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Final Report Spent Nuclear Fuel Retrieval System Primary Cleaning Development Testing

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P. V. Meeuwsen

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Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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Spent Nuclear Fuel Retrieval System
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Summary

Primary cleaning development testing was performed in support of the Fuel Retrieval System (FRS) Sub-Project at the Hanford Site in Richland, Washington. The Spent Nuclear Fuel Project is responsible for retrieving K-Basin spent nuclear fuel (SNF) from existing storage locations in the fuel storage basins, clean and remove the fuel from the storage canisters, repackage it into fuel storage baskets, and load the baskets into a multi-canister overpack (MCO). Once in the MCO, the fuel will undergo hot and cold vacuum drying in preparation for interim dry storage at the Canister Storage Building (CSB). This process includes retrieving the fuel canisters, sufficiently remove the uranium corrosion products (or sludge) from the fuel elements, empty the fuel from the canisters, sort the various debris and scrap from intact elements and pieces, and repackage the fuel in the MCO baskets in preparation for MCO loading.

A primary clean machine will be used to remove the gross sludge from canisters and fuel while maintaining water quality in the downstream process area. The sludge will be confined within the outer containment box of the primary clean machine and pumped through associated piping to the water treatment system. To facilitate SNF separation from canisters and minimize the impact to water quality, all canisters will be subjected to mechanical agitation and flushing with the Primary Clean Station. The Primary Clean Station consists of an outer containment box with an internally mounted, perforated wash basket. A single canister containing up to 14 fuel assemblies will be loaded into the wash basket, the confinement box lid closed, and the wash basket rotated for a fixed cycle time. During this cycle, basin water will be flushed through the wash basket and containment box to remove and entrain the sludge and carry it out of the box. Secondary cleaning, which was not within the scope of this testing, will be performed downstream, as required, on the fuel handling process table and will use some form of brushing action.

Primary cleaning tests were performed at the 305 Building Equipment Testing Laboratory from June through September 1996 and provided information concerning the removal of sludge from the fuel assemblies while in the basin canisters. The testing was also used to determine if additional fuel cleaning is required outside of the fuel canisters. Hydraulic performance and water demand requirements of the cleaning station were also evaluated.

Completed tests have demonstrated that sludge can be dislodged and suspended sufficiently to remove it from the canister. Furthermore, visual examination of dummy fuel elements after completing the cleaning process suggests that better than 95% of the exposed fuel surfaces have been cleaned to a point that no visual evidence of any film, such as corrosion, etc., remains. The remaining 5% surface area was limited to random thin film deposits. When less conservative simulants were used, the cleanliness of the fuel approached 100%, although approximately only 50% of the sludge placed under simulated breached cladding was removed.

As a result of this testing, the recommended cleaning cycle consists of loading the fuel canister into the wash basket and rotating the fuel clockwise at 4 rpm for 20 minutes while the fuel is allowed to translate 4 inches up and down inside the canister. The flush nozzles should each flush continuously at

20 gpm and 225 psig and flush the canister as it passes by the nozzles during each rotation. The second phase of the primary cleaning cycle (i.e., basket washing) provided insignificant cleaning value during the testing process.

Abbreviations and Acronyms

BNFL	British Nuclear Fuels Limited, Inc.
CSB	Canister Storage Building
CCW	Counter Clockwise
CW	Clockwise
FRS	Fuel Retrieval System
IWTS	Integrated Water Treatment System
MCO	Multi-Canister Overpack
SNF	Spent Nuclear Fuel
SPR	Single Pass Reactor
XXS	Double Extra Strong

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1.0 Introduction

Primary cleaning development testing was performed in the summer of 1996 in support of the Fuel Retrieval System (FRS) Sub-Project at the Hanford Site in Richland, Washington. The Spent Nuclear Fuel Project is responsible for retrieving K-Basin spent nuclear fuel (SNF) from existing storage locations in the fuel storage basins. This process includes retrieving the fuel canisters, removing the uranium corrosion products (or sludge) from the fuel elements, emptying the fuel from the canisters, sorting the various debris and scrap from intact elements and pieces, and repackaging the fuel in the MCO baskets in preparation for MCO loading. Once in the MCO, the fuel will undergo hot and cold vacuum drying in preparation for interim dry storage at the Canister Storage Building (CSB).

A primary clean machine will be used to remove the gross sludge from the canisters and fuel while maintaining water quality in the downstream process area. The sludge will be confined within the outer containment box of the primary clean machine and pumped to the water treatment system. To facilitate SNF separation from canisters and minimize the impact to water quality, all canisters will be subjected to mechanical agitation and flushing at the Primary Clean Station. The Primary Clean Station consists of an outer containment box with an internally mounted, perforated wash basket. A single canister containing up to 14 fuel assemblies will be loaded into the wash basket, the confinement box lid closed, and the wash basket rotated for a fixed cycle time. During this cycle, basin water will be flushed through the wash basket and containment box to remove and entrain the sludge and carry it out of the box. Secondary cleaning, which was not within the scope of this testing, will be performed as required downstream on the fuel handling process table, and will use some form of brushing action.

Testing of the primary clean machine was performed at the 305 Building Equipment Testing Laboratory, Figure 1.1, from June through September 1996. The testing provided information concerning the removal of sludge from the fuel assemblies and aided in determining if additional cleaning would be required after the fuel was removed from the fuel canisters. Hydraulic performance and water demand requirements of the cleaning station were also evaluated. Testing was performed in accordance with the specification of Appendix A and the procedure listed in Ketner (1996).

For testing purposes, a full scale mockup of the primary clean machine was fabricated and a previously unused fuel canister and several dummy fuel assemblies, fabricated from heavy wall pipe, were assembled to mockup a typical fuel canister to be washed. The pipe used for the dummy fuel assemblies was chosen to closely approximate actual fuel dimensions. Fuel assemblies are made up of two hollow cylinders, one inside the other, and each storage canister has two barrels, which hold seven complete fuel assemblies each.

In the tests, a single sample canister, containing up to 14 dummy fuel assemblies, was loaded into the wash basket and the primary clean machine confinement box lid was closed. The wash basket was then rotated inside the confinement box for a fixed cycle time while high-pressure nozzles fed flush water through slots in the perforated basket down the length of the canister barrels. This flush water was

Figure 1.1. 305 Building Test Bed for Primary Clean Machine

used to mobilize and flush simulant sludge from the canister barrel and dummy fuel elements. The entrained sludge was removed from the confinement box by the suction pump in the flush system.

1.1 Test Objectives

The major objectives of primary clean development testing were:

- Evaluate water flow paths, volumetric flow rates, and nozzle sizes and locations needed to remove sludge from the fuel assemblies effectively
- Evaluate the mechanical motions required, with regard to rotation of the wash basket and drop distance of the fuel assembly in the basket
- Evaluate the level of cleanliness accomplished, with the goal of minimizing the need for secondary cleaning, and determine if the primary clean system can adequately clean sludge out of the fuel assembly annulus and center hole.

The test objectives were grouped into two phases of primary cleaning operations—Phase 1, gross de-sludge of the fuel and canisters, and Phase 2, the fuel cleaning cycle.

The primary objective of Phase 1 testing was to remove the sludge entrained within the canister and fuel annulus in an environment isolated from the basin water. Phase 1 testing was designed to characterize the following:

- the effect of fuel translation in the canister on canister de-sludging
- the effect of nozzle configuration/size/location on canister de-sludging
- the effect of cradle slot width and orientation on nozzle flow pattern
- the effect of nozzle pressure and flow rate on canister flushing
- the effect of canister angle on canister flushing
- the effectiveness of sludge removal from the outer containment box
- the cycle time required to de-sludge the canister

The primary objective of Phase 2 testing was to remove the sludge and corrosion products adhering to the fuel element surfaces and minimize any impact on downstream processes. Phase 2 testing was designed to characterize the following:

- whether fuel dumped in a vertical position would translate to a horizontal position during basket rotation
- the effect of basket rotation speed on the effectiveness of fuel cleaning
- whether fuel rolls or slides in the basket
- whether any rolling motion of the fuel affects or enhances the cleaning (e.g., outer elements rolling against outer elements and inner elements rolling against outer elements)
- whether fuel shoes affect fuel rolling
- the effectiveness of sludge removal from the outer containment box
- the cycle time required to clean fuel

1.2 Test Strategy

The Characterization Sub-Project was funded to test the adherence of sludge to fuel assemblies as part of the on-going retrieval (at K East basin) and characterization activities (at 325/327/222S Buildings). To evaluate the washing process proposed for the basins, a Plexiglas™ tube, large enough to hold three fuel assemblies (approximately 12 inches in diameter by 3 feet long), was fabricated with removable end caps.

The tube was designed to be remotely rotated about its longitudinal axis and its transverse axis. Three fuel assemblies were loaded into the Plexiglas™ tube and the tube was rocked back and forth to simulate the transverse washing process. The tube was then rolled around its longitudinal axis to simulate the rotational washing process. A secondary cleaning process using a wire brush system was also evaluated. Results of the characterization tests described above are included in Bergman (1996).

To meet the three primary test objectives for primary clean system testing, a cold test platform was prepared and tested using simulated sludge. Spare fuel canisters were used to hold a full load of dummy fuel and a simulated wash basket was designed to rotate the fuel. Flexibility was designed into the flush system to allow measurable variations in water flow path, volume, velocity, and pressure. Sludge simulants were selected and tested based on the best available information. This strategy recognizes that the actual behavior of sludge is difficult to characterize; therefore, a range of simulants representing diverse physical characteristics was selected to bound the anticipated range of physical properties.

1.3 Test Method

Testing was designed to begin with a baseline set of conditions, as shown in the second column of Table 1.1. These parameters were varied, based on results of the initial tests, until the acceptance criteria (listed below) were met.

1.3.1 Phase 1 Testing

To imitate the baseline Phase 1 cleaning process, the primary clean cradle was loaded with a K Basin canister full of dummy inner and outer elements (steel pipe). The cradle was mounted in the outer containment box, the box sealed and process water flushed through the box. The cradle was rotated for a fixed period of time, then stopped in a position aligning the cradle slot with the flush nozzles. The flush nozzles were engaged for a fixed period of time, turned off, and then the cradle rotated again for a second fixed period of time with all other variables held constant. This process sequence and the process parameters listed in Table 1.1 were varied as required to achieve the acceptance criteria.

1.3.2 Phase 2 Testing

To imitate the baseline Phase 2 clean process, the cradle supporting the canister and fuel was removed from the outer containment box, the bottom half of the basket placed back in the outer containment box, and the canister of fuel (from Phase 1 testing) dumped into the basket. The top half of the basket was then assembled and the basket rotated for a fixed period of time. This process sequence and the process parameters listed in Table 1.2 were varied as required to achieve the acceptance criteria.

1.3.3 Acceptance Criteria for Phase 1 and Phase 2 Testing

Each test was considered a success if, after Phase 2 testing was completed, all fuel elements were visually clean as viewed from a 1X power (magnification) video camera at a distance of 2 feet from the fuel surface. This included a 100% inspection of the inner, outer, and end surfaces of the fuel elements.

Table 1.1. Phase 1 Process Variables

Parameter	Starting ^(a)	Option 1 ^(a)	Option 2 ^(a)
Outer Containment Box Water Flow Throughput (gpm)	80	60	100
Cradle Rotation Speed (rpm)	2	--	--
Initial Cradle Rotation Period (minutes)	5	10	--
Fuel Translation (inches)	4	2	6
Cradle Flush Location - 0 degrees up (degrees)	255	180	225
Flush Period (minutes)	5	2	10
Nozzle Type	Commercial	Open pipe	--
Nozzle Orifice Size (inches)	1/2	3/8	--
Nozzle Flow Rate (gpm) ^(b)	15	10	20
Cradle Slot Size (inches)	1/2	1	--
Cradle Slot Location	Top	Middle	--
Dummy Fuel Assemblies (steel pipe inner and outer)	Mixed ^(d)	All good	All bad ^(c)
Final Cradle Rotation Period (minutes)	5	10	--
Simulant Type for lower section of fuel assembly	Kaolin with boride powder ^(e)	Min-u-sil (ground silica) with soda ash ^(e)	--
Simulant Type for upper section of fuel assembly	Rust film	Vegetable oil with lamp black	Chalk

(a) These parameters were varied based on test results and the decisions of the design team.
(b) This flow rate is included in the flow throughput listed for the outer containment box.
(c) Shim stock tie wrapped to dummy representing breached cladding
(d) 2 bad (shim stock tie wrapped to dummy representing breached cladding), 3 good, 2 with inner fixed to outer; 7 assemblies per each half of canister for a total of 14 dummy assemblies.
(e) Formula was provided by the test manager and varied as a result of testing.

Table 1.2. Phase 2 Process Variables

Parameter	Initial ^(a)	Option 1 ^(a)	Option 2 ^(a)
Outer Containment Box Water Flow Throughput (gpm)	80	60	100
Basket Rotation Speed (rpm)	2	1	3
Basket Rotation Period (minutes)	5	10	15
Dummy Fuel Assemblies	Steel pipe ^(b)	lead ^(b)	mixed ^(b)

(a) These parameters may be varied with any combination of the starting and options listed depending on the decision of the design team.
(b) Use as found dummies from Phase 1 testing.

1.4 Test Equipment

A developmental test platform, Figure 1.2, was fabricated by the 305 Building staff (Equipment Testing Laboratory), based on design input provided by the design agent, British Nuclear Fuels, Limited, Inc. (BNFL). The primary clean machine consisted of an outer containment box approximately 4 feet wide, 4 feet deep, and 4 feet high. The box was designed to house a cradle and basket that rotates at approximately 2 rpm.

