Instrumented, Shielded Test Canister System for Evaluation of Spent Nuclear Fuel in Dry Storage

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EXECUTIVE SUMMARY

This document describes the development of an instrumented, shielded test canister system to store and monitor aluminum-based spent nuclear fuel (Al SNF) under dry storage conditions. The document is organized into the following three parts:

- Part I: Objectives for Tests Using Instrumented Canisters
- Part II: Design and Fabrication of the Instrumented, Shielded Test Canister System
- Part III: Vacuum Drying of Al SNF for Canister Storage

The primary test objectives using the instrumented canisters are to:

- validate drying and storage criteria for road-ready storage;
- validate corrosion models;
- validate gas release models;
- validate heat transfer analysis methodology; and
- provide lead-assembly-surveillance for a dry storage system.

These objectives will be achieved following the loading of Materials Test Reactor type (MTR) fuel assembly into the canister and the analysis of data collected under the test environmental conditions of storage.

An instrumented, shielded test canister system has been designed and fabricated (see photograph below). The canister can house an MTR assembly in a sealed dry storage configuration and is instrumented to measure and record the following parameters during storage to characterize the environment internal to the canister and the fuel materials response:

- fuel clad and air space temperatures
- gas species (released from fuel; corrosion reaction products)
- pressure
- relative humidity
- fuel material visual condition

The canister is capable of being dried to any desired level. Tests to demonstrate unheated vacuum drying of the test canister containing a mock Materials Test Reactor fuel assembly and water have been performed. The results show that free water can be removed to a minimal vapor. A vacuum of less than 5 torr at room temperature is readily achievable, meeting the site-established criteria for road-ready storage. Drying of a representative Foreign Research Reactor/Domestic Research Reactor (FRR/DRR) MTR assembly using the unheated vacuum drying technique will be performed as part of the validation testing.

The instrumented test canister system design is one-of-a-kind in capability to monitor the storage environmental conditions and the response of nuclear fuel in a dry storage system. In calendar year 1998, two canisters will be loaded with FRR MTR assemblies; dried using unheated vacuum drying; backfilled with air and a finite level of water corresponding to the environmental limit prescribed for dry storage; sealed; and staged in the SRS L-disassembly dry cave. These actions will be performed following preparation of the area and documentation of safety reviews. Data will be accessible at the staged location, and also remotely via computer network. The response of the SNF to varying environmental conditions will be monitored to validate the storage criteria.

**Instrumented, Shielded Test Canister System for Dry Storage of AI SNF.
The Test System includes the Fuel/Canister Monitoring System, the Data
Acquisition System, and the Canister with Shielding.**

WSRC-TR-97-00269, Part I
Objectives for Tests Using Instrumented Canisters
by R. L. Sindelar

Background

A total inventory of up to approximately 24 metric tons or approximately 32,000 aluminum-based spent nuclear fuel (Al SNF) assemblies are expected to be shipped to SRS over the next several decades. These fuels will be shipped from foreign research reactors (FRR), domestic research reactors (DRR), and the Idaho National Environmental Engineering Laboratory (INEEL) to the Savannah River Site (SRS). Some assemblies have already been received at SRS and are being temporarily stored in the L-Basin and the Receiving Basin for Off-site Fuels (RBOF) [1].

An Alternative Treatment Technology Program is currently evaluating options for the disposition of this SNF in a geologic repository. A pre-conceptual design of a facility for Transfer and Storage Services (TSS) has been completed [2] in support of this program. Under one alternative, namely direct/co-disposal, fuels would be removed from basin storage and prepared for placement in sealed canisters for interim dry storage at SRS while the repository is undergoing licensing and final site preparation. The desired service life of the facility is 40 years.

Nuclear fuel from commercial and research reactors has been in dry storage systems throughout the world [3]. Australia, Japan, Canada, [4] and Brazil [5] have been dry storing Al SNF for several years. The dry storage systems were designed with good engineering judgment but without specific criteria tied to long-term performance to maintain structural integrity over many decades. Degradation has been observed when water and air have inadvertently entered into the storage environments.

Site criteria have been established for interim dry storage conditions for Al SNF to avoid excessive degradation during the handling, processing, and interim storage prior to repository disposition [6, 7]. To demonstrate that the fuel condition is maintained within expectations and that the environment is within criteria when drying to the specified level, a test apparatus is needed for validations. In addition, such apparatus could be used as lead surveillance for an interim dry storage system. This report outlines the design and development of an instrumented canister system that could be used to monitor Al SNF performance in dry storage.

Objectives for Tests Using the Instrumented, Shielded Test Canister System

The test canister system described in part II of this report is designed to be an apparatus for tests of Materials Test Reactor type (MTR) fuel assemblies in dry storage although other fuel, fuel segments, and waste forms could be accommodated. The storage environments can be set by water injection and gas back fill. Self-heating of the waste form is the heat source in the canister.

The primary test objectives in using the canister are:

- validate drying and storage criteria for road-ready storage;
- validate corrosion model;

- validate gas release model;
- validate heat transfer analysis methodology; and
- provide lead-assembly-surveillance for dry storage system.

The drying and storage criteria governing the handling, processing, and interim dry storage of AI SNF, originally developed and reported in reference 6, have been adopted as technical functional performance requirements for a dry storage system in reference 7. A summary of these technical functional performance requirements follows.

Fuel Temperature Limit:	200°C
Canister Storage System:	Sealed
Free Water Limit in Canister:	Limit H ₂ Build-up to 4%
Fuel/Clad Consumption Limit:	0.003"
Canister Cover Gas:	Helium

The preliminary intended storage condition of FRR/DRR MTR fuel assemblies in the canisters will be to store in an initial air/water vapor environment such that limited corrosion would occur. Based on a level of free water injected into the system, hydrogen could be generated up to the limit.

The response of the fuel to the storage is predicted using analytical models of the materials' response which have been developed for interim dry storage conditions. A brief summary of the models and expected fuel response to the storage environment is provided in the next section. The actual response of the fuel will be compared to its predicted response following the loading of the MTR assemblies and the analysis of data collected under the test environmental conditions of storage in calendar year 1998.

Fuel Materials' Response to Environments of Dry Storage

The spent nuclear fuel to be stored at the Savannah River Site is aluminum-based. The fuel core for these fuels is characterized as an aluminum matrix in which particles (dispersoids) of either UAl_x , U_3Si_2 , or U_3O_8 oxide particles are embedded. The core is protected by a cladding of aluminum alloy which is metallurgically bonded to the core. The fuel response in a dry storage system is dependent on the environment and period of storage. The environment includes the surrounding gas, relative humidity, and temperature of the fuel. Site criteria have been established to limit the amount of degradation that occurs during the handling, processing, and storage periods of the spent fuel [6, 7].

Thermal Analysis Model- The temperature of the fuel is dependent on the canister design, heat loading within the canister, and the heat removal from the canister. Previously, analyses were performed to identify the appropriate heat transfer code and develop the appropriate analytical methods to model heat removal from a system with low differential temperatures and low convective flow within the canister and outside the canisters [8]. This methodology will be applied in analyzing the temperature data from the tests.

Corrosion Model- General corrosion of the fuel is the primary degradation mode and would occur by vapor corrosion in a dry storage system in the presence of corrodant species. A extensive testing program is in progress, and test results have been used to benchmark a semi-empirical model for the corrosion the cladding alloys [9]. As a consequence of the corrosion reaction, hydrogen gas is generated, and the amount based on initial free water in

a closed system can be calculated [9]. An Arrhenius relation is used to describe the temperature and time dependence of the weight gain, W, or the consumption of the metal:

$$W = A \cdot \exp(-Q_1/nRT) \cdot t^n,$$

where A is an coefficient which in general is a function of material, relative humidity, corrodant species, etc., Q_1 is related to the diffusion of oxygen in the oxide film or activation energy for diffusion in Boehmite, R is the universal gas constant, T is the absolute temperature in Kelvin. No direct measure of weight gain will be performed in the test; however two means to assess the corrosion response will be available. The direct visual examination of the fuel plate surface including the crevice region at the fuel plate/end plate intersection will be performed to check for evidence of additional corrosion during storage. The second means to assess corrosion is the build-up of hydrogen through the corrosion reactions. The following two reactions are considered to be the predominant reactions of aluminum corrosion at the expected storage temperatures

Gibbsite Reaction -

Boehmite Reaction -

Measurement of the amount of hydrogen generated during the test and comparison to the amount that would be generated based on the available free water will be performed.

