir
1	No. 1-16 i.d.	2.33 ± 0.05 E-4	2 ± 1.0 E-6	0 ± 6 E-7	--	101	9	--	--
2	No. 1-28 i.d.	2.29 ± 0.04 E-4	5 ± 7 E-7	3 ± 5 E-7	--	100	2	4	--
3	No. 1-7 i.d.	2.33 ± 0.03 E-4	0 ± 5 E-7	1 ± 3 E-7	--	101	--	1.4	--
4	No. 1-1 i.d.	2.19 ± 0.06 E-4	0 ± 2 E-6	6 ± 7 E-7	--	95	--	8	--
5	No. 1-22 i.d.	2.25 ± 0.05 E-4	0 ± 1.2 E-6	3 ± 7 E-7	--	98	--	4	--
6	No. 1 o.d.	2.27 ± 0.05 E-4	0 ± 1.1 E-6	1 ± 7 E-7	--	99	--	1.4	--
7	No. 1 slag	4.72 ± 0.06 E-5	0 ± 1.2 E-7	3 ± 7 E-8	--	21	--	--	--
8	No. 3-7 i.d.	2.31 ± 0.03 E-4	2 ± 5 E-7	0 ± 4 E-7	1.64 ± 0.07 E-5	100	1	--	96
9	No. 3-16 i.d.	2.38 ± 0.04 E-4	2 ± 8 E-7	4 ± 6 E-7	1.78 ± 0.10 E-5	103	1	6	105
10	No. 3-1 i.d.	2.37 ± 0.04 E-4	2 ± 7 E-7	3 ± 5 E-7	1.62 ± 0.10 E-5	103	1	4	95
11	No. 3-4 o.d.	2.32 ± 0.05 E-4	0 ± 1 E-6	0 ± 7 E-7	1.83 ± 0.12 E-5	101	--	--	108
12	No. 3-23 i.d. 2	2.29 ± 0.02 E-4 98	0 ± 3 E-6	1.4 ± 1.8 E-7		1.67 ± 0.03 E-5			100
13	No. 3-5 o.d.	2.31 ± 0.05 E-4	2 ± 9 E-7	3 ± 6 E-7	1.77 ± 0.04 E-5	100	1	4	104
14	No. 3 slag	1.55 ± 0.03 E-4	1 ± 0.5 E-6	4 ± 3 E-7	9.6 ± 0.7 E-6	67	5	6	56
15	No. 3-3 o.d.	2.32 ± 0.05 E-4	5 ± 3 E-7	6 ± 6 E-7	1.74 ± 0.12 E-5	101	2	8	102
	Original <sup>a</sup>	2.3 E-4	2.2 E-5	1.4 E-5	1.7 E-5 <sup>b</sup>				

a. Original corrected to time of analysis

b. Iridium content of samples (average) of ingot No. 3 from TABLE II.

The radiation activity and smearable surface contamination on the machined rings and end pieces (croppings) were determined. The activity at contact (detector distance from the rings and croppings) was about 0.4 mrem/h. No smearable activity was obtained from the machined castings. Contamination control and cleanup problems in the machining operation were negligible.

These tests have demonstrated that centrifugal castings can be made from a stainless steel supply contaminated with isotopes of cobalt, strontium, cesium, and iridium. With radiation levels of about 0.4 mrem/h (which approaches the DWPf upper limit), no smearable surface contamination was obtained from the machined cylinders.

#### CONCLUSIONS

The CFDA program was undertaken to develop an environmentally acceptable method of using large quantities of radioactively contaminated steel located throughout the United States. Fabrication of HLW canister from radioactively contaminated stainless steel would reduce the cost and technical problems associated with the disposal of this metal and reduce the

consumption and consequent permanent loss of noncontaminated stainless steel which would otherwise be required for fabricating these canisters.

All of the test programs conducted in support of HLW canister fabrication resulted in the conclusion that radioactively contaminated stainless steel can successfully be used in canister fabrication.

#### REFERENCES

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