The cradle was designed to hold and rotate a K Basin fuel canister loaded with 14 dummy fuel assemblies and weighing up to 800 pounds. As the cradle rotated, the canister was fixed in the cradle while the fuel remained free to translate back and forth a nominal 4 inches. The translation was achieved by force of gravity, as the canister was rotated end over end. The top of the cradle was designed to allow two nozzles to flush the canister with water, at a nominal 15 gpm and 100 psig each. The nozzles were mounted in the outer containment box so that the canister could be brought into an inverted orientation and stopped in position to allow direct flushing of the canister and fuel.

The basket was also designed to hold 14 fuel elements weighing up to 800 pounds. After the cradle testing was completed (Phase 1), the cradle and canister of fuel were removed from the outer containment box, the lower half of the basket was loaded back into the outer containment box, and the canister of fuel was dumped into the basket. The other half of the basket was then assembled and the system was rotated at a fixed speed.

Support equipment included a 1500 and 1000 gallon water supply tank and a tank of approximately 1200 gallons, which was used to collect the process water before it was transferred to the process sewer. The outer containment box was flushed with water using a downstream, low-pressure, discharge pump at a nominal rate of 80 gpm. A second low-pressure pump was used to supply a 10-foot head above the outer containment box, to simulate the nominal basin head above the Primary Clean Station. The flush

Figure 1.2. Primary Clean Test System Process Diagram

water was supplied by a high-pressure pump at a nominal rate of 19 gpm at approximately 225 psig, with one nozzle operating; or 30 gpm (15 gpm per nozzle) at approximately 100 psig with two nozzles operating.

Dummy fuel elements, outers and inners respectively, were fabricated from 26 in. lengths of 2 in. Schedule 160 and 1 in. double extra strong (XXS) pipe. Simulated shoes, fabricated from 3/16 inch by 1/4 inch by 1 inch long bar stock, were welded on one set of inner dummy elements (Figure 1.3). Three of these shoes were attached symmetrically, approximately 4 inches from each end of the dummy element. A test instrumentation and calibration list is shown in Table 1.3, and Table 1.4 is the materials and equipment list used in this testing.

Figure 1.3. Example of Simulated Shoes Welded to Dummy Inner Fuel Element

Table 1.3. Instruments and Calibration List

Instrument Type	Manufacturer	Serial #	Size	Range	Accuracy	Calibration
Pressure	Marsch	N/A	N/A	0-600 psig	N/A	None
Flow	GPI O4531GM	N/A	1 in.	3-50 gpm	+/- 1% of range	None*
Flow	Endress and Hauser	1943-0983629R95	3 in.	0-220 gpm	N/A	None*
Turbidity	Monitek 134	7-6799	2 in.	0-10	N/A	User Calibrated
Scale	Chatillon BP15-50T	90475	--	0-50 lb.	+/- 0.25 lb	347-66-01-001 Expires 09/11/96
Scale	Fairbanks Morse 1124A	G501580	--	0-500 lb.	+/- 1.0 lb.	750-66-06-001 Expires 6/11/97
Scale	Toledo 8140	4387160	--	0-5000 lb.	+/- 1.0 lb.	750-66-01-044 Expires 12/21/96

* For indication only; a known volume and a stopwatch were used to verify the reasonable accuracy of the instrument.

Table 1.4. Materials and Equipment List

Equipment	Service Range/Specification	Manufacturer/Model	Purpose/Description
Pump	27 gpm @ 173 psig; 20 gpm @ 217 psi; 7.5 hp.; 3510 rpm	Reliance P21 G6760B motor Sunflo P1DSC pump	Supply nozzle pressure/flow
Pump	0-130 gpm; 2.5 hp	Sta-Rite	Pressurizes outer containment box to 10 feet of head
Pump	0-130 gpm.; 2.5 hp	Sta-Rite	Discharge pump for outer containment box flow
Tank	1500 gallon polyethylene	PolyTank	Water supply
Tank	1000 gallon polyethylene	PolyTank	Water supply for outer containment box & flush nozzles
Tank	1200 gallon polyethylene	PolyTank	Discharge and settling tank for outer containment box
Outer Containment Box	4 ft. cubed steel box with Plexiglas window ports	N/A	Houses fuel cradle and basket. Includes bearings and motor drive for cradle/basket rotation.
Motor	2 hp.; 3450 rpm	Doerr	Powers basket rotation
Gear box	1000 to 1 reduction;	Acrison 6MSFD	Reduces motor speed to basket
Controller	0 to 2 times motor speed	Reliance Electric SP500 VS Drive	Controls motor speed to gear box
Cradle	Holds 800 lb.; mounts to motor drive and easily removable; allows fuel to slide from 2-6 in. with canister held in place.	N/A	Houses and rotates K- basin fuel canister and dummy fuel for cleaning
Basket	32 in. diameter; circumference with ¼-in. diameter holes with ~50% penetration; holds up to 800 lb. Fuel	N/A	Receives and tumbles dummy fuel for cleaning
Nozzles	2 commercial ¼-in. collimated flow	Spraying Systems	Flush nozzles to remove gross sludge from inside canister
Swivel Joint	½" pipe;	Aeroquip Swivel 5900 Series	Allows continuous flushing of the canister
Hoist/Crane	2 ton & 5 ton	N/A	Lift cradle/ basket full of dummy fuel. Move equipment for test setup.
Pipe	26 in. lengths of 2 in. Schedule 160 and 1 in. Schedule XX pipe	N/A	Fuel dummies - 14 inners and 14 outers; balance used for partials, bits, and scraps.
Lead Fuel Dummies	Lead encased and sealed in 2 inch stainless steel; ~50 lb.	N/A	Fuel dummies representative of Mark IV fuel OD, length and weight.
Shim Stock	3 mil stainless steel at 4" wide and full circumference of steel dummies	N/A	Represent breached clad on dummy elements. Wrapped around end of dummy fuel with ties
Clamps	Plastic ties	N/A	Hold shim stock onto dummy elements
Water	Potable	N/A	Process media for flushing
Barite	Barium Sulfate, powder form; sp. gr. ~4.2	Baroid	Sludge Simulant
Kaolin Clay	96% Kaolin Clay; balance silica; sp. gr. ~ 2.6	N/A	Sludge Simulant
Sand	Generic	N/A	Sludge Simulant

2.0 Test Descriptions and Results

A series of 30 tests were performed in sequence to evaluate the parameters described in the test specification (Appendix A). Each test, and its basis, is described in this section. A summary of results follows each test description. Note that test 18 was conducted in two separate stages, denoted as 18a and 18b; and Test 22 is planned at a later date, to evaluate the cleaning of shorter pieces of fuel.

Test 1

The first test was a pre-operational test performed to baseline test parameters using the draft test procedure (WHC-SD-SNF-TC-007) to verify equipment operation. Steel pipe fuel dummy assemblies were lightly rusted to simulate a thin film coating that was easily removed with mechanical action. The rust could be removed with a little water and simple scrubbing action. The balance of the fuel dummies were lead-filled and representative of the fuel assembly weight.

Simulant was prepared to represent sludge and corrosion product build-up in the bottom of the canister. It consisted of a mix of 40 wt% boride, 40 wt% kaolin clay, and 20 wt% water. The simulant was poured into the canister before loading the fuel and resulted in a simulant depth of 4 to 5 inches with the fuel in place. The boride provided a heavy (specific gravity = 4.7) fine particulate. Kaolin clay was used for adherence to the fuel. Kaolin clay also provided a soluble media to observe flow patterns. The simulants were chosen based on videotape footage of fuel sludge characterization and a report by Makenas (1996). This simulant mix resulted in a specific gravity of 2.3.

Date: June 28, 1996

Canister Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Simulant Depth: 4 inch to 5 inch after elements in canister

Fuel Simulant: Rust

Fuel Dummies (left barrel): 4 steel inner and outer elements without shoes, 4 lead-filled tubes (8 total elements were placed into barrel); center assembly lead

Fuel Dummies (right barrel): 7 lead-filled tubes

Canister weight full of water before test: 696.5 pounds

Cradle Top: 0.5 inch slots along axis of rotation and width of canister barrels

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Fuel Translation: 4 inch

Cradle Rotation: CCW @ 1.8 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: Test discontinued after Phase 1 test process of 4.5 min. cradle rotation and fuel was inspected.

Results: Water clouded quickly (visibility lost after 70 seconds of rotation). The outer surfaces of the inner elements were smeared with sludge along the length of the inner elements, primarily where they came in contact with the outer elements. Outer elements were relatively clean on the outside surface. Surface rust appeared to be removed.

Test 2

This test was a repeat of Test 1 with baseline test conditions per WHC-SD-SNF-TC-007, Rev. 0. One change that was made to the process was to provide clean process water continuously to the clean system, rather than recycling the cloudy water. Key process parameters included a Phase 1 pre-cleaning cycle of 5 minutes of canister rotation followed by a flush cycle (without canister rotation) of 5 minutes in each barrel. The Phase 1 test cycle was completed with 5 minutes of canister rotation. During the flush cycle, the 1/4-inch nozzles were operated for 5 minutes in each canister barrel, a total elapsed time of 10 minutes, with a source pressure of approximately 225 psig.

Date: July 1, 1996

Canister Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: Rust

Fuel Dummies (left barrel): 3 steel inner and outer elements without shoes, 4 lead-filled tubes; center assembly lead

Fuel Dummies (right barrel): 7 lead-filled tubes

Canister weight full of water before test: 648 pounds

Cradle Top: 0.5 inch slots along axis of rotation and width of canister barrels

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 225 psig

Nozzle Flow: 18 to 19 gpm

Fuel Translation: 4 inch

Cradle Rotation: CCW @ 1.8 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 5 min. cradle rotate, water drained to align nozzle, outer containment box filled and flush nozzle run for 5 min. on the right barrel followed by 5 min. on the left barrel. The cradle was finally rotated for 5 min. and fuel was inspected.

Canister Weight after Phase 1 test: 647.25 pounds

Results: Water clouded quickly (visibility lost after 80 seconds of rotation). Water cleared significantly during final rotation of cradle. Rust appeared to be removed. All of the steel elements had dime-size spots of simulant at random locations. One steel inner element had a simulant plug in the end. 1/3 of the lead-filled tube dummies had dime-size spots. The balance was clean. The surface finish of the lead-filled tubes was smoother than that of the steel dummies. Each canister barrel had about a thimble full of simulant remaining in it.

Phase 2 Process: Not performed due to cleanliness of fuel in Phase 1 testing.

Note: A wire brush was used to demonstrate that the simulant smeared when brushed without water, and dissolved when brushed with water. A low-pressure/low-volume stream of water was also shown to remove the simulant. The element was wet prior to simulant application.

Test 3

This test was performed with baseline test parameters per WHC-SD-SNF-TC-007, Rev. 0., except that, again, only two steel dummy assemblies were used in each canister barrel and a new canister bottom simulant was used. Steel pipe dummies were rusted; the balance of the fuel dummies were lead-filled.

Canister bottom simulant was prepared as a mix of 2 pounds sand, 2 pounds boride, 2 pounds kaolin clay, and enough water to achieve a pancake batter consistency. Simulant was poured into the canister pre-filled with dummy fuel and water and allowed to settle for 5 days. The settling time was allotted in an attempt to get a packed sludge base. This simulant was used to represent a canister sludge that had adherent properties with a larger particle size, and was based on a recommendation by the design agent (BNFL). Flush nozzles were operated individually with a source pressure of ~225 psig.

Date: July 8, 1996

Canister Simulant: 2 pounds kaolin clay, 2 pounds boride, 2 pounds sand, balance water to obtain a pancake batter consistency. Simulant was poured into canister and allowed to settle for 5 days.

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: Rust

Fuel Dummies (left barrel): 4 steel inner and outer elements without shoes, 3 lead-filled tubes; center assembly lead

Fuel Dummies (right barrel): 7 lead-filled tubes

Canister weight full of water before test: 650.5 pounds

Cradle Top: 0.5 inch slots along axis of rotation and width of canister barrels

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 225 psig

Nozzle Flow: 18 to 19 gpm

Fuel Translation: 4 inch

Cradle Rotation: CCW @ 1.8 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 5 min. cradle rotate, water drained to align nozzle, outer containment box filled and flush nozzle run for 5 min. on the right barrel followed by 5 min. on the left barrel. The cradle was finally rotated for 5 min. and fuel was inspected.

Canister Weight after Phase 1 test: 648 pounds

Results: Water clouded quickly (visibility lost after 35 seconds of rotation). Water cleared significantly during final rotation of cradle. Rust appeared to be removed. All of the steel elements had 1/8-inch-dia. size spots of simulant at random locations, mostly at the canister bottom end. A couple of the inner and outer elements had trace amounts of simulant on the bottom edge. All of the lead-filled tube dummies were clean. The canister bottom was clean. Estimate 99% clean. Another significant observation was that the lead-filled tube dummies had no noticeable end damage (i.e., no flaring), after 3 tests of dropping and banging from their own weight.

Phase 2 Process: Not performed due to cleanliness of fuel in Phase 1 testing.