Creep Model- Under extended periods of storage and at high storage temperatures [10] deformation of the fuel under self-weight loading will occur. The deformation mechanism for this is based on a phenomenological model of creep considering grain boundary sliding. The creep law is given by:

$$\dot{\epsilon}_{Co}^{cr} = A_{Co} D_{0(gb)} \exp\left(-\frac{Q_{gb}}{RT}\right) \left(\frac{Gb}{kT}\right) \left(\frac{b}{d}\right)^3 \left(\frac{\sigma}{G}\right)$$

for pure aluminum, where

A_{Co} = dimensionless Coble creep constant = 66.8,

$D_{0(gb)}$ = grain boundary frequency factor = $1.86 \text{ cm}^2 \text{ sec}^{-1} = 1.86\text{E-}04 \text{ m}^2 \text{ sec}^{-1}$,

R = gas constant = $8.31441 \text{ J mol}^{-1} \text{ K}^{-1}$,

k = Boltzmann's constant = $1.38\text{E-}23 \text{ J K}^{-1}$,

Q_{gb} = grain boundary diffusion activation energy = $86.04 \text{ kJ mol}^{-1}$,

G = shear modulus at temperature T = $G_0 - DGT = 3.022\text{E+}04 \text{ MPa} - (16.0 \text{ MPa K}^{-1})T$,

b_B = Burger's vector = $2.86\text{E-}08 \text{ cm} = 2.86\text{E-}10 \text{ m}$.

d = average grain size (cm)

σ = von Mises equivalence stress (Mpa or psi)

T = absolute temperature (K)

The deformation response of the plates of an MTR assembly have been analyzed [10]. Up to 200°C, and even after several decades of storage, no significant deformation would be expected. Visual information will be available in the instrumented canister to verify no creep deformation of fuel occurs.

Gas Release Model- A simple model for the release rate from breached fuel at low temperatures is based on the consideration of binary diffusion of volatile species [11] in aluminum either through the cladding or directly from exposed fuel meat since no copious cracking of the fuel microstructure is created during irradiation. The fission products that have the highest diffusion and/or highest vapor pressures are Cs, Xe, and Kr [11].

The model for gas release is being refined and additional laboratory testing is in progress. It is anticipated that very little if any release would occur over years of storage. Measurement of the concentration of species in the canister gas will verify this.

Preliminary Selection of MTR Assemblies and Conditions for Storage in Test Canister

An estimate of 10% of the fuel assemblies have corrosion or mechanical damage that has resulted in minor penetrations (breaches) of the aluminum cladding and exposure of the fuel core to the ambient environment. Fuels with minor breaches are acceptable for direct placement in the dry storage canisters [7]. The basis for this acceptance is that the materials and structure of the AI SNF provides a measure of confinement of the radionuclides. The corrosion of any exposed fuel material is expected to be on the same order as the cladding [9]. In addition, significant diffusion and release of species through the fuel matrix and cladding is not expected at low temperature ($< 200^{\circ}\text{C}$), short term (< 50 years) storage [11]. The canister test will verify that the release of volatile products from exposed fuel is low.

The MTR assembly placed in the canisters during the tests will be based on availability, existing degraded condition, and fission product inventory which affects heat generation and radiation field. Preliminary selection of two fuels have been tentatively selected, fuel with exposed meat from the SAPHIR and fuel with exposed meat from the R2 reactor. Figure I-1 below shows fuel plate 243 from the SAPHIR assembly SES02 with an apparent exposure of fuel meat.

Figure I-1 Saphir fuel plate #243 Saphir with Cladding Breach

In fiscal year 1998, L-Dry Cave will be prepared to stage the canister system [12]. Safety documentation and a fuel/canister handling procedure will be issued. The fuels will then be transferred from RBOF to L-disassembly basin. The fuels will be loaded underwater into the shielded canisters. The canister will be vacuum dried, then vented to air and injected with a controlled amount of water. The system will be sealed and staged in the L-area dry caves and the collection of data will begin.

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WSRC-TR-97-00269, Part II
Design and Fabrication of the Instrumented, Shielded Test Canister System
by D. J. Pak, P. J. French, R. F. Eakle, and R. L. Sindelar

Design Considerations

The instrumented test canister system is to store a single MTR Aluminum SNF assembly in a canister in closed environment and to collect data on fuel conditions and storage environment for some period of time. Initially the fuel will be monitored as a test case, then should long term dry storage prove to be a desirable option, the canisters will be used as a lead case for long term stored fuel monitoring. To meet the objectives of this task, the canister system requires to be equipped to monitor following key parameters.

- Temperatures: fuel surface, canister, ambient, circulating air
- Gas generation: Hydrogen, Oxygen, NO_x
- Gas release from fuel: Cesium, Xenon, Krypton
- Internal pressure
- Relative humidity
- Circulating air flow rate
- Visual inspection on fuel surface

All monitoring and data collecting operations shall be done remotely and automatically. The canister monitoring loop also must be designed to prevent any accidental release of fission products from the stored SNF assembly.

The system also requires to allow remote fuel loading to minimize radiation exposure to the operating personnel. In addition, due to the high radiation level of the fuel assembly, the canister must have adequate shielding to protect personnel during the monitoring period.

Deliverable Items

Two complete independent systems to store and monitor two Al SNF assemblies under test conditions were designed and fabricated. These include two canisters, two shields, two camera brackets, two air monitoring loops with instrumentation, and one data acquisition system with uninterrupted power supply to manage and record data on environmental conditions inside the two test canisters.

All engineering documents generated for the design and fabrication of the test canister system are filed in EES Job No. 22585 folder.

System Designs and Features

The instrumented test canister system consists of an instrumented canister, shield, fuel monitoring system and data acquisition system. Designs and features of each component are described in the following.

Instrumented Canister

The instrumented canister (Figure II-1 photograph) provides sealed containment for a Materials Test Reactor (MTR) fuel assembly which is approximately 3-inches square and just over two feet long. The fuel assembly is supported by an aluminum sensor rack to center it and to allow positioning of thermocouple tips on the fuel surface. The canister body is made from a section of 6" outside diameter Type 304 stainless steel tubing with a

wall thickness of 1/8". The top of the body is welded to a commercial 8" vacuum flange. A blank flange, which is welded to the shield lid, bolts to twenty threaded holes in the flange of the canister and gives the vacuum tight enclosure. The bottom of the canister tube is seal welded to a flat 1/8-inch thick 304 stainless steel plate.

Three stainless steel tubes, 1/2" o.d. with .050" wall tubing, are welded to the canister. One lower tube and one upper tube serve as air inlet and outlet ports, respectively, to mate with the air circulation loop for air sampling. For air sampling during the test, air enters the canister through the bottom tube, passes the fuel assembly and exits one of the top tubes. All thermocouple wires exit through the third port which serves as a conduit. The canister is housed within a lead shield (see Figures II-2, 3, and 4 schematics from Reference Drawing number EES-22585-R1-001) to reduce the radiation exposure to allow limited access to the L-area dry cave where the canister will be staged. It also has a 4 inch diameter sealed quartz viewing window to allow direct visual inspection of the fuel surface approximately 8 inches from the bottom. This observation will be done with the aid of a video camera that can be seen in the cross section plan view, in Figure II-4. The camera is mounted around a 90° corner and views the assembly through a front surface mirror mounted in the viewing tunnel to avoid the high direct radiation field directly in front of the assembly.

Shield

The shield (Figure II-5 photograph) is needed due to the high radiation field expected from a spent fuel assembly. A shielding analysis was performed to determine shielding requirements (Appendix 1 to this report).

The shield consists of a 1/8 inch-thick stainless steel shell construction filled with molten lead. Based on the analysis, the shield has 4.25" of lead shielding to keep the dose rate on the shield surface for one High Flux Beam Reactor assembly below 100mR/hr. The approximate weight of the shield with the canister is 6,640 pounds.

Design Calculations for Instrumented Canister

Maximum Pressure in Canister: The canister will be initially at atmospheric pressure at room temperature when vented to air following vacuum drying after fuel loading. A finite level of water will then be injected to simulate incomplete drying as an initial condition of the stored fuel and the system will remain sealed throughout the test. This environment is expected to cause limited, predictable corrosion. Two chemical reactions of the aluminum with water are considered:

Gibbsite Reaction -

Boehmite Reaction -

If the canister temperature is raised sufficiently before corrosion takes place, all water will evaporate. In this case, the initial partial pressure due to water vapor will be greater than

the final partial pressure from hydrogen generated after the corrosion reaction. Using gibbsite reaction to estimate the total pressure of the canister at high temperature is conservative.