Test 4

This test was performed with baseline test parameters per WHC-SD-SNF-TC-007, Rev. 0., except that a new simulant was used. Fuel dummies were used with baseline conditions and each canister barrel included 2 steel assemblies with inner elements locked to prevent sliding relative to the outer elements, and 5 steel assemblies with inner elements able to slide relative to the outer elements. Two of the five outer elements had shim stock clamped to the outside to represent breached cladding. The simulant was changed to create a higher density. The simulant mix consisted of 70 wt% boride, 10 wt% kaolin clay, and 20 wt% water, resulting in a specific gravity of 2.6. Flush nozzles were operated in both canister barrels at the same time at ~125 psig.

Date: July 9, 1996

Canister Simulant: 70 wt% kaolin clay, 10 wt% boride, 20 wt% water

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: Rust

Fuel Dummies (left barrel): 7 total steel inner and outer elements without shoes; 2 inner elements welded to the outer elements; 1 outer element with shim stock clamped on the full length, 1 outer element with shim stock clamped on half the length. Simulant was not placed under shim stock or down the full length of the annulus of the welded steel assemblies.

Fuel Dummies (right barrel): Same as left barrel.

Canister weight full of water before test: 443.75 pounds

Cradle Top: 0.5 inch slots along axis of rotation and width of canister barrels

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 125 psig

Nozzle Flow: 15 gpm

Fuel Translation: 4 inch

Cradle Rotation: CCW @ 1.8 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 5 min. cradle rotate, water drained to align nozzle, outer containment box filled and flush nozzle run for 5 min. on the right barrel followed by 5 min. on the left barrel. The cradle was finally rotated for 5 min. and fuel was inspected.

Canister Weight after Phase 1 test: 440.5 pounds

Results: Water clouded quickly (visibility lost after 60 seconds of rotation). Water cleared significantly during final rotation of cradle. Rust appeared to be removed. 4 inner elements had plugs remaining. One welded inner to outer element had a plug. All elements had random spots, streaks and smears of simulant. Bottom of canister had approximately ¼ cup of simulant remaining in each barrel. Shim stock was not removed for inspection. Estimate 80% clean.

Phase 2 Process: Dirty elements of Phase 1 testing were randomly stacked into the lower half of the basket without regard to other element orientations. Inner elements were not kept inside outer elements. The upper half of the basket was installed and the elements were tumbled CCW for 5 minutes at 1.8 rpm.

Results: All but one of the inner elements aligned themselves with the axis of rotation just after a minute of rotation. The elements slid on the basket surface rather than rolling. Plugs still remained in all inner elements and one welded element. Outer surfaces of elements were somewhat cleaner, but fuel was still less than 95% clean. There was some evidence that the simulant was just spread out rather than removed. Shim stock was not removed for inspection.

Test 5

Baseline test per WHC-SD-SNF-TC-007, Rev. 0, with no simulant. Provided visualization of fuel movement and process water flow for baseline comparison.

Date: July 11, 1996

Canister Simulant: None

Simulant Depth: N/A

Fuel Simulant: None

Fuel Dummies (left barrel): 7 total steel inner and outer elements without shoes; 2 inner elements welded to the outer elements; 1 outer element with shim stock clamped on the full length, 1 outer element with shim stock clamped on half the length.

Fuel Dummies (right barrel): Same as left barrel.

Average clean dry welded steel assembly weight: 23.91 pounds

Average clean dry inner element weight: 16.26 pounds

Average clean dry outer element weight: 24.05 pounds

Canister weight full of water before test: N/A

Cradle Top: 0.5 inch slots along axis of rotation and width of canister barrels

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 225 psig

Nozzle Flow: 19 gpm

Fuel Translation: 4 inch

Cradle Rotation: CCW @ 1.8 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 5 min. cradle rotate, water drained to align nozzle, outer containment box filled and flush nozzle run for 5 min. on the right barrel followed by 5 min. on the left barrel. The cradle was finally rotated for 5 min.

Canister Weight after Phase 1 test: N/A

Results: Test was performed to visualize the cleaning process. Elements fell from the bottom of the can at about 45° below horizontal. Elements were returned to the canister bottom at about 40° above horizontal. Flow exiting out the middle of the inner elements was observed at 225 psig, but not at 125 psig.

Phase 2 Process: Elements of Phase 1 testing were randomly stacked into the lower half of the basket without regard to other element orientations. Inner elements were kept inside outer elements. The upper half of the basket was installed and the elements were tumbled CCW for 5 minutes at 1.8 rpm.

Results: All but one of the elements aligned themselves with the axis of rotation in just under a minute of rotation. The remaining element aligned itself after 90 seconds. After aligning with the axis, the elements slid on the basket surface rather than rolling.

Test 6

Repeat of Test 4 with nozzle pressure at ~225 psig. This test was performed to evaluate whether the new simulant or low pressure caused the cleaning problem observed in Test 4. An alignment system was installed on the cradle so that the cradle could be positioned for flushing without emptying the outer containment box.

Date: July 12, 1996

Canister Simulant: 70 wt% kaolin clay, 10 wt% boride, 20 wt% water

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: Rust

Fuel Dummies (left barrel): 7 total steel inner and outer elements without shoes; 2 inner elements welded to the outer elements; 1 outer element with shim stock clamped on the full length, 1 outer element with shim stock clamped on half the length.

Fuel Dummies (right barrel): Same as left barrel.

Canister weight full of water before test: 441 pounds

Cradle Top: 0.5 inch slots along axis of rotation and width of canister barrels

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 225 psig

Nozzle Flow: 19 gpm

Fuel Translation: 4 inch

Cradle Rotation: CCW @ 1.8 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 5 min. cradle rotation. With cradle fixed (an alignment device was used so that the outer containment box need not be emptied), the flush nozzle ran for 5 min. on the right barrel followed by 5 min. on the left barrel. The cradle was finally rotated for 5 min. and fuel was inspected.

Canister Weight after Phase 1 test: 440.5 pounds

Results: Water clouded quickly (visibility lost after 40 seconds of rotation). Water cleared significantly during final rotation of cradle. One of the shim stock pieces was blown out the top. Rust appeared to be removed. No simulant was found under the shim stock after removal. Bottom of barrel was also clean. This test met the acceptance criteria for 100% clean.

Phase 2 Process: Not performed due to cleanliness of fuel in Phase 1 testing.

Test 7

Repeat of Test 2 except that prior to loading the fuel elements into the cradle, the inner and outer surface of the fuel dummies were coated with a thin layer of simulant and allowed to dry over the weekend. Simulant was applied to the outside surface of the elements since there was concern that the rust was simply dissolving, rather than being physically removed.

Date: July 15, 1996

Canister Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water; coated on outer surfaces

Fuel Dummies (left barrel): 7 total steel inner and outer elements without shoes; 2 inner elements welded to the outer elements; 1 outer element with shim stock clamped on the lower 3 inches. Simulant was placed under shim stock. Simulant was not placed down the full length of the annulus of the welded steel assemblies (only about 3 inches covered at each end).

Fuel Dummies (right barrel): Same as left barrel.

Canister weight full of water before test: N/A

Cradle Top: 0.5 inch slots along axis of rotation and width of canister barrels

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 225 psig

Nozzle Flow: 19 gpm

Fuel Translation: 4 inch

Cradle Rotation: CCW @ 1.8 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 5 min. cradle rotation. With cradle fixed (an alignment device was used so that the outer containment box need not be emptied), the flush nozzle ran for 5 min. on the right barrel followed by 5 min. on the left barrel. The cradle was finally rotated for 5 min. and fuel was inspected.

Canister Weight after Phase 1 test: N/A

Results: Water clouded quickly. Water cleared significantly during final rotation of cradle. Elements were better than 99% clean; with only random very light smears. A light film remained on all the elements after drying. Some simulant (~50% covered) was found under the shim stock after removal. Bottom of barrel was covered with about a teaspoon of simulant.

Phase 2 Process: Elements of Phase 1 testing were randomly stacked into the lower half of the basket without regard to other element orientations. Inner elements were not kept inside outer elements. The upper half of the basket was installed and the elements were tumbled CCW for 5 minutes at 1.8 rpm.

Results: All but one of the elements aligned themselves with the axis of rotation in just under a minute of rotation. The remaining element aligned itself after 90 seconds. After aligning with the axis, the elements slid on the basket surface rather than rolling.

Test 8

Repeat of Test 3 with the flush nozzle pressure at ~ 125 psig. The simulant was allowed to settle overnight. This test was performed to evaluate the ability of low nozzle pressure to clean fuel with the sand simulant.

Date: July 17, 1996

Canister Simulant: 2 pounds kaolin clay, 2 pounds boride, 2 pounds sand, balance water to obtain a pancake batter consistency.

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: Rust.

Fuel Dummies (left barrel): 7 total steel inner and outer elements without shoes; 2 inner elements welded to the outer elements; 2 outer elements with shim stock clamped on the lower 3 inches.

Fuel Dummies (right barrel): Same as left barrel.

Canister weight full of water before test: N/A

Cradle Top: 0.5 inch slots along axis of rotation and width of canister barrels

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 125 psig

Nozzle Flow: 15 gpm

Fuel Translation: 4 inch

Cradle Rotation: CCW @ 1.8 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 5 min. cradle rotation. With cradle fixed (an alignment device was used so that the outer containment box need not be emptied), the flush nozzle ran for 5 min. on the right barrel followed by 5 min. on the left barrel. The cradle was finally rotated for 5 min. and fuel was inspected.

Canister Weight after Phase 1 test: N/A

Results: Water clouded quickly. Water cleared significantly during final rotation of cradle. Two-thirds of the elements were clean. The balance of elements had simulant streaks along their lengths. Shim stock was knocked off one of the elements. Other shim stock element was not inspected. Cleanliness was at least 90%. Canister bottoms were clean.

Phase 2 Process: Not performed.

Test 9

Repeat of Test 2 with the flush nozzles running continuously while the fuel rotated in the cradle for 10 minutes. This test was performed to evaluate the effect of continuous nozzle flow on the cleaning process.

Date: July 16, 1996

Canister Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: Rust.

Fuel Dummies (left barrel): 7 total steel inner and outer elements without shoes; 2 inner elements welded to the outer elements; 2 outer elements with shim stock clamped on the lower 3 inches.

Fuel Dummies (right barrel): Same as left barrel.

Canister weight full of water before test: N/A

Cradle Top: 0.5 inch slots along axis of rotation and width of canister barrels

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 225 psig

Nozzle Flow: 19 gpm

Fuel Translation: 4 inch

Cradle Rotation: CCW @ 1.8 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 10 min. cradle rotation while flushing nozzle on the right barrel for 5 min. followed by 5 min. on the left barrel. Canister was inverted as outer containment box was drained for inspection.

Canister Weight after Phase 1 test: N/A

Results: Water clouded quickly. All elements were clean. Most elements had simulant streaks along the lengths. Fuel was clean under shim stock. Fuel was 100% clean. Canister bottoms were clean.

Phase 2 Process: Not performed.

Test 10

Repeat of Test 3 with the flush nozzles running continuously at ~225 psig, while the fuel rotated in the cradle for 10 minutes. This test was performed to evaluate the effect of continuous nozzle flow on the cleaning process on the sand simulant.

Date: July 18, 1996

Canister Simulant: 2 pounds kaolin clay, 2 pounds boride, 2 pounds sand, balance water to obtain a pancake batter consistency.

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: Rust.

Fuel Dummies (left barrel): 7 total steel inner and outer elements without shoes; 2 inner elements welded to the outer elements; 2 outer element with shim stock clamped on the lower 3 inches.

Fuel Dummies (right barrel): Same as left barrel.

Canister weight full of water before test: N/A

Cradle Top: 0.5 inch slots along axis of rotation and width of canister barrels

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 225 psig

Nozzle Flow: 19 gpm

Fuel Translation: 4 inch

Cradle Rotation: CCW @ 1.8 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 10 min. cradle rotation while flushing nozzle on the right barrel for 5 min. followed by 5 min. on the left barrel. Canister was inverted as outer containment box was drained for inspection.

Canister Weight after Phase 1 test: N/A

Results: Water clouded quickly. All of the elements were clean except for a small dime-size spot on one element. Elements were clean under shim stock. Cleanliness was at least 99+%. One canister barrel bottom was clean; the other had a small amount of residual simulant.

Phase 2 Process: Not performed.

Test 11

Repeat of Test 6 with nozzles running continuously at ~225 psig, while fuel rotated in the cradle for 10 minutes. This test was to evaluate the effect of continuous nozzle flow on the cleaning process.

Date: July 22, 1996

Canister Simulant: 70 wt% kaolin clay, 10 wt% boride, 20 wt% water

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: Rust.

Fuel Dummies (left barrel): 7 total steel inner and outer elements without shoes; 2 inner elements welded to the outer elements; 2 outer element with shim stock clamped on the lower 3 inches.

Fuel Dummies (right barrel): Same as left barrel.

Canister weight full of water before test: N/A

Cradle Top: 0.5 inch slots along axis of rotation and width of canister barrels

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 125 psig

Nozzle Flow: 15 gpm

Fuel Translation: 4 inch

Cradle Rotation: CCW @ 1.8 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 10 min. cradle rotation while flushing nozzle on the right barrel for 5 min. followed by 5 min. on the left barrel. Canister was inverted as outer containment box was drained for inspection.

Canister Weight after Phase 1 test: N/A

Results: Water clouded quickly. All of the elements were clean. Elements were clean under shim stock. Cleanliness was 100%. Both canister barrel bottoms were clean.

Phase 2 Process: Not performed.

Test 12

Repeat of Test 9 with the following modifications. A couple of dozen nuts and bolts of various sizes were placed in the bottom of the canister and around the fuel. A new cradle top with the slot in-line with the flow path was used. Flush nozzles located at the bottom of the outer containment box were used. Turbidity of the outlet water was monitored every 15 seconds.

Date: July 31, 1996

Canister Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: Rust.

Fuel Dummies (left barrel): 7 total steel inner elements; 6 total outer elements without shoes; 2 inner elements welded to the outer elements; 2 outer element with shim stock clamped on the lower 3 inches; 2 pieces of short pipe stacked around one inner; no shim stock.

Fuel Dummies (right barrel): 6 total steel inner elements; 6 total outer elements without shoes; 2 inner elements welded to the outer elements; 2 outer element with shim stock clamped on the lower 3 inches; one piece of spare pipe placed in center; no shim stock.

Canister weight full of water before test: N/A

Cradle Top: 1.125 inch slots along arc of rotation and in-line with the flush nozzles

Nozzle Size: 0.25 inch

Nozzle Location: 180°

Nozzle Pressure: 225 psig

Nozzle Flow: 19 gpm

Fuel Translation: 4 inch

Cradle Rotation: CCW @ 1.8 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 10 min. cradle rotation while flushing nozzle on the right barrel for 5 min. followed by 5 min. on the left barrel.

Canister Weight after Phase 1 test: N/A

Results: Water clouded quickly. Fuel was not as clean as in Tests 6 - 11. Fuel had random spots/streaks of simulant on inner and outer surfaces. No simulant found on fuel under shim stock. Nuts and bolts fell out of canister. Estimate better than 95% clean. Both canister barrel bottoms were clean.

Phase 2 Process: Not performed.

Test 13

Test 7 was repeated without allowing the simulant to dry and with the new cradle slots/turbidity meter. Indications were that kaolin clay was less adhesive dry than wet. One of the steel dummy outer elements was rough sanded prior to applying the kaolin simulant.

Date: August 5, 1996

Canister Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water; coated on outer surfaces

Fuel Dummies (left barrel): 7 total steel inner and outer elements without shoes; 2 inner elements welded to the outer elements; 1 outer element with shim stock clamped on the lower 3 inches. Simulant was not placed under shim stock or down the full length of the annulus of the welded steel assemblies (only about 3 inches covered at each end).

Fuel Dummies (right barrel): Same as left barrel except one outer element was rough sanded.

Canister weight full of water before test: N/A

Cradle Top: 1.125 inch slots along arc of rotation and in-line with the flush nozzles

Nozzle Size: 0.25 inch
Nozzle Location: 255°
Nozzle Pressure: 225 psig
Nozzle Flow: 19 gpm
Fuel Translation: 4 inch
Cradle Rotation: CCW @ 1.8 rpm
Phase 1 Discharge Flow rate: 80 gpm
Phase 1 Process: 10 min. cradle rotation while flushing nozzle on the right barrel for 5 min. followed by 5 min. on the left barrel.
Canister Weight after Phase 1 test: N/A
Results: Water clouded quickly. Fuel was very dirty with over 30% of elements coated. Sanded element showed no difference. No simulant found on element under shim stock. About 3 tablespoons of simulant also remained in the bottom of the canister.
Phase 2 Process: Not performed.

Test 14

Repeat of Test 13 with a 10-minute Phase 1 cycle time.

Date: August 9, 1996
Canister Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water
Simulant Depth: 4 to 5 inches after elements in canister
Fuel Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water; coated on outer surfaces
Fuel Dummies (left barrel): 7 total steel inner and outer elements without shoes; 2 inner elements welded to the outer elements; 1 outer element with shim stock clamped on the lower 3 inches. Simulant was not placed under shim stock or down the full length of the annulus of the welded steel assemblies (only about 3 inches covered at each end).
Fuel Dummies (right barrel): Same as left barrel except one outer element was rough sanded.
Canister weight full of water before test: 445 pounds
Cradle Top: 1.125 inch slots along arc of rotation and in-line with the flush nozzles
Nozzle Size: 0.25 inch
Nozzle Location: 255°
Nozzle Pressure: 225 psig
Nozzle Flow: 19 gpm
Fuel Translation: 4 inch
Cradle Rotation: CCW @ 2.0 rpm
Phase 1 Discharge Flow rate: 80 gpm
Phase 1 Process: 10 min. cradle rotation while flushing nozzle on the right barrel for 5 min. followed by 5 min. on the left barrel.
Canister Weight after Phase 1 test: 438 pounds
Results: Water clouded quickly. Fuel was very dirty with over 30% of elements coated. Sanded element showed no difference. No simulant found on element under shim stock. Plugs of simulant extruded from the center of the inner elements were found at the bottom of the outer containment box. A few tablespoons of simulant remained in one of the two canister barrels.

Phase 2 Process: Elements of Phase 1 testing were randomly stacked into the lower half of the basket without regard to other element orientations. Inner elements were kept inside outer elements. The upper half of the basket was installed and the elements were tumbled CCW for 5 minutes at 2.0 rpm with both flush nozzles operating at 15 gpm and 125 psi.

Results: All but one assembly aligned with the axis of rotation. The one outer element that did not align remained dirty. The balance of the outer elements were fairly clean. The inner elements remained fairly dirty. Overall cleanliness of around 80%.

Test 15

Repeat of Test 13 with a 15-minute cycle time. The elements were inspected after every 5-minute cycle.

Date: August 12, 1996

Canister Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water; coated on outer surfaces

Fuel Dummies (left barrel): 7 total steel inner and outer elements without shoes; 2 inner elements welded to the outer elements; 1 outer element with shim stock clamped on the lower 3 inches. Simulant was not placed under shim stock or down the full length of the annulus of the welded steel assemblies (only about 3 inches covered at each end).

Fuel Dummies (right barrel): Same as left barrel except one outer element was rough sanded.

Canister weight full of water before test: 437 pounds

Cradle Top: 1.125 inch slots along arc of rotation and in-line with the flush nozzles

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 225 psig

Nozzle Flow: 19 gpm

Fuel Translation: 4 inch

Cradle Rotation: CCW @ 2.0 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 30 min. cradle rotation, at the same time as flushing of nozzle on the right barrel for 5 min. and inspection followed by 5 min. on the left barrel and inspection. This was repeated for a total 15 minutes of flush in each canister barrel.

Canister Weight after Phase 1 test: N/A.

Results: Water clouded quickly. The fuel was very dirty after 5 minutes, somewhat dirty after 10 minutes. The test was aborted since the nozzles were found to be out of alignment with the cradle slot.

Phase 2 Process: Not performed.

Test 16

Repeat of Test 15 on one of the two barrels. The second barrel was filled with 3 inch of boride only. The boride was allowed to settle with the hope that with its higher density and small particle size, it would pack.

Date: August 13, 1996

Right Canister Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Left Canister Simulant: boride

Simulant Depth: 4 to 5 inches after elements in canister

Right Canister Fuel Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water; coated on outer surfaces

Left Canister Fuel Simulant: Rust

Fuel Dummies (left barrel): 7 total steel inner and outer elements without shoes; 2 inner elements welded to the outer elements; 1 outer element with shim stock clamped on the lower 3 inches. Simulant was not placed under shim stock or down the full length of the annulus of the welded steel assemblies (only about 3 inches covered at each end).

Fuel Dummies (right barrel): Same as left barrel except one outer element was rough sanded.

Canister weight full of water before test: N/A

Cradle Top: 1.125 inch slots along arc of rotation and in-line with the flush nozzles

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 225 psig

Nozzle Flow: 19 gpm

Fuel Translation: 4 inch

Cradle Rotation: CW @ 2.0 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 40 min. cradle rotation, at the same time as flushing of nozzle on the right barrel for 5 min. and inspection, followed by 5 min. on the left barrel and inspection. This was repeated for a total 20 minutes of flush in each canister barrel.

Canister Weight after Phase 1 test: N/A.

Results: Water clouded quickly. Fuel was very dirty after 5 minutes in each barrel. After 10 minutes in each barrel, the fuel was 80% clean. After 15 minutes, the fuel was 90+% clean with some small streaks and smears. After 20 minutes, the fuel was 95+% clean with only small random spots. Kaolin clay side was slightly dirtier. One outer element near shim stock clamp had large area of residual simulant. No simulant found on fuel under shim stock.

Phase 2 Process: Not performed.

Test 17

Repeat of Test 14, except after 5 minutes of rotation with high pressure nozzles, the fuel was lanced with a cone spray nozzle at about 200 psig and ~ 20 gpm for 5 minutes in each barrel. This was followed with 5 minutes of rotation with high pressure nozzles.

Date: August 20, 1996

Canister Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water; coated on outer surfaces

Fuel Dummies (left barrel): 7 total steel inner and outer elements without shoes; 2 inner elements welded to the outer elements; 1 outer element with shim stock clamped on the lower 3 inches. Simulant was not placed under shim stock or down the full length of the annulus of the welded steel assemblies (only about 3 inches covered at each end).

Fuel Dummies (right barrel): Same as left barrel except one outer element was rough sanded.

Canister weight full of water before test: 447 pounds

Cradle Top: 1.125 inch slots along arc of rotation and in-line with the flush nozzles

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 225 psig

Nozzle Flow: 19 gpm

Fuel Translation: 4 inch

Cradle Rotation: CW @ 2.0 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 10-min. cradle rotation, at the same time as flushing of nozzle at high pressure on the right barrel for 5 min. and inspection, followed by 5 min. on the left barrel and inspection. The outer containment box water was lowered to the top of the canister and a coned lance was run in and out (~15 sec. per cycle) of the canister barrel for 5 minutes at high pressure (200 psig @ 20gpm) on each side. This was followed by 10 min. of rotation accompanied by 5 min. of flushing at high pressure with each nozzle.

Canister Weight after Phase 1 test: N/A.

Results: Water clouded quickly. Fuel was very dirty after 5 minutes in each barrel. Fuel was still very dirty after lancing. After the final cleaning cycle, the fuel was 90+% clean. A few of the outer elements had significant simulant patches left. No simulant was found on fuel under the shim stock.

Phase 2 Process: Not performed.

Test 18

Repeat of Test 14 for Phase 1 testing, flushing one barrel with counterclockwise rotation and one with clockwise rotation for 10 minutes each. Phase 2 testing included ribs in the basket to enhance fuel rolling. Test was intended to evaluate direction of fuel rotation and to purposely leave fuel dirty for Phase 2 cleaning. ¼-inch tall ribs were fixed full width in the basket at every 45°.

Date: September 3, 1996

Canister Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water; coated on outer surfaces

Fuel Dummies (left barrel): 7 total steel inner and outer elements without shoes; 2 inner elements welded to the outer elements; 1 outer element with shim stock clamped on the lower 3 inches. Simulant was not placed under shim stock or down the full length of the annulus of the welded steel assemblies (only about 3 inches covered at each end).

Fuel Dummies (right barrel): Same as left barrel except one outer element was rough sanded.

Canister weight full of water before test: 447 pounds

Cradle Top: 1.125 inch slots along arc of rotation and in-line with the flush nozzles

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 225 psig

Nozzle Flow: 19 gpm

Fuel Translation: 4 inch

Cradle Rotation: CW & CCW @ 2.0 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 10 min. cradle rotation in CCW direction, at the same time as flushing of nozzle at high pressure on the right barrel for 10 min. and inspection, then 10 min. cradle rotate in CW direction, at the same time as flushing of nozzle at high pressure for 10 min. on the left barrel and inspection.

Canister Weight after Phase 1 test: 432 pounds

Results: Water clouded quickly. Fuel was very dirty after Phase 1 cleaning. Could see no significant difference in cleanliness of fuel between barrels.

Phase 2 Process: Elements of Phase 1 testing were randomly stacked into the lower half of the basket without regard to other element orientations. Inner elements were kept inside outer elements. The upper half of the basket was installed and the elements were tumbled CCW for 10 minutes at 2.0 rpm without flush nozzles.

Results: Basket nubs caused fuel to rotate periodically and fuel was clean at completion of test. Fuel was very clean after 10 minutes except for one inner element with some spots, and sanded outer element with some smears. Estimate 98+% clean. Shim stock was torn off and destroyed.

Test 18b

Repeated of Test 18a for Phase 1 testing only. The test was performed for 20 minutes of flushing in each barrel with 5-minute interval checks.

Date: September 5, 1996

Canister Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water; coated on outer surfaces

Fuel Dummies (left barrel): 7 total steel inner and outer elements without shoes; 2 inner elements welded to the outer elements; 1 outer element with shim stock clamped on the lower 3 inches. Simulant was not placed under shim stock or down the full length of the annulus of the welded steel assemblies (only about 3 inches covered at each end).

Fuel Dummies (right barrel): Same as left barrel except one outer element was rough sanded.

Canister weight full of water before test: 437 pounds

Cradle Top: 1.125 inch slots along arc of rotation and in-line with the flush nozzles

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 225 psig

Nozzle Flow: 19 gpm

Fuel Translation: 4 inch

Cradle Rotation: CCW & CW @ 2.0 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 5 min. cradle rotation in CCW direction, at the same time as flushing of nozzle at high pressure on the right barrel for 5 min. and inspection. Then 5 min. cradle rotate in CW direction, at the same time as flushing of nozzle at high pressure for 5 min. on the left barrel and inspection. This process was repeated for a total duration of 30 minutes.

Canister Weight after Phase 1 test: 435 pounds

Results: Water clouded quickly. Fuel was very dirty after first 5 minutes in each barrel. Fuel was 90 % clean after 10 minutes in each barrel. Fuel was 95+% clean after 15 minutes in each barrel. It appeared that the fuel on the CW rotation side was cleaner than the fuel on the CCW rotation.

Phase 2 Process: Not performed.