Assume that the final pressure of the hydrogen generated as a result of corrosion is P_H . The initial vapor pressure (P_{water}) is thus

$$\text{Gibbsite: } P_{\text{water}} = 2 P_H$$

$$\text{Boehmite: } P_{\text{water}} = (4/3) P_H$$

The total pressure of the canister (P) has two major contributions: 1) The air trapped in the canister (P_{air}) when it is sealed (initial pressure is 1 atm at room temperature); 2) Water vapor pressure (P_{water}) in the beginning of the test or the hydrogen pressure (P_H) when all water is consumed by corrosion. As stated earlier, the initial water vapor pressure is higher than the final hydrogen pressure and will be used in the calculation. That is,

$$P = P_{\text{air}} + P_{\text{water}}$$

(1) Calculation of P_{air}

Let P_T be the air pressure at temperature T (Kelvin) and T_{rm} is the room temperature in Kelvin, using the ideal gas law:

$$P_T = (1 \text{ atm}) \cdot T / T_{\text{rm}}$$

(2) Calculation of P_{water}

Assume that the volume fraction of the final hydrogen buildup is X . Let the free volume of the canister be V . The number of moles of hydrogen is therefore XV/M , where V is in cubic meters and M is the molar volume of hydrogen ($24789.2 \times 10^{-6} \text{ m}^3$). As a result, the number of moles of water corresponding to that amount of hydrogen in the gibbsite reaction is $2XV/M$. Using ideal gas law, the initial vapor pressure at temperature T is

$$P_{\text{water}} = (2XV/M)RT/V = 2XRT/M,$$

where R is the universal gas constant ($8.205 \times 10^{-2} \text{ m}^3 \cdot \text{atm} / \text{kmol} \cdot \text{K}$).

(3) The total pressure in the canister is

$$P = (1 \text{ atm}) \cdot T / T_{\text{rm}} + 2XRT/M$$

With $T_{\text{rm}} = 300\text{K}$ and $T = 473.15\text{K}$ (or 200°C , the temperature limit),

$$P = (1 \text{ atm}) \cdot 473.15 / 300 + 2 \cdot X \cdot (8.205 \times 10^{-2} / 1000) \cdot 473.15 / 24789.2 \times 10^{-6}$$

Therefore

$$P \text{ (in atm)} = 1.577 + 3.132 X$$

or $P \text{ (in psia)} = 23.176 + 46.028 X$

or $P \text{ (in psig)} = P \text{ (in psia)} - 14.696 = 8.480 + 46.028 X$

(4) Assume that a conservative estimate of hydrogen production is 10% of the free volume ($X = 0.1$). The total gauge pressure in the canister is 13.1 psig which is less than the allowable internal pressure for the window (15 psig). The safety margin will increase when the temperature is lowered (from 200°C). Figure II-6 shows the canister pressure as a function of hydrogen concentration and temperature. For the test, the amount of free water will be limited to a lead to a nominal hydrogen pressure of 4%. In addition, the expected temperature in the canister will be well below 100°C.

Capacity of Canister against Buckling: This calculation is performed to check that vacuum drying does not collapse the canister. The calculation is performed using ASME code, Section VIII, paragraph UG-28 criteria. The canister is a cylinder length, L , of 27 5/8", the inside diameter, D_o , is 6", and the nominal thickness, t , is 1/8".

$$L/D_o = 27.625/6 = 4.604$$

$$D_o/t = 6/(1/8) = 48.$$

A maximum canister temperature of 200°C (approximately 400°F) is considered which corresponds to the fuel temperature limit for dry storage. The canister temperature expected in the tests will be nominally elevated above room temperature due to the low heat output of the fuel (< 10 watts). Young modulus for 304 SS at 400°F is 26.5E6 psi.

Using Appendix 5 of the ASME code, Chart 5-UGO-28.0, for $L/D_o = 4.604$ and $D_o/t = 48$, the factor A is 7.5E-4.

Using Figure 5-UHA-28.1 of Appendix 5, for 304 SS at 400°F, using interpolation, the factor B is 6643. The allowable external pressure P_a is

$$P_a = 4B/(3(D_o/t)) = 4 \times 6643 / (3 \times 48) = 184.5 \text{ psi.}$$

With a complete vacuum inside the canister, the safety margin against collapse is 184.5/14.7. The window welded to the vessel does not weaken the vessel if there is no external mechanical loading.

Capacity of Lifting Bails: The weight of the shielded canister is 6640 lbs. The lifting bail/bar design is such that it minimizes the moment loading at the 1/8" shell. This is due to the fact that moment loading is deflection limited. The deflection is negligible since bars (3" x 3/8") on the 2" diameter lifting bails limit the deflection. The moment loading at the shell is also negligibly small.

The stress on the bail section is:

$$\sigma = (7000/2)/(3/8 \times 1) = 9333 \text{ psi}$$

$$F_y = \text{yield stress} = 30,000 \text{ psi (per ASME BPV code, section II, part D)}$$

The allowable stress is $0.6F_y = 18,000 \text{ psi (per AISC manual)}$

Approximate deflection is $\sigma/E \cdot \text{length} = 9333 \cdot 1.5 / (28.3 \times 10^6) = 0.0005$ " which is negligible

Now the lifting pin is attached to the shell by a 5" diameter piece and a 3/16" fillet weld around the circumference.

The weld length = $5 \text{ PI} = 15.71$ "

The weld strength in shear (per AISC manual) = $0.3 \cdot 0.707 \cdot 3/16 \cdot 15.71 \cdot F_u$
where F_u is the minimum tensile strength of the weld material. For SS304 plate, $F_u = 75,000$ psi.

Therefore, the weld strength is $0.3 \cdot 0.707 \cdot 3/16 \cdot 15.71 \cdot 75000 = 46851$ lbs.

The total weld strength for both ends is $2 \cdot 46851 = 93702$ lbs.

The safety factor is $93702/7000 = 13.39$.

The shear stress in the shell is $(7000/2) / (15.71 \cdot 0.707 \cdot 3/16) = 1681$ psi.

The shear allowable is $0.4F_y = 0.4 \times 30,000 = 12,000$ psi.

Therefore the shell will not be damaged.

Fuel Monitoring System

The fuel monitoring system consists of a cabinet containing one complete instrumentation loop for each canister (Figure II-7 schematic). Each loop has two primary components; a gas chromatograph (GC) and an instrument manifold. The gas chromatograph takes a one microliter sample of air from the canister once per day. This sample is combined with a carrier gas in the instrument and is analyzed for hydrogen, nitrous oxides, and oxygen content. The carrier gas is ultra high purity argon which is contained in a cylinder just outside the cabinet. A calibration gas system is programmed to periodically confirm the GC output and automatically purges itself to prevent dilution of subsequent samples. Calibration gas bottles containing a mixture of hydrogen, nitrogen, and oxygen are located in the bottom of the cabinet.

The instrument manifold houses a temperature/relative humidity sensor and a pressure transducer. A radiation monitor is included between the instrumentation manifolds monitoring the loops for both canisters simultaneously. The radiation monitor senses the presence of gamma radiation indicating that radioactive material has been released from the fuel element and is circulating within one or both instrument loops. This material is retained by the system such that no radioactive panicles are admitted to the atmosphere. Further analysis to determine the exact source and constituents of the radiation will be required upon detection. Each loop is also equipped with a circulating pump, a flow meter, and line for introducing outside air in the event that pressure falls off over time. Solenoid valves are controlled by the data acquisition computer. These valves are used to direct air flow to the gas chromatograph during sampling and calibration procedures. Signals to and from all instrumentation are linked to the data acquisition system in an adjacent cabinet.

Data Acquisition System

A computer based data acquisition system has been developed to monitor environmental parameters associated with two identical shielded test canisters. The system consists of a central computer cabinet, instrumented process cabinet and two instrumented canisters (Figure II-8 schematic). The computer provides real-time display of data, data storage, and remote data access via network/internet connection. Sensors in the process cabinet allow monitoring of air temperature, air flow, canister gas composition, pressure, relative humidity, radiation. Sensors in the canister measure surface temperatures of the fuel, canister wall and temperatures of inlet and outlet air.. Circulating pumps located in the instrument cabinet (Figure II-6 photo) ensure continuous circulation of system air past all sensors. The visual appearance of stored fuel is monitored by a video camera mounted on each canister.

Data acquisition, storage and display are accomplished in four basic levels: sensor output, signal conditioning, communication and computer translation. All process sensors, except gas composition, video, and radiation, provide voltage or current level analog outputs proportional to the measured parameter. Each analog signal is converted to digital form by a dedicated signal conditioning module located in close proximity to the sensor. The signal conditioning modules reside in backplanes which convert the digital information to a robust serial format which ultimately enters the computer through a standard serial (RS232) communication port. Gas composition information is conditioned and transmitted directly from one of two gas chromatographs to a dedicated serial port on the computer. Video information is provided by one camera mounted on each of the canisters. Standard (NTSC) video signals are transmitted directly to the computer and received through one of two ports on a video capture board. Radiation detection is accomplished with a single dedicated sensor and meter. At a predetermined level the meter generates a contact closure. The contact closure is detected by a signal conditioning module where it is transmitted along with other signal data. The computer translates all received signals to tabular and/or graphical form for storage and display. Video from observation cameras can be displayed exclusively or concurrent with parameter information on the computer display.