Test 19

Repeat of Test 12, except for flushing one barrel at the 255° position, and the other barrel at the inverted 180° position. The test was performed for a 15-minute effective cleaning period in each barrel, alternating the flush nozzle every 5 minutes between barrels.

Date: September 9, 1996

Canister Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Fuel Dummies (left barrel): 7 total steel inner and outer elements without shoes; 2 inner elements welded to the outer elements; 1 outer element with shim stock clamped on the lower 3 inches. Simulant was not placed under shim stock or down the full length of the annulus of the welded steel assemblies (only about 3 inches covered at each end).

Fuel Dummies (right barrel): Same as left barrel except one outer element was rough sanded, and nuts and bolts were placed at the bottom of the canister.

Canister weight full of water before test: 444 pounds

Cradle Top: 1.125 inch slots along arc of rotation and in-line with the flush nozzles

Nozzle Size: 0.25 inch

Nozzle Location: 255° & 180°

Nozzle Pressure: 225 psig

Nozzle Flow: 19 gpm

Fuel Translation: 4 inch

Cradle Rotation: CCW @ 2.0 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 10 min. cradle rotation at the same time as flushing of nozzle at high pressure on the right barrel for 5 min. and inspection. Then, flushing of nozzle at high pressure for 5 min. on the left barrel and inspection. This process was repeated for a total duration of 30 minutes.

Canister Weight after Phase 1 test: 432 pounds

Results: Water clouded quickly. Fuel was very dirty after the first 5 minutes in each barrel. Fuel was 95+% clean after 15 minutes in each barrel. Most residual simulant was random spots. One large area remained below the shim stock on an outer element. There appeared to be no difference in the level of cleanliness between barrels.

Phase 2 Process: Not performed.

Test 20

Repeat of Test 2 except the steel fuel elements were allowed to rust for weeks to produce a pitted and scaly surface.

Date: September 25, 1996

Canister Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: Rust; soaked for 2 weeks in salt water and hydrogen peroxide. Surface was rough, pitted, and scaly with flakes.

Fuel Dummies (left barrel): 7 total steel inner and outer elements without shoes.

Fuel Dummies (right barrel): N/A

Canister weight full of water before test: N/A

Cradle Top: 1.125 inch slots along arc of rotation and in-line with the flush nozzles

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 275 psig

Nozzle Flow: 19 gpm

Fuel Translation: 4 inch

Cradle Rotation: CCW @ 2.0 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 20 min. cradle rotation at the same time as flushing of nozzle on the right barrel for 20 min. and inspection.

Canister Weight after Phase 1 test: N/A

Results: Water clouded quickly. Fuel was 100% clean. All exposed surfaces were smooth.

Phase 2 Process: Not performed.

Test 21

Repeat of Test 15 except the test ran for 10 minutes with 5-minute checks. A latex glove (surgical type glove) and a leather glove were stuffed into one of the barrels and at the sludge surface in the can. The gloves were not placed next to each other. Dummy single pass reactor (SPR) type fuel coated in simulant was placed in the right barrel.

Date: September 9, 1996

Canister Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Fuel Dummies (left barrel): 7 total steel inner and outer elements without shoes; 2 inner elements welded to the outer elements; 1 outer element with shim stock clamped on the lower 3 inches. Simulant was not placed under shim stock or down the full length of the annulus of the welded steel assemblies (only about 3 inches covered at each end). Latex and leather gloves were stuffed at the sludge depth.

Fuel Dummies (right barrel): 7 dummy SPR type fuel (~13 inch long inner) elements coated in simulant were placed vertically in the right barrel, and laid vertically in the bottom of the canister.

Canister weight full of water before test: 435 pounds

Cradle Top: 1.125 inch slots along arc of rotation and in-line with the flush nozzles

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 225 psig

Nozzle Flow: 19 gpm

Fuel Translation: 4 inch

Cradle Rotation: CCW @ 2.0 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 20 min. cradle rotation at the same time as flushing of nozzle at high pressure on the right barrel for 10 min. and inspection. Then, flushing of nozzle at high pressure for 10 min. on the left barrel and inspection.

Canister Weight after Phase 1 test: 431 pounds

Results: Water clouded quickly. Full length fuel was ~90% clean after first 10 minutes in each barrel.

Gloves remained in the bottom of the can. SPR fuel was very clean.

Phase 2 Process: Not performed.

Test 22

To be performed at a later date. Planned to evaluate the effect of shorter pieces of fuel.

Test 23

Tattletales (flow direction indicators) were placed approximately 6 six inches apart on the inner surface of the outer containment box to monitor flow.

Date: September 10, 1996

Canister Simulant: None

Simulant Depth: N/A

Fuel Simulant: None

Fuel Dummies (left barrel): N/A

Fuel Dummies (right barrel): N/A

Canister weight full of water before test: N/A

Cradle Top: N/A
Nozzle Size: 0.25 inch
Nozzle Location: 255°
Nozzle Pressure: 225 psig
Nozzle Flow: 19 gpm
Fuel Translation: 4 inch
Cradle Rotation: CCW @ 2.0 rpm
Phase 1 Discharge Flow rate: 80 gpm
Phase 1 Process: N/A
Canister Weight after Phase 1 test: N/A
Results: N/A

Phase 2 Process: The empty basket was installed and flow was monitored in clean process water. The basket was then rotated to observe flow patterns. Flush nozzles were later engaged to evaluate effects.

Results: With flush nozzles off and basket idle, tattletales indicated minimal flow path from the inlet to the discharge at the sides of the box. Tattletales at the top did indicate a slight CCW flow. When the basket was rotated, the flow pattern followed the basket. With flush nozzles on and the basket rotating, the flow around the basket on the nozzle side of the box was turbulent.

Test 24

A swivel joint was added at the bearing axis of the motor drive to allow the nozzles to move with the cradle and continuously flush during rotation. Test 15 was repeated on one canister barrel with continuous nozzle flow. No flushing of the second barrel was performed.

Date: September 12, 1996

Canister Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water; coated on outer surfaces

Fuel Dummies (left barrel): 7 total steel inner and outer elements without shoes; 2 inner elements welded to the outer elements; 1 outer element with shim stock clamped on the lower 3 inches. Simulant was not placed under shim stock or down the full length of the annulus of the welded steel assemblies (only about 3 inches covered at each end).

Fuel Dummies (right barrel): Same as left barrel except one outer element was rough sanded.

Canister weight full of water before test: 438 pounds

Cradle Top: 1.125 inch slots along arc of rotation and in-line with the flush nozzles

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 275 psig

Nozzle Flow: 19 gpm

Fuel Translation: 4 inch

Cradle Rotation: CCW & CW @ 2.0 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 5 min. cradle rotation at the same time as flushing of nozzle on the right barrel for 5 min. and inspection. This was repeated for a total 15 minutes of continuous flush in the canister barrel.

Canister Weight after Phase 1 test: 438 pounds

Results: Water clouded quickly. The test was discontinued after 10 minutes because the nozzle was out of position and a second nozzle had not yet been valved out properly. The fuel was very dirty on both canisters. Fuel elements with cladding were dirtier than those without. Because the flow was restricted where the nozzle was placed above the canister, a second nozzle was added to provide a flow path that didn't hit only the top of an element. The rotation direction was changed to CW for the retake of the test. Fuel without flushing was significantly dirtier than with flushing after 15 minutes of rotation. One inner element of the flushed side was very dirty. Elements with shim stock were much dirtier than those without. At this point in the testing, evidence was beginning to accumulate that the primary cleaning mechanism is mechanical rubbing. This test did not have as long a time of rotation previous tests. This implies that flushing is secondary cleaning mechanism and acts primarily to flush the suspended material out of the canister.

Phase 2 Process: Not performed.

Test 25

Repeat of Test 15 running for 20 minutes without stopping rotation. Filled only one barrel with fuel. Used shoes on five of the inner elements. Used one assembly with the inner element stuck to the outer. Used one assembly with no shoes on the inner element. Made sure that simulant was placed under shim stock.

Date: September 18, 1996

Canister Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water; coated on outer surfaces

Fuel Dummies (left barrel): 7 total steel inner and outer elements; 5 with shoes; 1 without shoes; 1 inner element welded to the outer elements; 1 outer element with shim stock clamped on the lower 3 inches.

Simulant was placed under shim stock and down the full length of the annulus of the welded steel.

Fuel Dummies (right barrel): N/A

Canister weight full of water before test: 405 pounds

Cradle Top: 1.125 inch slots along arc of rotation and in-line with the flush nozzles

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 225 psig

Nozzle Flow: 19 gpm

Fuel Translation: 4 inch

Cradle Rotation: CCW @ 2.0 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 20 min. cradle rotation at the same time as flushing of nozzle on the fuel barrel for 20 min. and inspection.

Canister Weight after Phase 1 test: N/A

Results: Water clouded quickly. After 20 minutes, the fuel was 80% clean. Non-shoed inner element was cleaner than the shoed elements. Non-shoed inners were very dirty. This test tends to confirm that primary mode of cleaning is mechanical rubbing.

Phase 2 Process: Not performed.

Test 26

Repeat of Test 25 running at 4 rpm.

Date: September 20, 1996

Canister Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water; coated on outer surfaces

Fuel Dummies (left barrel): 7 total steel inner and outer elements; 5 with shoes; 1 without shoes; 1 inner element welded to the outer elements; 1 outer element with shim stock clamped on the lower 3 inches. Simulant was placed under shim stock and down the full length of the annulus of the welded steel assemblies.

Fuel Dummies (right barrel): N/A

Canister weight full of water before test: 404 pounds

Cradle Top: 1.125 inch slots along arc of rotation and in-line with the flush nozzles

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 225 psig

Nozzle Flow: 19 gpm

Fuel Translation: 4 inch

Cradle Rotation: CW @ 4 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 20 min. cradle rotation at the same time as flushing of nozzle on the fuel barrel for 20 min. and inspection.

Canister Weight after Phase 1 test: 400 pounds

Results: Water clouded quickly. After 20 minutes, the fuel was 90% clean. All shoed inner elements dirty. Non-shoed inner element was very clean. Outer element with shim stock was very dirty. This test tends to confirm that the primary mode of cleaning is mechanical rubbing. Fuel under shim stock was very dirty.

Phase 2 Process: Not performed.

Test 27

Repeat of Test 26 with only a thin (paint brush) thickness of simulant on the surface of the elements

Date: September 23, 1996

Canister Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water; coated on outer surfaces
Fuel Dummies (left barrel): 7 total steel inner and outer elements; 5 with shoes; 1 without shoes; 1 inner element welded to the outer elements; 1 outer element with shim stock clamped on the lower 3 inches. Simulant was placed under shim stock and down the full length of the annulus of the welded steel.
Fuel Dummies (right barrel): N/A
Canister weight full of water before test: 408 pounds
Cradle Top: 0.5 inch slots along axis of rotation and width of canister barrels
Nozzle Size: 0.25 inch
Nozzle Location: 255°
Nozzle Pressure: 225 psig
Nozzle Flow: 19 gpm
Fuel Translation: 4 inch
Cradle Rotation: CW @ 4 rpm
Phase 1 Discharge Flow rate: 80 gpm
Phase 1 Process: 20 min. cradle rotation at the same time as flushing of nozzle on the fuel barrel for 20 min. and inspection.
Canister Weight after Phase 1 test: 404 pounds
Results: Water clouded quickly. After 20 minutes, the fuel was 98+% clean. All but one shoed inner element was clean. Non-shoed inner element was very clean.
Phase 2 Process: Not performed.

Test 28

Repeat of Test 27 with a kaolin clay/sand mixture. Cradle rotation was in the CW direction.

Date: September 23, 1996
Canister Simulant: 3 pounds kaolin clay, 3 pounds sand, balance water to get soft oatmeal consistency that was adherent.
Simulant Depth: 4 to 5 inches after elements in canister
Fuel Simulant: 3 pounds kaolin clay, 3 pounds sand, balance water to get soft oatmeal consistency
Fuel Dummies (left barrel): 7 total steel inner and outer elements; 5 with shoes; 1 without shoes; 1 inner element welded to the outer elements; 1 outer element with shim stock clamped on the lower 3 inches. Simulant was placed under shim stock and down the full length of the annulus of the welded steel assemblies.
Fuel Dummies (right barrel): N/A
Canister weight full of water before test: 404 pounds
Cradle Top: 1.125 inch slots along arc of rotation and in-line with the flush nozzles
Nozzle Size: 0.25 inch
Nozzle Location: 255°
Nozzle Pressure: 225 psig
Nozzle Flow: 19 gpm
Fuel Translation: 4 inch
Cradle Rotation: CW @ 4 rpm
Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 20 min. cradle rotation at the same time as flushing of nozzle on the fuel barrel for 20 min. and inspection.

Canister Weight after Phase 1 test: 401 pounds

Results: Water clouded quickly. After 20 minutes, the fuel was 99+% clean.

Phase 2 Process: Not performed.

Test 29

Repeat of Test 27 with the rotation CCW.

Date: September 24, 1996

Canister Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Fuel Dummies (left barrel): 7 total steel inner and outer elements; 5 with shoes; 1 without shoes; 1 inner element welded to the outer elements; 1 outer element with shim stock clamped on the lower 3 inches.

Simulant was placed under shim stock and down the full length of the annulus of the welded steel assembly.

Fuel Dummies (right barrel): N/A

Canister weight full of water before test: 405 pounds

Cradle Top: 1.125 inch slots along arc of rotation and in-line with the flush nozzles

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 225 psig

Nozzle Flow: 19 gpm

Fuel Translation: 4 inch

Cradle Rotation: CCW @ 4 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 20 min. cradle rotation at the same time as flushing of nozzle on the fuel barrel for 20 min. and inspection.

Canister Weight after Phase 1 test: 400 pounds

Results: Water clouded quickly. After 20 minutes, the fuel was 95+% clean. All outer elements except the shim-stock-covered one were very clean. This implies again that the rubbing action is most important. Some simulant remained on the fuel under the shim stock. All inner elements with shoes were very dirty. The one inner without shoes was clean. The welded assembly also appeared to be clean. Since this test was a repeat of Test 27, and was much dirtier than Test 27, the direction of rotation appears to be important for effective cleaning.

Phase 2 Process: Not performed.

Test 30

Repeat of Test 27. Coated 3 of the element assemblies with simulant after the elements were wetted. Coated 3 of the element assemblies with simulant after the elements were dry.

Date: September 24, 1996

Canister Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Simulant Depth: 4 to 5 inches after elements in canister

Fuel Simulant: 40 wt% kaolin clay, 40 wt% boride, 20 wt% water

Fuel Dummies (left barrel): 7 total steel inner and outer elements; 6 with shoes; 1 inner element welded to the outer elements. Simulant was placed down the full length of the annulus of the welded steel assemblies.

Fuel Dummies (right barrel): N/A

Canister weight full of water before test: 406 pounds

Cradle Top: 1.125 inch slots along arc of rotation and in-line with the flush nozzles

Nozzle Size: 0.25 inch

Nozzle Location: 255°

Nozzle Pressure: 225 psig

Nozzle Flow: 19 gpm

Fuel Translation: 4 inch

Cradle Rotation: CW @ 4 rpm

Phase 1 Discharge Flow rate: 80 gpm

Phase 1 Process: 20 min. cradle rotation at the same time as flushing of nozzle on the fuel barrel for 20 min. and inspection.

Canister Weight after Phase 1 test: 399

Results: Water clouded quickly. After 20 minutes, the fuel was 98+% clean. All wet elements were clean. Two of the dry inner elements were still fairly dirty. The third one was in the path of the flush nozzle and was clean.

Phase 2 Process: Not performed.

3.0 Discussion

The tests described previously demonstrated that sludge can be dislodged and suspended sufficiently to remove it from the canister. Visual examinations^(a) of dummy fuel elements, after completion of the cleaning process, suggest that better than 95% of the exposed fuel surface can be cleaned (Figure 3.1) to the point where no visual evidence of any film, such as sludge, corrosion, etc., remains (Tests 7, 16, 18b, 19, 27, 29, and 30). The remaining 5% of exposed surfaces were limited to random thin films totaling much less than the suggested limit of 16 kg per multi-canister overpack (MCO). When less conservative simulants were used, the cleanliness of the fuel approached 100% (Tests 3, 6, 9, 10, 11, 12, 20, 28, 30).

As recommended by BNFL, the proposed baseline approach to cleaning fuel was performed in two phases. In phase 1, the canister was loaded into the wash basket and rotated at 2 rpm for 5 minutes while the fuel was allowed to translate 4 inches in the canister. The canister was then stopped with its opening in front of a pair of commercial nozzles flushing at 15 gpm @ 100 psig. Phase 1 cleaning concluded with an additional 5 minutes rotation of the fuel at 2 rpm while the fuel translated 4 inches back and forth in the canister. The Phase 2 clean cycle consisted of inverting the canister and dumping the fuel into the

Figure 3.1. Cleaned Dummy Fuel Elements

(a) Visual examination is subjective. The values of percent clean presented are based on two independent examinations.

wash basket. The basket was closed and then rotated at 2 rpm for 5 minutes. On the basis of these tests, the recommended clean cycle (Tests 27, 28, and 30) is to load a canister into the wash basket and rotate it clockwise at 4 rpm for 20 minutes while the fuel is allowed to translate 4 inches back and forth in the canister.

Rather than stop the wash basket for nozzle flushing, the commercial nozzles should be run continuously to flush the canister as it passes by the nozzles, which should flow at 20 gpm @ 250 psig. Slots were cut in the top of the canister cradle, in line with the canister rotation, Figure 3.2. Testing results also suggest that the Phase 2 clean cycle provides insignificant cleaning value (Tests 4, 5, 7, and 14), unless ribs are added to the inner circumference of the wash basket, Figure 3.3. The ribs force the fuel to tumble rather than slide (Test 18b). Even with the ribs, inner elements do not appear to gain any Phase 2 cleaning, since there is no flow through the annulus and the element shoes restrict contact. Testing evidence also suggests that Phase 2 cleaning is much more destructive to the fuel (Test 18b). Eliminating the Phase 2 cycle will reduce the operational steps and the time required to process fuel while still maintaining the desired level of cleaning.

Test results also have indicated that the Phase 1 process is streamlined by rotating the basket without stopping, while running the flush nozzles continuously, Figures 3.4 and 3.5. This limits any maintenance problems associated with the number of starts and stops that the wash basket must perform. Results have

Figure 3.2. Canister Cradle Top with In-line Flush Nozzle Slots

Figure 3.3. Primary Wash Basket

Figure 3.4. Flush Nozzles and Viewing Port Inside Outer Containment Box

Figure 3.5. Commercial 1/4-inch Flush Nozzle

also demonstrated (Test 24) that cleaning is enhanced by continuous canister rotation past the fixed nozzles, instead of stopping the canister at a fixed location.

One set of tests was performed using shorter fuel (SPR) with shim stock attached (simulating cladding breach) and with debris also contained in the canister (nuts, bolts, gloves). SPR fuel was mocked-up using 13-inch-long inner dummy elements (Test 21). Seven elements were covered with simulant and placed vertically in the bottom of the canister. The elements would not stay aligned and had to be contained within the top of the canister with a wire mesh screen.^(a) This suggests that smaller elements will fall out of the canister and into the wash basket during cleaning. The test was run for only 10 minutes, but the elements were spotless.

Shim stock was used to mock-up breached cladding during testing, Figures 3.6 and 3.7. However, most of the tests were performed without placing simulant under the cladding before cleaning. No simulant remained under the cladding after washing in these tests. Further testing (Test 25 and later tests) was performed with simulant placed under the cladding, and visual inspection after cleaning showed some removal of simulant; but in general, 50% or more remained.

(a) If the element fell out the top of the canister, the test system might have been damaged. In the baseline BNFL design, the fuel would be allowed to exit the canister and would be collected in the wash basket holding the canister.

Figure 3.6. Fuel Canister Loaded with Steel Dummies

Figure 3.7. Full Length Shim Stock Removed From Outer Element

Tests 12 and 19 were performed with nuts and bolts added to the bottom of the test canister and under the fuel. Both test results showed that the fuel was cleaned successfully. Test 21 also had two gloves stuffed down the canister barrel containing a full complement of fuel. The test ran only 10 minutes, half the normal process cycle, and the fuel came out better than 90% clean. Typically during test runs, small debris would fall out of the canister onto the outer containment box floor. As a result of these tests, it can be assumed that debris has no impact on fuel cleanliness, under the conditions tested.

3.1 Primary Cleaning Mechanism

Tests have shown that there are three mechanisms of cleaning during the Phase 1 process. The primary mechanism appears to be mechanical sliding that simply rubs fuel element surfaces against each other (or against the canister wall). This was also demonstrated in the Characterization Sub-Project tests performed earlier in the basin (Bergman 1996). In addition, early tests showed that non-shoed inner elements come out very clean, but after shoes are applied the elements take much longer to clean. It was determined that the difference was in the contact surface available for rubbing the elements clean. Outer elements with shim stock clamped to the outer surface also consistently take more time to clean than outer elements without shim stock. In this instance, it is determined that the difference is due to the interference between elements caused by the clamped shim stock. Secondary effects, which take much longer to clean the fuel, were required to sufficiently clean the fuel in these cases.

Early tests were performed at 2 rpm, with each canister barrel isolated to allow each to be run with different test parameters. As a result, the tests ran twice as long as normal. Later, when these tests were repeated by washing each canister barrel at the shorter, normal, time interval, it was discovered that the fuel elements were not coming out clean. The canister rotation (rpm) was then doubled, and the results again approached the original test results. The implication here is that either rubbing or hydraulic pumping is the primary cleaning mechanism. Further testing, where the elements were inspected before completing the clean cycle, resulted in simulant patterns streaked along the length of the elements. It was reasoned that hydraulic pumping would not have resulted in this type of streaking, and therefore the streaks must be attributed to surface contact or rubbing action.

3.2 Secondary Cleaning Mechanisms

One of the two secondary cleaning mechanisms apparently is hydraulic pumping of the fuel inside the canister. When the canister is full of fuel and is being rotated in the wash basket, the elements slide back and forth and act like pistons, running up and down the canister in 4-inch strokes. This action appears to drive the water volume contained inside the canister in and out of the elements. It also forces slugs of water to quickly pass the exposed surfaces of the fuel elements. It is unclear if this action forced the simulant plugs up the center holes of the inner elements, but that is considered unlikely. When fewer elements were present in the canister, this action did not occur. One such test was performed, but was not documented or videotaped due to a system failure. It included only 3 steel assemblies in a canister barrel, complete with inner element shoes, and resulted in relatively dirty elements both inside and outside. It is possible that these assemblies did not remain vertical during the cleaning process and therefore did not adequately contact, or rub against, each other and the canister wall during translation. The implication is

that the only vehicles or mechanisms of cleaning are nozzle flushing and limited surface rubbing when the elements align themselves or are against the wall. Since the fuel was very dirty compared to previous tests of similar nature, an argument could be made that hydraulic action accounted for the difference, if the elements were able to rub. This could not be confirmed or disproven from test data collected at this time, but is not believed to be the case.

The other apparent cleaning mechanism is nozzle flushing. Flushing was earlier shown to suspend the bulk simulant (excess simulant applied during pre-test). All tests showed that the simulant sprayed out the top of the can as soon as the nozzle aligned with the canister top. Tests that flushed at lower pressures (Tests 4, 8, and 11) resulted in reduced cleaning, while the higher pressures of 225 to 250 psig were required to overcome the liquid mass associated with the canister column. Test 5 showed that with the nozzle at 125 psig, the water remained stagnant above the canister top; and at 225 psig, water was seen exiting the center annulus of the inner elements. To reach the inner element annulus, the water stream had to travel to the bottom of the canister and displace the canister liquid volume, which resulted in the spray coming out the top. Many tests resulted in simulant plugs (Test 14) being jetted up the center hole of the inner elements and left resting on the bottom of the outer confinement box. These plugs ranged in size from less than one inch long up to approximately 5 inches long, Figure 3.8.

Figure 3.8. Bottom of Outer Containment Box with Residual Simulant and Plugs

3.3 Simulant Effects

As discussed in the Test Strategy section, the test simulants were chosen to bound known sludge conditions, rather than duplicate them. The kaolin clay simulants were specifically chosen because of their adherent properties, Figures 3.9 and 3.10, while boride was chosen for its fine particle size and high density. Sand was used to represent larger particles, and rust was used to simulate the light film on the outer surface of elements. The light film to be simulated by rust was seen in many of the Characterization Sub-Project videotapes, Figures 3.11 and 3.12. The test results indicated that the two combinations of kaolin clay, boride, and water acted very similarly, and were the most difficult to remove from the fuel element surfaces. The kaolin clay mixed with sand was much easier to remove (Tests 3, 8, 10, and 28) and rust was removed easily whether it was light or heavy (Tests 2 through 4, 6 through 12, and 20). Test 16, which proved successful, was performed with pure boride in the canister bottom to simulate a packed fine particulate.

Early discussions with staff from the Characterization Sub-Project^(a) provided some insight into the K-East canister sludge. Preliminary results indicated that at least 90% of the sludge is heavy and highly dispersible (i.e., with no adherent properties), while the balance of the canister bottom sludge is definable

Figure 3.9. Kaolin Clay Simulant Coated Steel Dummy Elements

(a) Meeting to discuss sludge properties and sludge simulants with B. J. Makenas and R. B. Baker, September 24, 1996.

Figure 3.10. Canister Bottom with Approximately 3 inches of Kaolin Clay Simulant

Figure 3.11. Clean vs. Rusty Dummy Elements

Figure 3.12. Close-up of Rusty Steel Dummy Elements

as fine particulate and adherent in nature, but primarily only to the canister. The surface of fuel resting in canister bottom sludge typically appears as clean zirconium. It appears that the bottom sludge protects a couple of inches of the element against forming the dissimilar, adherent thin layer of grayish sludge. The composition of this bottom layer is unknown, but as Characterization Sub-Project tests show (Bergman 1996), it readily brushes off to some extent. Based on this information, it is undetermined if the canister bottom sludge adheres or packs tightly. In addition, to remove the sludge from shipping containers at the 325 Building, it had to be scraped off; and when scraped, the sludge does not separate from itself easily. Indications are that none of the sludge seen by the Characterization Sub-Project adheres to the fuel like the simulants used during this testing; therefore, the tests should provide a conservative, and bounding, basis for fuel cleaning.