Computer System: The computer system is the central component of the data acquisition system. The basic configuration consists of a CPU chassis, keyboard, mouse and color display. The chassis is a Texas Micro Systems (TMS) passive backplane with nine ISA, three PCI type slots and a 300W power supply. One slot of the chassis is occupied by a TMS single board CPU. The CPU is Pentium/133MHz based with 32 Megabyte of RAM. Two serial, one parallel, SCSI and IDE interfaces are included on the CPU board. An SVGA video display driver board with 2 megabytes of RAM is located in a PCI slot next to the CPU board. Other slots contain interface boards for video capture and two additional communication ports. Removable media is accommodated by a 3.5", 1.44Mb high density floppy drive and 4X CD ROM drive. Operator inputs are entered into an IBM™ AT compatible, sealed, industrial grade keyboard. Cursor movements are input through a serial communication port by a sealed track ball mouse located in the keyboard housing. Video display is provided by an Intecolor™ 20" color monitor. A Hewlett Packard color printer provides hard copy output of both data and video images.

Temperature Sensing: Temperature sensing is performed within the process cabinet and each canister. In the process cabinet measurement is performed at three locations: canister 1 air plenum, canister 2 air plenum, and ambient air. The sensors used are HyCal model CT-839-A-R-(30/130F)-(0/100%) humidity/temperature transmitters configured with a model EL-705 platinum temperature element. Each transmitter provides an industry

standard 4 - 20mA output proportional to temperature over the range 30 to 130 degrees F. Specified accuracy is $\pm 0.3^\circ\text{C}$ at 25°C or $\pm 0.8\%$ of span. Mounting of canister air sensors is accomplished by insertion into the plenum air stream and sealing with swage type fitting. Within the each canister temperature measurements are made at five fuel surface locations, one canister surface and at the air inlet and air outlet. Canister sensors are Omega Engineering model KMQSS-040U-72 thermocouples. Each thermocouple is K type, ungrounded, and sealed in a .040" x .72" long 304 stainless steel sheath. Combined with the signal conditioning module K type thermocouples have a range of 0 to 1000°C and a maximum error of $\pm 0.75^\circ\text{C}$.

Humidity: Relative humidity measurements are performed in the process cabinet at three locations: canister 1 air, canister 2 air, and ambient air. The sensors used in each location are HyCal model CT-839-A-R(30/130)-(0/100%) humidity/temperature transmitters configured with a model IH-3602-A humidity sensing element. Each transmitter provides an industry standard 4 - 20mA output proportional to humidity over the range of 0 to 100% relative humidity. Specified accuracy is $\pm 2\%$ for 0-90%RH at 25°C and $\pm 3\%$ over 15°C to 50°C . Mounting of canister air sensors is accomplished by insertion into the plenum air stream and sealing with swage type fitting.

Pressure: Pressure is measured at five locations in the process cabinet: canister 1 air, canister 2 air, ambient, gas chromatograph 1 (GC1), and gas chromatograph 2 (GC2). Canister and ambient pressure sensors are Lucas model P4183-0005-030PA digitally compensated transducers. Combined accuracy is $\pm 2\%$ over the range of 0 to 30 psi absolute. Output is an industry standard 4 - 20mA over the operating range. Each transducer is contained in a NEMA 4 316SS housing and all exposed process surfaces are 316SS. Canister transducers are connected to canister air plenums by a NPT female port. GC1 and GC2 pressure sensors are Druck model 960 transducers with 0 - 50 psig operating range. Output is 0 to 100mV over the specified range.

Flow Rate: Circulating air flow is measured within the process cabinet for canister 1 and canister 2. Each air stream is measured with an Eldridge Products model 8659-SSS-103B-DC24-AIR thermal mass flowmeter. Specified accuracy is $\pm 2\%$ over the operating range of 0 to 3 SCFM with a one second response time. The signal output is an industry standard 4 - 20mA output over the specified operating range.

Gas Chromatographs: Canister 1 and canister 2 air streams are each sampled by a dedicated gas chromatograph (GC). The GC units are MTI Analytical Instruments model M200 configured with a 5 angstrom 4 meter molecular sieve. The units will be calibrated for O₂, H₂ and NO_x gases, however the GC can respond to a spectrum of gases allowing the detection of unanticipated gas species. The resulting serial data output provides a spectral distribution based on molecular size or gas species.

Video Observation: Canister 1 and canister 2 are each equipped with a video camera and light source for fuel observation. The camera and light assembly are aligned with the quartz window view port on each canister. The NTSC color video signal from each camera is connected to independent input on the video capture board located in the computer chassis. The video capture board is a Creative Labs model SE1000. Video capture allows viewing and storage of either canister observations and is operable in either a Windows or DOS software system.

Radiation Detection: A single radiation monitor is employed to detect the unlikely buildup of contaminants from fuel anomalies. The system consists of an Eberline RM-14SA count

rate meter coupled with an Eberline SPA-9, 2", NaI scintillation probe. The count rate meter has selectable ranges from 0-50 to 5 million counts per minute full scale. An adjustable alarm set point generates an alarm output to the data acquisition system if the set point is exceeded. The probe is mounted equidistant between canister 1 and canister 2 air plenums within the process cabinet. Should contaminants be detected a multichannel analyzer can be used to identify specific species.

Signal Conditioning: Analog and digital signals from sensors are conditioned and communicated to the computer through a system of intelligent modules and backplanes. Each analog signal is connected to an Omega Engineering OM6-TC module where the specific signal type is converted to digital form for transmission to the computer. Each module is configured prior to installation so that it has a unique digital address and the appropriate method of conversion for the incoming signal. Analog modules are mounted in Omega Engineering, sixteen position, model OM6-BP16-485 or OM6-BP16-232 backplanes. Digital modules are manufactured as either input or output and for specific voltage ranges. Configuration of the module consists only of assigning a unique address. Digital modules have four channels and are installed in an Omega Engineering model OM6-DIO-1, six position backplane. When installed in a backplane modules become part of an RS-485 communication network and can be queried as needed.

Backplanes and modules reside in three locations: one analog (BP1) and one digital backplane (BP2) in the process cabinet, one analog backplane (BP3) on canister 1 and one analog backplane (BP4) on canister 2. BP1 is an Omega model OM6-BP16-232 which provides an RS232 interface between the computer and all modules in the system. The additional backplanes are connected in series to BP1 through a serial RS-485 network. Use of the RS-485 and remotely located backplanes ensures reliable communication and minimizes cabling.

Fuel Loading and Canister Handling

The SNF loading operation is to be done in the 105-L Transfer Bay and the loaded canister system will be stored in the 105-L Disassembly Area Dry Cave for monitoring [1].

To provide the adequate shielding during the loading operation, the SNF will be loaded into the shielded canister in the Transfer Bay pit pool using water as a shield. The shield assembly is designed to be submersible for this reason. Initially the bottom shield assembly with the canister and the thermocouple sensor rack will be lowered into the pool. Then the specific SNF will be loaded into the canister. After the fuel is loaded, the canister lid will be put on top of the bottom shield. Before the shielded canister assembly leaves the Transfer Bay pit, two bolts will be put on to secure the lid and the assembly will be rinsed with clean water while it is over the Transfer Bay pit. The assembly will then be lowered onto the Transfer Bay floor near the northeast corner and it will be surveyed for any surface contamination and adequacy of shielding. Once it clears the Radiation Control survey, a pump will be used to remove the bulk of water from the canister via the half inch tubing which serves as the air circulation system. The canister lid is then completely closed using 5/16 - 24 x 13" long bolts.

At this point, the vacuum pump will be connected to the canister for drying of the canister assembly by drawing a vacuum until the vacuum gage reaches below approximately five Torr on the system.

Once the drying operation is complete, the canister system will be transported to the 105-L Disassembly Basin Dry Cave which is its designated long term storage location [1]. The canister will be vented to atmosphere and a limited volume of water will be injected into the system. Data collection cycle and monitoring operation plan will be determined by the Spent Fuel Storage Division and SRTC personnel.

Acknowledgments

The following individuals contributed to the success of this work: Juan Hill for drafting support; 717-A, 749-A, & Construction Shop personnel; G. Reeves for DAS development; N. K. Gupta and P. S. Lam for the canister design calculations; C. S. Stripling for photographs; and Si-Young Lee for T/C placement

References for Part II

1. **SFS-SNF-970089**, "Plan for Instrumented Dry Storage of SNF," W. S. Large and D. G. Blanchard, September 9, 1997.

Figure II-1 Photograph of Test Canister for Housing an MTR Fuel Assembly. The visible features are the quartz viewing window, the thermo-couple feed-through line, and the circulation inlet and outlet lines.

Figure II-2 Schematic of Side View 1 of Test Canister within Lead Shield for Containing an MTR Fuel Assembly.

Figure II-3 Schematic of Side View 2 of Test Canister within Lead Shield for Containing an MTR Fuel Assembly. Note the lifting bails for the shield/canister assembly.

Figure II-4 Schematic of Top View of Test Canister within Lead Shield for Containing an MTR Fuel Assembly. Note the camera mounted around a 90° corner to view the assembly through a front surface mirror (item 17) mounted in the viewing tunnel to avoid the high direct radiation field directly in front of the assembly.

Figure II-5 Photograph of Shield for Test Canister. Note the lifting bails and skid mounting of the shield.

Figure II-6 Predicted Pressure from H_2 Build-up as a Function of Canister Internal Temperature. Free water will be limited to avoid significant H_2 build-up.

CANISTER AIR CIRCULATION SCHEMATIC

Figure II-7 Fuel Monitoring Instrumentation Schematic

Figure II-8 DAS Schematic

WSRC-TR-97-00269, Part III
Vacuum Drying of Al SNF for Canister Storage
by W. S. Large, K. Chen, and R. L. Sindelar

Background

Vacuum drying at slightly elevated temperatures (~120°F) appears to be an acceptable method of preparing aluminum SNF for extended dry storage. Achieving a vacuum below the triple point of water (~4.5 torr) within a heated canister will vaporize all free liquid water. High temperature drying to remove water of hydration from the aluminum oxide on the SNF cladding is not practical, as the temperature required to dehydrate the oxide is high (> 300°C). The quantity of hydrated water is insufficient to cause excessive additional corrosion.

Proposed conditions for vacuum drying [1] are based in part on evaluation of spent nuclear fuel (SNF) drying and stabilization methods under development at the Hanford and Idaho National Environmental Engineering Laboratory (INEEL) sites [2]. SRS experience with vacuum drying methods has also been considered.

A vacuum drying test program at SRS began in August 1997 to demonstrate the feasibility of drying mock (Materials Test Reactor type) MTR SNF assemblies to below 5 torr. The tests quantified vacuum drying times versus initial water volume, and provided operating experience with the drying apparatus and instrumentation. All drying tests were conducted within the Building 105-L assembly area. The primary objectives in the drying tests are :

- Demonstrate feasibility of drying to below 5 torr in an unheated canister system; and
- Provide check-out of drying apparatus in preparation for underwater loading followed by drying of the MTR SNF in the instrumented canister.

Aluminum SNF Drying Concerns

Three sources of water can potentially contribute to corrosion of aluminum SNF:

- Free water on the SNF surface and in pits, crevices, etc.;
- Water of hydration within the aluminum oxide surface coating;
- Adsorbed water on the surface of aluminum oxide and aluminum metal

The major potential contributor to corrosion is free water on the SNF surface. An acceptance criterion of 1 milliliter of water per 0.1 square meter of surface area has been established for interim dry storage of aluminum SNF to meet the corrosion limit. This criterion to ~18 milliliters (0.04 pounds) per cropped MTR assembly and could produce ~0.0001 inches of uniform aluminum corrosion. A more limiting criterion is the avoidance of the generation of hydrogen above 4% in a sealed canister.

The preliminary drying specification for fuels to be placed inside the shielded canisters for the test includes to:

- Dry to less than 5 torr with minimal or no heat input; and
- Backfill the canisters with air and a finite amount of water.

The maximum predicted hydrogen pressure as a function of hydrogen volume percent is shown in Figure II-6 assuming all of the residual free water reacts with aluminum to form Boehmite and hydrogen gas.

Vacuum Drying Test Setup

The vacuum drying test hardware include the test canister, mock MTR fuel assembly, vacuum pump, instrumentation and data acquisition equipment.

Vacuum Canister and Mock Fuel Assembly

A test canister, similar in design to the instrumented canisters, and a mock MTR fuel assembly were designed by EES and utilized in the tests (see part II to this report). The canister, constructed of Type 304 stainless steel, is 6 inches diameter, 35.4 inches high, with a volume of ~934 cubic inches. The removable lid is sealed with a standard copper vacuum gasket. The mock assembly contains 18 aluminum plates and variable wattage heaters on the outer two plates. A photograph of the canister and mock-up in L assembly is in figure III-1. A photograph of the vacuum canister stand and scale is in figure III-2. A photograph of the assembled canister in a test is in figure III-3. A photograph of the assembly in the canister is in figure III-4. A photograph showing the dry can post-test is in figure III-5.

Vacuum Equipment

Drying tests utilized a 480 VAC skid-mounted Kinney KLRC 300KFA liquid ring rotary vacuum pump in series with a KMBD 1604 blower and an air ejector, as shown in Figure III-6. The oil-free liquid ring pump utilizes water as the vacuum chamber sealant and coolant. Nominal pump capacity is 300 cfm at 100 torr, and the pump and blower combination can achieve a maximum vacuum of ~0.5 torr. The pump was connected to the canister via 50 feet of 1-1/2 inch diameter flexible stainless steel hose. The 1/2-inch diameter port on the test canister was connected to the stainless steel hose via ~6 inches of 3/8-inch ID Tygon tubing.

Water mass changes within the canister during tests was measured with new Mettler Toledo precision bench scales. The scales have a readability of 0.0002 pounds with a maximum capacity of 70 pounds. The canister and assembly weighed ~47 pounds and remained on the scales during drying.

Instrumentation and Data Acquisition

Two calibrated vacuum gages monitored the approach to dryness during tests. A Varian model WV110-2 digital vacuum gage with a range of 0.001 to 1500 torr was installed in the canister lid to monitor pressure. A Varian model 801 thermocouple vacuum gage with a range of 0 to 2 torr was installed at the 1-1/2 inch hose inlet. SRTC equipped the canister with two thermocouples and a humidity sensor to monitor interior conditions. The thermocouples measured side plate temperatures at the top of the assembly. A thermocouple was also taped to the canister exterior below the initial water level for selected tests.

The digital scales, humidity sensor, interior thermocouples, and vacuum gage were connected to a computerized data acquisition system that displayed and stored readings

every 5 seconds during tests. Readings were also recorded manually at ~10 minute intervals during tests. Figure III-7 shows the test loop.

Test Methodology

The empty canister and mock SNF were weighed prior to the start of each test to establish baseline weights. A measured quantity of water was then added directly to the canister or poured over the assembly, and the lid was sealed. The sealed canister was weighed at least five times to establish the gross weight of the canister, mock SNF, and water. The weight/volume of water added was determined by the weight difference. The vacuum hose and instrumentation cables were connected to the canister after weighing, and data acquisition was initiated upon startup of the vacuum pump. Vacuum immediately stabilized at 25-30 torr as water inside the canister began to boil.

Strip heaters on the mock SNF were operated at 14 or 5 watts during selected tests to simulate heat generating SNF. Heat generation was controlled by regulating the voltage and current on an adjustable power supply.

Temperatures, vacuum, and humidity readings were recorded throughout each test. Drying continued until a vacuum of 1 torr or better was achieved inside the canister indicating all water had been removed. Typical final vacuum was 0.4 to 0.7 torr. The canister was backfilled with room air to atmospheric pressure after completing drying. Hoses and cables were disconnected prior to obtaining a final gross weight.

Condensate on the exterior of the canister and scale platform during nonheated drying tests skewed weights. The scale platform and canister were hand-dried to remove all condensate prior to final weighing for these tests. The canister was opened after drying was completed, the mock SNF was removed, and the canister and assembly were visually inspected to ensure no moisture remained.

Test Matrix

A series of drying tests was conducted over a two week period with varying initial quantities of water and heat inputs to obtain baseline drying performance data. The water content inside the test canister varied from 15 to 689 ml. The 300 milliliter tests equate to ~1 inch of standing water (0.6 pint) inside the canister, and the 450 milliliter tests equate to ~1-1/2 inches of standing water (1.5 pints) inside the canister. The actual instrumented test canisters are expected to retain 1/2 to 1 inch of water after the SNF is loaded and the bulk water is pumped out. The power input to the test varied from 0.0 to 14 watts, compared to an estimated decay heat from a spent MTR fuel assembly of 1 watt. The results from the high power input conditions provide information to improve the drying time when the vacuum dry system is used to dry the MTR fuel assemblies. Short duration drying tests with a dry assembly, damp assembly, and dripping assembly were also conducted to provide reference data. Table III-1 lists the major test matrix.

Test Results

Appendix 1 contains the field procedure with data collected. Drying tests with the mock MTR assembly demonstrated that vacuum drying is feasible for the two shielded, instrumented canisters after loading SNF. The general configuration of the vacuum pump, hose, and instrumentation was satisfactory.

The parameters measured during the vacuum test were pressure, temperature and relative humidity inside the canister, pressure in the vacuum hose and weight of the test assembly.