3.4 Fuel Element Effects

Tests 1 through 3 used 50-pound lead-filled stainless steel tubes for fuel dummies. The same lead dummies were dropped 4 inches for at least 35 minutes (at 2 rpm) without any end flaring or mechanical damage. Lead is considered a soft malleable metal (the outer tube had a wall thickness of only 0.065 inch), and rotating at 2 rpm for 35 minutes produces just slightly fewer impacts than the recommended 4 rpm for 20 minutes. This fact, combined with results from these tests, leads us to conclude that damage to the fuel during cleaning should be minimal. Furthermore, the difference in rpm, 2 vs. 4, has a negligible effect on fuel damage, since the elements free-fall due to gravity as soon as they overcome the canister wall friction, rather than being forced back and forth by the rotational energy. In

contrast, the steel dummies had shown some edge flaring after 3 to 4 clean tests. The inner edges of the outer elements had to be lightly filed to clear the shoes and withdraw the inner elements.

3.5 Other Test Effects

Turbidity of the process water exiting the containment box was monitored on all tests, starting with Test 15. A general conclusion was drawn that turbidity approached a constant level within 10 minutes after canister flushing was stopped. Turbidity is not a quantitative measure, though values were assigned to water clarity during testing. Characterization Sub-Project videotapes of fuel canister plumes suggest that heavy particles drop out quickly and that localized visibility appears to be restored in less than 5 minutes. This might suggest that the basin water treatment system provides very effective filtering. However, one canister disturbed over many days is much different than multiple canisters disturbed in a single day. Since the clean machine is intended to be used continuously over a relatively short period of time, it is possible that a plume generated from the primary clean system by opening the outer containment box before achieving acceptable water clarity could affect overall quality of the basin water. For this reason, it is suggested that the basin operations staff be provided the means, via design implementation by BNFL, to observe the water quality in real time inside the outer containment box. Using time to control the washing process, as suggested by the design agent, does not allow operators the ability to evaluate the clarity of the process water before opening the box. The tradeoffs of throughput and water clarity need to be addressed further and evaluated during process validation.

Since flow in the containment box is very low (Test 23), it is possible that in-leakage to support the 80 gpm discharge may be insufficient to overcome the disruption (plume) created by rotating and flushing the canisters. Improper design of the clean system could possibly allow diffusion and particle velocities to overcome the in-leakage of the clean system. An opening of 1/4-inch around the center of the box produces in-leakage velocities of less than 2 inches per second, and a quarter inch gap between the top and the bottom half of the outer containment box is well within normal fabrication tolerance for such a system. It is therefore suggested that some form of seal be designed into the interface of the top and bottom halves of the outer containment box.

Inspection of the elements was performed using a video camera at a distance of less than 2 feet. But since "clean" is a relative and imprecise term, the results are subjective to the viewer. In the tests using rust as a simulant, "clean" was very hard to define. Rust appeared to have been removed after the elements were washed, Figure 3.11, but the surfaces were dark and contrast was not ideal. If the elements were rubbed, rust was still detected. In comparison, kaolin clay simulants could be easily seen if the elements were not clean, Figure 3.13. It was very apparent, visually, that the bulk of the simulant had been removed from the outer surfaces. However, the inner surface contrast was difficult and the only evidence of cleanness was that there were no ridges or bumps that would clearly indicate that simulant remained. A defect in the fuel surface could easily have been misinterpreted as simulant. However, we had the advantage during testing of being able to push a rod down the annulus or center hole to scrape the inside looking for remaining simulant.

Figure 3.13. Cleaned Elements Showing Residual Kaolin Clay Simulant

After the elements dried, a film was seen that was not visible when the elements were still wet. Though the film was negligible in terms of total quantity, it again raised the issue of how to specify "clean". The current thinking within the FRS project is that during process validation, clean will be defined and captured with video or photographs and used as a basis of comparison for the operators. Before this process is validated, a more precise definition of clean may be required in order to quantify the amount of sludge remaining on the element surfaces.

4.0 Conclusions

Primary cleaning tests have demonstrated that sludge can be dislodged and suspended sufficiently to remove it from a fuel canister. Additionally, visual examinations of dummy elements, after they have completed the cleaning process, suggest that better than 95% of the exposed fuel surface has been cleaned to the level of no visual evidence of any remaining film, such as sludge, corrosion, etc. The remaining 5% of exposed surfaces exhibited a random thin film. Finally, when less conservative simulants were used, the cleanliness of the fuel approached 100%.

As a result of this testing, the recommended cleaning cycle consists of loading the fuel canister into the wash basket and rotating the fuel clockwise at 4 rpm for 20 minutes while the fuel is allowed to translate 4 inches up and down inside the canister. The flush nozzles should each flush continuously at 20 gpm and 225 psig, and flush the canister as it passes by the nozzles during each rotation.

Test results also suggest that the basket tumbling cycle (Phase 2) provides insignificant cleaning unless ribs are added to the inner circumference of the wash basket. The ribs would force the fuel to tumble rather than slide. However, as demonstrated in the tests, even with the ribs, inner elements are not completely cleaned because flow through the element annulus does not occur, and because the element shoes restrict contact between the inner and outer elements. It was also determined that Phase 2 cleaning is much more destructive to the fuel. Therefore, it is highly recommended that Phase 2 cleaning be eliminated from the standard cleaning process. In addition, eliminating the Phase 2 cycle reduces the time required to process fuel without reducing the level of cleaning provided.

Results indicate that Phase 1 cleaning is optimized by continuously rotating the wash basket and running the flush nozzles. It was also demonstrated that passing the canister by a fixed nozzle, rather than stopping it in a fixed location for stationary flushing, enhances cleaning.

As stated in the discussion section, it was shown that there are three mechanisms of washing during the Phase 1 cleaning process. The primary mechanism appears to be rubbing of fuel element surfaces against other fuel elements or the canister wall, while the two secondary mechanisms are nozzle flushing and hydraulic action caused by the element movement within the canister during basket rotation. All tests had the simulant spray out the top of the can as soon as the nozzle aligned with the canister top. Tests that flushed at lower pressures, less than 225 psig, resulted in reduced cleaning effectiveness. In addition, when the canister is full of fuel and being rotated in the wash basket, the elements sliding back and forth act like pistons, running 4 inches up and down the canister interior. This action apparently drives the water volume inside the canister in and out and forces slugs of water to quickly pass across exposed surfaces of the fuel.

Monitoring water clarity during testing showed that turbidity approached a constant level within 10 minutes after canister flushing was terminated. It also became apparent that using time as an absolute means to control the washing process, as suggested by the design agent, does not provide operators

sufficient ability to control the cleaning operation based on current evaluations of water clarity. The tradeoffs of throughput versus water clarity need to be addressed further and evaluated during in-pool process validation.

Since flow in the main box is very low, it is possible that in-leakage velocities at the 80 gpm discharge flow rate may not be sufficient to overcome the disruption (plume) created by rotating and flushing the canisters. Improper design of the clean system could allow diffusion and particle velocities to overcome the in-leakage velocity in the primary clean system. It must be noted that a 1/4-inch opening around the center of the box produces in-leakage velocities of less than 2 inches per second. A 1/4-inch gap between the top and the bottom half of the outer containment box would not be outside standard fabrication tolerance for such a system. It is therefore suggested that some form of seal be designed into the interface between the top and bottom halves of the outer containment box.

In conclusion, clean is a vague term, and cleaning results are somewhat subjective. For example, it was found that in tests using rust as a simulant, clean was very hard to define. During these tests, contrast was limited on the inner surfaces and if there were no ridges or bumps, the elements were assumed to be clean. However, a defect in the fuel surface could have easily been misinterpreted as simulant buildup and additionally, after the elements dried, they exhibited a film that was not detectable when the elements were wet. Though this film was negligible in terms of total material quantity, it again raises the question of how to accurately and precisely specify what is meant by clean. It is therefore recommended that before process validation is performed, a clearer definition of clean be determined in order to more accurately describe the amount of sludge remaining on the element

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Attachment 1

Primary Clean Machine Test Specification

SNF Fuel Retrieval Sub-Project

No. SNF-FRS-SPC-01
Revision: Rev. 0

TITLE: Primary Clean Machine Test Specification

Client: Westinghouse Hanford Company

Safety Class: Non-safety related

Prepared by:

Ken Powell 6/28/96.
Name, Discipline Date

Checked by:

Ian McCourt, Engineering Manager 6/28/96
Name, Discipline Date

Approved by:

Ian McCourt, Engineering Manager 6/28/96.
Name, Position Date

Westinghouse
Hanford Company

Internal
Memo

From: Fuel Retrieval Systems
Phone: 373-0832 R3-85
Date: July 2, 1996
Subject: TEST SPECIFICATIONS

To: G. L. Ketner K5-22
W. C. Mills R3-85
E. J. Shen R3-86

cc: B. S. Carlisle R3-85
W. H. Cloose X3-72
FRS Project File R3-85
CSB Project File S8-07
TLY/LB File R3-85

Attached is the Primary Clean Machine Test Specification (SNF-FRS-SPC-01, Rev 0) as provided by British Nuclear Fuels, Limited.

If you have any questions please call me on 373-0832.

T. L. Yount

ddr

BNFL Inc.
1835 Terminal Drive, Suite 200
Richland, WA 99352
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SNF-PM-96-057
File# 110200.O (ltr)
170500.S

June 28, 1996

Mr. Thomas L. Yount
Westinghouse Hanford Company
P.O. Box 1970, MSIN R3-85
Richland, WA 99352

Subject: Test Specifications

Reference: WHC-SD-SNF-SOW-004, Rev. 1

Dear Mr. Yount:

We are pleased to submit the following design end item as required by the Statement of Work for the Design of the SNF Fuel Retrieval Sub-Project:

SNF-FRS-SPC-01, Rev. 0, *"Primary Clean Machine Test Specification"*

All comments resulted from the review of the draft submitted to you have been resolved.

If you have any questions, please feel free to call me at 946-4006.

Sincerely,

A handwritten signature in black ink, appearing to read "Stewart M. Mackay".

Stewart M. Mackay
Project Manager

le

cc: Bruce Carlisle, WHC
Jim Knight, WHC
Dana Wolfe, WHC

Dean Tulberg, FW
Berry Lieberman, BNFL
Project Files

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PRIMARY CLEAN MACHINE TEST SPECIFICATION

1.0 PURPOSE/SCOPE

1.1 PURPOSE

This test specification establishes objectives and requirements for functional demonstration tests. This information will provide proof of concept and criteria, optimize equipment layout, integrate equipment and identify required design changes in support of performance specification development as early as possible in the definitive design process. This testing is proposed to be performed on mockups in a cold test facility.

1.2 SCOPE

This specification applies to Westinghouse Hanford Company (WHC) test engineers involved in preparation of procedures, documents, and tests to support K Basins Fuel Retrieval Sub-Projects design concept validation. This test specification pertains to the Fuel Primary Clean Station and focuses on the following specific tasks:

- Gross De-sludge of Fuel and Canisters
- Fuel Cleaning
- Outer Confinement Box Sludge Removal

2.0 TEST REQUIREMENTS

2.1 GENERAL DESCRIPTION

Test objectives are provided in the following sections which have been grouped into three phases of fuel cleaning operations. The phases of operation are:

- Phase 1 Gross de-sludge of fuel and canisters
- Phase 2 Fuel cleaning cycle
- Phase 3 Outer confinement box test

The testing will be carried out to develop design information, support the optimization of the fuel cleaning operations to meet downstream requirements, and develop times for each phase to support time and motion studies.

Tests will be carried out in a stationary outer confinement box (SK-101) housing a rotating canister cradle (SK-102) for Phase 1 tests or a rotating fuel cleaning basket (SK-103) for Phase 2 tests. The sketches identified are indicative of the equipment required to conduct the primary wash tests, and can be reconfigured by the WHC cognizant test engineer if required. Any reconfiguration shall be agreed with BNFL prior to works being carried out. Phase 3 tests will be conducted in conjunction with Phase 1 and 2 tests. All tests will be conducted utilizing a range of flows as indicated in the Test Parameters, Section 2.2.3, to determine the water flow rates which optimize the fuel/canister de-sludging, fuel cleaning, and outer confinement box sludge removal processes.

2.1.1 Prior to any test works being carried out, BNFL will agree with the WHC cognizant test engineer Witness and Hold points on the various phases of testing following review of the test procedures.

2.2 PHASE 1 GROSS DE-SLUDGE CYCLE TEST OBJECTIVE

2.2.1 The primary objective of the gross de-sludge cycle is to remove the sludge contained within the canister and fuel in a confined environment. ALL Phase 1 tests will be carried out using standard solid based canisters containing 14 dummy fuel elements and simulated sludge. The sludge simulant should bound the existing basin/canister sludges using the best information available. Simulated sludge materials are to be determined by the WHC test team leader and agreed with BNFL.

2.2.2 Phase 1 tests to determine the following:

- Canister/fuel gross de-sludge performance
- De-sludge nozzle type/size/location and cradle slot width
- Characterize and enhance water pressure and flow characteristics
- Characterize and enhance canister angle for de-sludging
- Characterize and enhance fuel translation in canister to aid de-sludging
- Characterize and enhance flow through outer confinement box
- Establish optimum cycle time

2.2.3 Test Parameters

The gross fuel/canister desludge cycle will be carried out using the following range of test parameters.

Nozzle location in relation to canister/cradle slot	$\frac{1}{2}$ "	$\frac{3}{4}$ "
Cradle slot width	$\frac{1}{2}$ "	1"
Nozzle size (fire hose type)	$\frac{1}{4}$ "	$\frac{3}{8}$ "

Nozzle flow	10 gpm	<u>15 gpm</u>	20 gpm
Nozzle pressure	1100 psig Nom ^L		
Canister angle	180°	235°	<u>255°</u> from vertical
Fuel translation	2"	<u>4"</u>	6"
Water flow (discharge)	60 gpm	<u>80 gpm.</u>	100 gpm.
Canister rotation	<u>2 rpm</u>		
Fuel dummies/barrel	Mixed-2 bad	3 good	2 fixed
<u>Cycle Time</u>			
Rotation	<u>5 mins</u>	10 mins	
Flush	2 mins	<u>5 mins</u>	10 mins
Rotation	<u>5 mins</u>	10 mins	

The parameters underlined will be the primary parameters for the gross fuel/canister desludge tests. If the primary parameters prove successful, there will be no further testing of the gross fuel/canister cycle secondary parameters.