Figures III-8 to III-13 show measured pressure transients. It was found that air inside the canister was sucked out rapidly when the vacuum pump was turned on. This was indicated by a sharp pressure drop inside the canister. After this initial pressure drop, the pressure inside the canister remained constant at an equilibrium value determined by the rate of evaporation of water inside the canister and the rate of evacuation of vapor by the vacuum pump. The pressure inside the canister experienced another sharp drop when the canister became dry and no more water could evaporate to make up for the vapor that was evacuated. This same pressure drop pattern was observed at the vacuum hose line, except that the pressures there were lower than inside the canister.

Figures III-14 to III-19 depict relative humidities inside the canister. The initial drop of the relative humidity indicates that the vacuum suction was sufficient to control the vapor content inside the canister. After the pump evacuated the initial vapor in the canister, the relative humidity inside the canister remained at a constant level controlled by the evaporation and evacuation rates. The relative humidity dropped sharply when the water inside the canister was depleted.

Figures III-20 to III-25 compare measured temperatures and pressures inside the canister. The temperature inside the canister dropped as the water evaporated due to the heat of vaporization (~1000 Btu per pound of water). When the water inside the canister became depleted, evaporation ceased, and the temperature inside the canister increased due to ambient heat transfer and the power input. The rate of temperature increase for powered tests was higher than that for unpowered tests.

A thermocouple taped to the canister exterior below the internal water level was monitored during selected tests. Figures III-26 to III-28 compare these measured exterior temperatures with pressures inside the canister. Initially, the canister exterior temperature decreased due to heat transfer into the canister. Later, this temperature returned to ambient levels after evaporation inside the canister ceased. For the unpowered tests, the canister exterior temperature was below ~5°C and condensation occurred on the exterior surface. Condensate accumulated on the scale surface and ran off onto the floor.

For the unpowered test with 461 ml water added to the canister, four pieces of napkin were placed on the scale to prevent condensate from running off. The amount of condensate collected was 0.09 lb, which accounts for a transfer of 4 watts to the canister due to condensation.

Figures III-29 to III-34 show the measured weight during the vacuum process. This weight includes canister, mock fuel, water, condensate and forces from hose connection and instrumentation lines.

Figure III-35 shows that the drying time decreased when heat was applied to the mock fuel assembly and increased when the amount of water added to the canister increased.

Recommendations for Instrumented SNF Drying

Figures III-8 to III-28 show that any of the measurements (pressure, relative humidity and temperature) could be used as an indication of dryness during the vacuum dry process. To

minimize personnel radiation exposure and design complications, the pressure measurement on the vacuum hose is recommended to monitor dryness for vacuum drying of irradiated SNF.

Drying tests using the shielded SNF canisters and the mock MTR assembly are planned prior to loading irradiated SNF. The Saphir SES02 assembly proposed for loading into one of the canisters has a very low heat output (~1 watt), which suggests that drying of this assembly could be expedited by external heating. Simple concepts such as a warm air purge also will be evaluated.

Thermocouples within the instrumented canisters are intended for long-term monitoring after drying is completed. Consideration will be given to using thermocouple data to confirm dryness.

Acknowledgments

The following individuals contributed to the success of this work: D. J. Pak for vacuum canister design and oversight of fabrication by the 717-A, 749-A shops; P. J. French for canister design and preparation of the field procedure; R. F. Eakle for sensor system design, fabrication, and calibration; C. S. Stripling for calibrations, photographs, and test support; and G. Reeves for sensor data logging.

References for Part III

1. **WSRC-TR-97-0075**, "Review of Drying Methods for Spent Nuclear Fuel (U)," W. S. Large and R. L. Sindelar, Westinghouse Savannah River Co. report, April 1997.
2. **SRS-SNF-970064**, "Trip Report - SNF Drying Review at INEEL," W. S. Large, May 28, 1997.

Table III-1 Test Matrix and Measured Drying Time

Water Volume in Canister (ml)	Heat Input (Watt)	Drying Duration (Minute)
14.3	14.0	6
15.5	0.0	27
300	14.0	230
448	14.0	378
297	4.8	290
297	0.0	348
461	0.0	518
689	0.0	779

Figure III-1 Vacuum canister and electrically-heated fuel mock-up

Figure III-2 Stand to hold vacuum canister. Note the scale on which the canister rests.

Figure III-3 Assembled Canister in a Test

Figure III-4 Assembly inside the Canister

Figure III-5 Post Test Canister Interior

Figure III-6 Vacuum Pump

Figure III-7 Test Loop (Not to scale) **Figure III-8 Measured Vacuum Pressure (300 ml, 14 Watts, 8/19/87)**

Figure III-9 Measured Vacuum Pressure (448 ml, 14 Watts, 8/20/87)

Figure III-10 Measured Vacuum Pressure (297 ml, 4.8 Watts, 8/21/87)

Figure III-11 Measured Vacuum Pressure (297 ml, 0.0 Watts, 8/25/87)

Figure III-12 Measured Vacuum Pressure (461 ml, 0.0 Watts, 8/27/87)

Figure III-13 Measured Vacuum Pressure (689 ml, 0.0 Watts, 8/28/87)

Figure III-14 Measured Relative Humidity inside the Canister (300 ml, 14 Watts, 8/19/97)

Figure III-15 Measured Relative Humidity inside the Canister (448ml, 14 Watts, 8/20/97)

Figure III-16 Measured Relative Humidity inside the Canister (297ml, 4.8 Watts, 8/21/97)

Figure III-17 Measured Relative Humidity inside the Canister (297ml, 0.0 Watts, 8/25/97)

Figure III-18 Measured Relative Humidity inside the Canister (461ml, 0.0 Watts, 8/27/97)

Figure III-19 Measured Relative Humidity inside the Canister (689 ml, 0.0 Watts, 8/28/97)

Figure III-20 Measured Temperature inside the Canister (300 ml, 14 Watts, 8/19/97)

Figure III-21 Measured Temperature inside the Canister (448 ml, 14 Watts, 8/20/97)

Figure III-22 Measured Temperature inside the Canister (297 ml, 4.8 Watts, 8/21/97)

Figure III-23 Measured Temperature inside the Canister (297 ml, 0.0 Watts, 8/25/97)

Figure III-24 Measured Temperature inside the Canister (461 ml, 0.0 Watts, 8/27/97)

Figure III-25 Measured Temperature inside the Canister (689 ml, 0.0 Watts, 8/28/97)

Figure III-26 Measured Temperature at the Bottom of Canister Outer Surface (297 ml, 0.0 Watts, 8/25/97)

Figure III-27 Measured Temperature at the Bottom of Canister Outer Surface (461 ml, 0.0 Watts, 8/27/97)

Figure III-28 Measured Temperature at the Bottom of Canister Outer Surface (689 ml, 0.0 Watts, 8/28/97)

Figure III-29 Measured Total Weight (300 ml, 14 Watts, 8/19/97)

Figure III-30 Measured Total Weight (448 ml, 14 Watts, 8/20/97)

Figure III-31 Measured Total Weight (297 ml, 4.8 Watts, 8/21/97)

Figure III-32 Measured Total Weight (297 ml, 0.0 Watts, 8/25/97)

Figure III-33 Measured Total Weight (461 ml, 0.0 Watts, 8/27/97)

Figure III-34 Measured Total Weight (689 ml, 0.0 Watts, 8/28/97)

Figure III-35 Measured Drying Duration as a Function of Water Content inside the Canister and Power Input

Appendix 1 to WSRC-TR-97-00269

Dry Monitored Storage Canister Shielding (U)
Calculation Set No. N-CLC-L-00009
by S. J. Nathan

Calculation Cover Sheet

Project SPENT NUCLEAR FUEL		Calculation Number N-CLC-L-00009	Project Number N/A
Title DRY MONITORED STORAGE CANISTER SHIELDING (U)		Functional Classification N/A	Sheet 1 of 50
		Discipline NUCLEAR	
☐ Preliminary ☒ Committed ☐ Confirmed			
Computer Program No. (s) SCALE ☐ N/A		Version/Release No. 4.3 (PC and Workstation)	
Purpose and Objective The purpose of this Engineering Calculation is to estimate the dose rates and shielding requirements for MTR fuel assemblies in dry storage. This calculation is in support of the preliminary design for dry storage of up to two instrumented MTR assemblies to allow for long term monitoring. This is a follow on to work previously performed by Reuben Rainisch.			
Summary of Conclusion The dose rates as a function of lead and steel shielding have been calculated for High Flux Beam Reactor (HFBR) and Rhode Island Atomic Energy Commission (RIAEC) fuel assemblies. The dose rate at the surface of the fuel assembly is 1.2E+04 rem/hr for HFBR fuel, and 1.4E+03 rem/hr for RIAEC fuel. The shielding required to reduce the dose at the surface of the test canister to less than 200 mrem/hr is 4 inches of lead. It is recommended that this be increased to 4 1/4 inches of lead to accommodate uncertainties in the calculation. The dose rate at the exit of the camera port penetration slightly exceeds the design dose rate. Administrative controls will be required to restrict access during handling of the test canister.			
Revisions			
Rev. No.	Revision Description		
0	Original Issue		
Sign Off			
Rev No.	Originator (Print) Sign / Date	Verification / Checking Method	Verifier / Checker (Print) Sign / Date
0	S. J. Nathan 8/12/97 <i>S. J. Nathan</i>	Independent Technical Review	R. L. Reed 8/12/97 <i>Raymond L Reed</i> J. Brotherton 8/14/97 <i>J. Brotherton</i>
Classification		ADC and Reviewing Official: <i>Steven J. Nathan</i> Steven J. Nathan, Principal Engineer Date: August 12, 1997	
UNCLASSIFIED DOES NOT CONTAIN UNCLASSIFIED CONTROLLED NUCLEAR INFORMATION			