Success Criteria

All tests will be monitored visually and by CCTV.

Rotation-flushing-rotation of the fuel/canisters removes gross sludge from the canisters and fuel and ensures there are no fuel particles remaining in the canister. (Fuel particles will be incorporated into the sludge simulant recipe). No gross accumulation of sludge in the outer confinement box. All tests are completed within the requirements of total throughput criteria as per WHC Specification WHC-S-0461 Draft 2, and the BNFL Witness Model requirement and timescales.

Test Method

With the test rig equipment set to the primary parameters:

2.2.3.1 Locate the canister containing the reference sludge simulant recipe and up to 14 dummy fuel elements into the canister cradle.

2.2.3.2 Secure cradle cover, locking canister in position.

2.2.3.3 Secure and seal outer confinement box lid. Flush nozzles to be scaled down fire hose units and sized to meet the test start point data (15 gpm @ 100 psig).

2.2.3.4 Fill outer confinement box with water.

2.2.3.5 With discharge pumps operating at 80 gpm, rotate the canister cradle at 2 rpm in order to fluidize the sludge for a period of 5 minutes.

2.2.3.6 Stop cradle at the designated position 255° from the vertical and the ¼" fire nozzles located adjacent to the top cradle slot. Flush the canister for 5 minutes at 15 gpm at 100 psig per nozzle to remove fuel/canister sludge.

2.2.3.7 Stop flush nozzle flow and rotate the canister cradle for a further 5 minutes to remove any remaining particulate.

2.2.3.8 Repeat operations 2.5.2.5 to 2.5.2.7 varying key parameters to achieve total canister de-sludge.

These tests will be carried over the full range of selected sludge recipes. These tests to be repeated with the secondary parameters as required.

2.2.4 Required Test Data (For Definitive Test Data, see Section 5.1)

- Monitor cycle times
- Nozzle size
- Nozzle configuration
- Nozzle flow
- Nozzle pressure
- Cradle slot dimensions
- CCTV video tape of preferred configuration

2.3 PHASE 2 FUEL CLEAN CYCLE TEST OBJECTIVE

2.3.1 The primary objective of the fuel clean cycle is to remove sludges and corrosion products adhering to the fuel element surfaces to minimize impact on downstream processes. All tests shall commence with the simulated fuel randomly located vertically in the fuel cleaning basket. Simulated sludge shall be compacted in the annulus and on the inner and outer surfaces of the fuel elements to replicate in basin conditions.

2.3.2 Phase 2 tests will determine the following:

- Random fuel translates to the horizontal during basket rotation
- Speed of rotation

- Does rolling motion of fuel affect/enhance fuel cleaning (outers against outers and inners against outers)
- Does fuel roll or slide
- Do fuel shoes affect the fuel rolling
- Establish optimum cycle time

2.3.3 Test Parameters

The fuel cleaning cycle will be carried out using the following range of test parameters.

- Does vertical fuel translate to the horizontal during rotation

Basket rotation	1 rpm	<u>2 rpm</u>	3 rpm
Basket rotation cycle	<u>5 mins</u>	10 mins	15 mins
Water flow	60 gpm	<u>80 gpm</u>	100 gpm
Variable oscillate basket speed	Equivalent to <u>2 rpm</u>		

The parameters underlined will be the starting basis for the fuel cleaning cycle. If the primary parameters prove successful there will be no further testing of the fuel cleaning secondary parameters.

Success Criteria

Pictures and CCTV to confirm fuel is visually clean at 1 magnification at 1 foot. There is no gross accumulation of sludge within the outer confinement box during the fuel cleaning cycle. All tests will be completed to meet the requirements of the total throughput criteria as per WHC Specification WHC-S-0461 Draft 2, and BNFL Witness model requirements and time scales.

2.3.3.1 Randomly locate fuel in a near vertical orientation in the bottom section of the fuel cleaning basket.

2.3.3.2 Close the top section of the fuel clean basket and secure.

2.3.3.3 Secure and seal outer confinement box lid.

2.3.3.4 Fill the outer confinement box with water.

2.3.3.5 With discharge pumps operating at 80 gpm, rotate the fuel cleaning basket at 2 rpm for a time period of 5 minutes. View for compacted sludge removal and fuel translation to the horizontal.

2.3.3.6 Repeat cycle 2.6.2.5 as required to achieve fuel cleaning.

2.3.4 Required Test Data (For Definitive Test Data, see Section 5.2)

- Monitor
- Fuel cleaning cycle times
- Water flow through outer confinement box
- Fuel translation to horizontal
- Fuel rolling/sliding
- CCTV video tape

2.4 OUTER CONFINEMENT BOX TEST OBJECTIVES

2.4.1 The primary objective of the outer confinement box test is to ensure that there is no retention of sludges or fuel corrosion products within the outer confinement box during and after the fuel/canister de-sludging and fuel cleaning cycles.

2.4.2 Phase 3 tests will determine the following:

- Confirm water throughput to ensure no sludge holdup in outer box
- Confirm wash nozzle configuration

2.4.3 Test Parameters

2.4.3.1 During Phase 1 and Phase 2 cycle tests, monitor the outer confinement box for fuel corrosion product and sludge build up.

2.4.3.2 If buildup is noted in the outer confinement box, wash sprays are to operated until the box is free of sludge and corrosion products. Spray nozzle locations will be varied to characterize and enhance sludge removal.

2.4.4 Required Test Data (For Definitive Test Data, see Section 5.3)

- Monitor
- Wash water flow and pressure
- Wash water nozzle configuration
- CCTV video tape

3.0 PLANT CONDITIONS

No special conditions required.

4.0 SPECIAL EQUIPMENT

4.1 The following is a list of special equipment and recommended configuration sketches required to meet the test requirements identified in Section 2 of this document:

<u>Sketch Number</u>	<u>Description</u>	<u>Test phase</u>
SK 100	Flow schematic	All phases
SK101	Outer confinement box	All phases
SK 102	Canister cradle	Phase 1
SK 103	Fuel cleaning basket	Phase 2

The following is a list of specific design details which are required to test the primary clean machine.

Canister cradle to incorporate sufficient flexibility to allow for varying fuel translation lengths, i.e.: 2", 4", and 6". Canister cradle top plate to incorporate two full length slots, one on the center line and one 3½" above the canister center line.

The canister cradle will also incorporate a canister locking fixture, to minimize canister movement during gross fuel/canister desludge operation.

The machine will embody power drives and associated gear boxes, bearings, etc. to ensure full rotation of the canister cradle and basket at 2 rpm.

The configuration of the wash machine test assembly and the water feed head tank should be such as to replicate in basin conditions.

The WHC cognizant test engineer will supply photographs and as-built information of the test rig for incorporation into the final reports.

4.1.1 WHC test organization is responsible for the procurement and adequacy of all test equipment. WHC test organization is also responsible for the provision of solid dummy fuel elements reflecting fuel element weight and size or dummy fuel elements manufactured from pipe reflecting inner and outer element size and configuration.

4.1.2 The test equipment should be arranged as in accordance with the flow schematic SK 100 which simulates in-basin conditions.

4.1.3 The materials of construction shall be such that all operations can be viewed without the use of artificial aids.

4.1.4 All special equipment shall be fabricated in such a way as to allow for easy modification or relocation of critical items as required.

4.1.5 Sludge Simulant

The WHC cognizant test engineer will liaise with the basin sludge characterization group regarding compilation of a suitable range of simulated sludge recipes.

In the event that suitable sludge recipes are not available in time to meet the test schedule, the following shall apply:

- Tests shall be conducted using simulants to bound the in-basin conditions. Initial testing will be performed using simulants identified in the Draft Test Procedure WHC-SD-SNF-TC-007. Further simulants may be pursued if indicated by initial test results.

5.0 ACCEPTANCE CRITERIA AND REQUIRED DATA

5.1 The acceptance criteria for the Phase 1 testing identified in Section 2.2 of this document is as follows:

- Canister/Fuel Gross Sludge Removal - Requires the removal of all fuel particulate from the canister and gross sludge removal from the fuel in the optimum cycle time.

The data required to support the Canister/Fuel Gross Sludge Removal testing is identified in the following table:

DATA REQUIRED	TEST 1	TEST 2	TEST 3	TEST 4
Nozzle location in relation to canister and canister cradle slot				
Canister cradle slot width				
Nozzle size				
Nozzle flow				
Nozzle pressure				
Nozzle angle				
Canister angle				
Fuel translation in canister				
Water flow through confinement box				
Location of residual simulant and amount				
Simulant recipe				
Cycle time				

5.2 The acceptance criteria for the Phase 2 testing identified in section of this document is as follows:

- Fuel Cleaning Cycle - Requires the removal of all sludges and corrosion products adhering to the fuel elements in the optimum cycle time.

The data required to support the Fuel Cleaning Cycle is identified in the following table:

DATA REQUIRED	TEST 1	TEST 2	TEST 3	TEST 4
Vertical fuel translates to horizontal during rotation				
Basket rotation effect on cleaning				
Basket speed				
Does fuel roll/slide during rotation				
Water flow through confinement box				
Location of residual simulant and amount				
Cycle time				

5.3 The acceptance criteria for the Phase 3 testing identified in Section 2.4 of this document is as follows:

- Outer Confinement Box Tests - Requires the removal of all residual simulants from the interior of the outer confinement box and associated equipment.

The data required to support Outer Confinement Box tests is identified in the following table:

CRITERIA	TEST 1	TEST 2	TEST 3	TEST 4
Nozzle location				
Nozzle size				
Nozzle flow				
Nozzle pressure				
Water flow through confinement box				
Simulant recipe*				
Simulant location*				
Cycle time				

Note: Criteria identified * to use data compiled during Phase 1 and Phase tests.

Figure 1 - Sample

Test Basis:

Test Objective:

Comments:

Witness (BNFL):

Ref #	Test Procedure step/reference # requiring data record. (Hold points are to be selected based upon a review of the Test Procedure)	Results Summary/data record or qualitative analysis.	Test Tech. Signature/ date	Resp Eng.	Comments/Conclusions/Recommendations	Design mod Req.	Close out Signature/ Date BNFL/ WHC
	This table is a sample format for the recording and transmitting of test data. The equivalent concept as provided in the Test Procedure will be reviewed and approved prior to initiation of testing.						

Appendix A

Sketches

APPENDIX A - SKETCHES

The following sketches are provided to support fabrication of the Primary Clean Station Test Rig.

PLAN
SCALE 1-1/2"=1'

FRONT ELEVATION
SCALE 1-1/2"=1'

(3) 1" NB BULKHEAD CONNECTORS FOR SPARY NOZZLE PIPEWORK. SPARY NOZZLE JET TO BE LOCATED 1/4" MIN. 3/8" MAX OUTSIDE THE COVERPAD

④ TIPPING CRADLE ASSY
SK-101 SCALE: 1-1/2"=1'

④ TIF
SK-101

③ CANISTER TIPPER CRADLE COVER
1/4"=1'

② TIPPING CRADLE ASSY
SCALE: 1-1/2"=1'

G CRADLE ASSY
SCALE: 1-1/2"=1'

1/2" WIDE
QUANTITATIVELY
CENTERLINE

④ 1/2" SLOT PROFILE
SCALE: 1/4"=1'

PRELIMINARY

STATE OF	
REGISTERED PE	
FUEL RETRIEVAL SUB-PROJECT	
U.S. DEPARTMENT OF ENERGY National Operations Office BNFL, Inc.	
PROPOSED PRIMARY CLEAN TEST RIG CANISTER CRADLE	
F	105 K
SK-102	
SHOW	

NO	TITLE	REV NUMBER	REV DATE	REV DESCRIPTION	REV BY	REV DATE
1	DRAWING TRACEABILITY LIST					
2	NEXT USED ON					
3	CADFILE	SK101KP				
4	CADCODE	WHJ.11.402.13.0.SS

BASKET 2'-10" O/D x 2'-10" LG
MANUFACTURED FROM 3/4" THK CS
PERFORATED PLATE MIN. 50% OPEN AREA
FULLY SEAM WELD CONSTRUCTION

5 FRONT VIEW
1-1/2" ± 1"

6 SIDE VIEW
1-1/2" ± 1"

7 DETAIL - PLATE PROFILE
1/4" ± 1"

7

ANGLE WELDED TO PLATE
3/8" FILLET (INSIDE FACES
ONLY) BOTTOM BASKET ONLY

8 VIEW
NTS

PRELIMINARY

STATE OF	
REGISTERED PE	
FUEL RETRIEVAL SUB-PROJECT	
U.S. DEPARTMENT OF ENERGY Nuclear Operations Office BNFL, Inc.	
BNFL	
PROPOSED PRIMARY CLEAN TEST RIG FUEL CLEANING BASKET	
REV F	105 K
SK-103	

NO	TITLE	REV NUMBER	REV DATE	REV BY	REV FOR
1					
2					
3					
4					
5					

DRAWING TRACEABILITY LIST	NEXT USED ON	CADFILE	SK101KP	REVISON	WBS:J,11:AGD:13,0:SS
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