Calculation No.	N-CLC-L-00009
Sheet No.	2 of 50
Rev.	0

DRY MONITORED STORAGE CANISTER SHIELDING

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COMPUTER PROGRAMS USED

NAME	CONFIGURATION CONTROL VERSION	If no, description on page/in reference
SAS2H	Yes	No
ORIGENS	Yes	No
QADS	Yes	No
SAS3	Yes	No

DRY MONITORED STORAGE CANISTER SHIELDING

Introduction:

This Engineering Calculation estimates the dose rates and shielding requirements for Material Test Reactor (MTR) fuel assemblies in dry storage. This calculation is in support of the preliminary design for dry storage of instrumented MTR assemblies to allow for long term monitoring. The assemblies will be stored in test canisters fabricated of steel plates. This is a follow on to work previously performed by Reuben Rainisch [1].

Dose rates are calculated using the QADS module of the SCALE Code System. The assemblies identified as candidates for dry monitoring [2] are from the High Flux Beam Reactor (HFBR) and the Rhode Island Atomic Energy Commission (RIAEC). The HFBR assembly was chosen since it is expected to bound any assembly that could be used in the test. The RIAEC assembly was chosen as representative of lower burnup fuel.

Reference:

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3. Shepherd, G., Appendix A - Agreement, Spent Nuclear Fuel Acceptance Criteria, DOESRAA-96-001, Rev. 0, Brookhaven National Laboratory, Upton, NY. February 8, 1996. Transmitted as an attachment to: Stout, G. W. (PAI), "High Beam Flux Reactor Appendix A," Memorandum to Trent Andes, et al (WSRC), February 21, 1996.
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8. Untitled Sketch of Instrumented Test Canister for Spent Nuclear Fuel obtained from D. J. Pak 6/30/97.
9. Hermann, O. W., and Parks, C. V., "SAS2H: A Coupled One-Dimensional Depletion And Shielding Analysis Module," NUREG/CR-0200, Revision 5, Volume 1, Section S2, (ORNL/NUREG/CSD-2/V2/R5), Draft, Oak Ridge National Laboratory, Oak Ridge, TN, September 1995.
10. Hermann, O. W., and Westfall, R. M., "ORIGEN-S: Scale System Module To Calculate Fuel Depletion, Actinide Transmutation, Fission Product Buildup And Decay, And Associated Radiation Source Terms," NUREG/CR-0200 Revision 5 Volume 2, Section

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F7 (ORNL/NUREG/CSD-2/V2/R5), Draft, Oak Ridge National Laboratory, Oak Ridge, TN. September 1995.

11. SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation," NUREG/CR-0200, Rev. 5.(ORNL/NUREG/CSD-2/R5), Vols. I, II, and III. Final Draft, Oak Ridge National Laboratory, Oak Ridge, TN, January 1997.
12. West, J. T., "SAS3: An Automated Monte Carlo Shielding Analysis Module," NUREG/CR-0200, Revision 5, Volume 1, Section S3 (ORNL/NUREG/CSD-2/V1/R5), Draft, Oak Ridge National Laboratory, Oak Ridge, TN, September 1995.

Input:

The parameters for the HFBR fuel element (plate) and fuel assembly are [3]:

Fuel Plate Data

Element thickness (including clad)	0.127 cm.
Element Active length	57.79 cm
Element width	6.63 cm
Element Active width	5.69 cm
Chemical form of SNM	U ₃ O ₈ blended with Al powder
Dispersing material weight	0.043 kg Al 0.0038 kg O
Clad Material	Al 6061
Clad thickness	0.034 cm
Clad weight	84.5 gm

Assembly Data

Number of Elements per Assembly	18
Assembly Dimensions	
thickness	7.19 cm
width	8.13 cm
cut length	62.23 cm
Assembly Uranium weight	377. gm ^a
Assembly Uranium-235 weight	351. gm ^b
Overall Assembly weight	4.425 kg
Non fuel end plate thickness	0.257 cm
Assembly side plate thickness	0.439 cm

^a Maximum of all assemblies reported in reference 3. Data is for assembly 663

^b Maximum of all assemblies reported in reference 3. Data is for assemblies 513 and 514

 DRY MONITORED STORAGE CANISTER SHIELDING

Irradiation History	
Power Level	2.148 MW ^c
Irradiation Time	55.667 days ^d
Decay Time	4369 days ^e

The parameters for the RIAEC fuel element (plate) and fuel assembly are [4]:

Fuel Plate Data

Element thickness (including clad)	0.06 in
Element width	2.774 in
Element Active length	25 in
Element total weight	190 gm
Element Uranium weight	7.4 gm
Element Uranium-235 weight	6.88 gm
Chemical form of SNM	U and Al
Clad Material	Al 6061
Clad thickness	0.024 in

Assembly Data

Number of Elements per Assembly	18
Assembly Dimensions	
thickness	3 in
width	3 in
length	25 in
Overall Assembly weight	4.661 kg
Side plate thickness	0.187 in
Irradiation History	
Power Level	8 kW (estimated)
Irradiation Time	1793 days
Decay Time	6 years

^c Maximum of all assemblies reported in reference 3. Data is for assembly 621

^d Maximum of all assemblies reported in reference 3. Data is for assemblies 584 through 597

^e Minimum of all assemblies reported in reference 3. Data is for assemblies 596 and 640. Data is adjusted from values in reference 3 by adding 540 days (18 months * 30 days/month) to account for time from 1/1/96 to 7/1/97.

DRY MONITORED STORAGE CANISTER SHIELDING

The composition of Aluminum 6061 is [5]:

Element	Weight Percent
Al	95.925
Mg	1.0
Cu	0.275
Fe	0.7
Si	0.6
Mn	1.5
Z	0.25

The test canister dimensions are [6, 7, 8]:

Description	Dimension (inches)
Outer width	27½
Side Wall thickness	8
Height of main canister	37¾
Bottom Thickness	8
Top Plate Thickness	2
Lid	8
Camera Port Shield Height	12½
Camera Port Shield Depth	13½
Camera Port Tube OD	4
Camera Port Tube Wall Thickness	0.085
Camera Port Tube Center Line (Relative to base of Cavity)	7.875
Fuel Base (Relative to base of Cavity)	0.12

Assumptions:

- The RIAEC fuel is operated at 8 kW power. This is based on averaging the power level calculated from the time in reactor and the burnup.

Open Items

The following open items must be certified by the customer before this calculation can be confirmed:

- The selection of fuel assemblies to be used in the test canisters.

DRY MONITORED STORAGE CANISTER SHIELDING

- The dose criterion for selecting shielding thickness (currently assumed to be 200 mrem/hr based on shipping cask limits).
- The drawings used for canister details [6, 7, and 8] are preliminary or sketches.

Analytical Methods and Calculations:

The SCALE Code System will be used to determine the source term and the photon transport for a single fuel assembly. Calculations of dose rate are performed using the ANSI Standard dose conversion factors that are provided with the cross-section libraries.

The fuel properties presented above were used in a MATHCAD worksheet (Appendix A and B) to develop input for the SAS2H module of the SCALE Code System [9]. The following description of SAS2H is excerpted from reference 9.

Using a prescribed reactor history and cooling time, the SAS2H module is able to determine the spent fuel characteristics (isotopics, heat generation, and radiation sources). Nuclide compositions are computed for a specified reactor assembly, which is allowed to decay for a given cooling time after discharge. The subsequent gamma source includes radiation from fission products, activation products of both the fuel and structural materials, and (n, γ) reactions resulting from neutrons produced by some of the heavy isotopes. The neutron source includes neutrons from spontaneous fission and (α ,n) reactions with oxygen isotopes.

The fuel assembly model used for SAS2 is shown schematically in Figure 1.

The decay of the products of the fuel irradiation was calculated using the ORIGEN-S module of the SCALE Code System [10]. The following description of ORIGEN-S is excerpted from reference 10.

ORIGEN-S computes time-dependent concentrations and source terms of a large number of isotopes, which are simultaneously generated or depleted through neutronic transmutation, fission, radioactive decay, input feed rates, and physical or chemical removal rates. The calculations may pertain to fuel irradiation within nuclear reactors, or the storage, management, transportation, or subsequent chemical processing of removed fuel elements. The matrix exponential expansion model of the ORIGEN code is unaltered in ORIGEN-S. Essentially all features of ORIGEN were retained, expanded, or supplemented within new computations.

The assembly data were also used to develop input for the QADS module of the SCALE Code System [11]. The following description of QADS is excerpted from reference 11.

The QADS module analyzes three-dimensional gamma-ray shielding problems using point kernel techniques.

The QADS model is shown schematically in Figure 2.

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The canister data were used to develop inputs for the SAS3 (MORSE) module of the SCALE Code System [12]. The following description of SAS3 is excerpted from reference 12.

SAS3 is the SCALE Shielding Analytical Sequence for three-dimensional geometry problems. The system incorporates the input and cross-section processing capabilities found in CSAS with the radiation transport capabilities of the MORSE-SGC Monte Carlo code. Three-dimensional geometry features of the combinatorial MARS (Multiple Array System) package can be used within the MORSE model specification. The SAS3 control module executes in sequence BONAMI, NITAWL-II, XSDRNPM (optionally), ICE, and the MORSE-SGC codes.

The canister model is shown in Figures 3 through 6. Figure 3 shows the actual layout of the canister. Figure 4 shows the simplified model used to make geometry setup tractable. This model retains the important geometric features while allowing the use of simple geometric shapes for the bodies in MORSE. Figures 5 and 6 are prepared using the SCALE Picture utility that draws sections through the geometry based on the MARS input data. This model was used specifically to calculate the streaming through the camera port penetration.

Biasing is required to facilitate computation in reasonable time when using Monte Carlo techniques. SAS3 implements several techniques for biasing as described in Reference 12. The biasing used is based on empirical considerations:

- Biasing region 1 includes the fuel assembly, the air gap, the internal void (region outside the shield and penetration) and the shield region immediately surrounding the bend in the penetration, and an annular region 2 inches thick around the first leg of the penetration. No splitting is allowed, no path length stretching is performed, russian roulette is played with WTLO=0.2, and WTAVE=1.0.
- Biasing region 2 includes the first leg of the penetration, and the duct surrounding it. Splitting is allowed with WTHIGH=0.5, path length stretching is performed along the axis of the penetration (positive x direction, russian roulette is played with WTLO=0.02, and WTAVE=0.1.
- Biasing region 3 includes most of the shield material. No splitting is allowed, no path length stretching is performed, russian roulette is played with WTLO= 10^{34} , and WTAVE= 10^3 (essentially no particles survive entering these zones).
- Biasing region 4 includes the second leg of the penetration and the duct surrounding it. Splitting is allowed with WTHIGH=0.5, no path length stretching is performed, russian roulette is played with WTLO=0.02, and WTAVE=0.1

The SAS2H and QADS calculations were performed using the PC-SCALE versions of the codes. The SAS3 calculations were performed on the UNIX workstation because of the length of the runs. Input Files for all cases are presented in Appendix C.

DRY MONITORED STORAGE CANISTER SHIELDING

File Name	Description
hfbra	SAS2H and ORIGENS input file for HFBR assembly irradiation and decay calculation
hfbra1	QADS input file for HFBR assembly with steel shield
hfbrb1	QADS input file for HFBR assembly with lead shield
riaec	SAS2H input file for RIAEC assembly irradiation calculation
driaec.in	ORIGENS input file for RIAEC assembly decay
riaecqad.in	QADS input file for RIAEC assembly with lead shield
riaecqada.in	QADS input file for RIAEC assembly with lead shield additional points
riaecss.in	QADS input file for RIAEC assembly with steel shield
riaecssa.in	QADS input file for RIAEC assembly with steel shield additional points
sas3ssb	SAS3 input file for HFBR assembly in canister with penetration
sspic	PICTURE input file for plan view on penetration midplane
sspic1	PICTURE input file for cross section on penetration axis

Files with the suffix "out" appended or replacing the suffix "in" are the respective output files for each case. Pictures are stored as file00.gif where file is the input file name.

Files on the UNIX workstation are located in directory /afs/srtc.srs.gov/u3/s8033/snf/mtrsnf. Files on the PC are located in a "zipped" archive canister.zip in directory c:/snf/mtr/monitor on the author's computer.

DRY MONITORED STORAGE CANISTER SHIELDING

Results:

The photon source for HFBR Fuel as calculated using ORIGEN-S is:

GAMMA SOURCE SPECTRUM FOR HFBR FUEL TIMESTEP 3

4369.00 DAY TIME OF THE REQUESTED NUCLIDES

ENERGY INTERVAL IN MEV		PHOTONS / SECOND	MEV / SECOND
1.0000E-02 TO	5.0000E-02	6.5398E+12	1.9619E+11
5.0000E-02 TO	1.0000E-01	1.9000E+12	1.4250E+11
1.0000E-01 TO	2.0000E-01	1.3030E+12	1.9545E+11
2.0000E-01 TO	3.0000E-01	4.0937E+11	1.0234E+11
3.0000E-01 TO	4.0000E-01	2.8996E+11	1.0149E+11
4.0000E-01 TO	6.0000E-01	3.1576E+11	1.5798E+11
6.0000E-01 TO	8.0000E-01	9.3438E+12	6.5407E+12
8.0000E-01 TO	1.0000E+00	1.0549E+11	9.4942E+10
1.0000E+00 TO	1.3300E+00	6.6389E+10	7.7343E+10
1.3300E+00 TO	1.6600E+00	9.2508E+09	1.3830E+10
1.6600E+00 TO	2.0000E+00	7.6385E+08	1.3978E+09
2.0000E+00 TO	2.5000E+00	1.3844E+08	3.1148E+08
2.5000E+00 TO	3.0000E+00	1.8252E+06	5.0194E+06
3.0000E+00 TO	4.0000E+00	2.1918E+05	7.6712E+05
4.0000E+00 TO	5.0000E+00	8.0440E+00	3.6198E+01
5.0000E+00 TO	6.5000E+00	3.1387E+00	1.8047E+01
6.5000E+00 TO	8.0000E+00	5.9997E-01	4.3498E+00
8.0000E+00 TO	1.0000E+01	1.2510E-01	1.1259E+00
TOTALS		2.0284E+13	7.6243E+12

TOTAL ENERGY FROM NUCLIDES WITH SPECTRUM DATA = 7.6243E+12

TOTAL ENERGY FROM NUCLIDES WITH NO SPECTRUM DATA = 2.5866E+06

The photon source for RIAEC Fuel as calculated using ORIGEN-S is:

GAMMA SOURCE SPECTRUM FOR RIAEC FUEL TIMESTEP 3

7.00 YEAR TIME OF THE REQUESTED NUCLIDES

ENERGY INTERVAL IN MEV		PHOTONS / SECOND	MEV / SECOND
1.0000E-02 TO	5.0000E-02	8.7280E+11	2.6184E+10
5.0000E-02 TO	1.0000E-01	2.5496E+11	1.9122E+10
1.0000E-01 TO	2.0000E-01	1.7456E+11	2.6184E+10
2.0000E-01 TO	3.0000E-01	5.4142E+10	1.3536E+10
3.0000E-01 TO	4.0000E-01	3.8956E+10	1.3635E+10
4.0000E-01 TO	6.0000E-01	4.3195E+10	2.1598E+10
6.0000E-01 TO	8.0000E-01	1.1998E+12	8.3984E+11
8.0000E-01 TO	1.0000E+00	1.1272E+10	1.0145E+10
1.0000E+00 TO	1.3300E+00	5.4787E+09	6.3827E+09
1.3300E+00 TO	1.6600E+00	1.2234E+09	1.8290E+09
1.6600E+00 TO	2.0000E+00	1.3008E+08	2.3804E+08
2.0000E+00 TO	2.5000E+00	2.2874E+08	5.1467E+08
2.5000E+00 TO	3.0000E+00	2.0241E+06	5.5662E+06
3.0000E+00 TO	4.0000E+00	2.3299E+05	8.1547E+05
4.0000E+00 TO	5.0000E+00	1.4522E-01	6.5351E-01
5.0000E+00 TO	6.5000E+00	5.6830E-02	3.2677E-01
6.5000E+00 TO	8.0000E+00	1.0893E-02	7.8976E-02
8.0000E+00 TO	1.0000E+01	2.2758E-03	2.0482E-02
TOTALS		2.6567E+12	9.7921E+11

TOTAL ENERGY FROM NUCLIDES WITH SPECTRUM DATA = 9.7921E+11

TOTAL ENERGY FROM NUCLIDES WITH NO SPECTRUM DATA = 4.5490E+05

 DRY MONITORED STORAGE CANISTER SHIELDING

The QADS calculated dose rate on the mid-plane near the surface^f of the fuel assemblies with steel buildup factors is:

Assembly	Dose Rate (Rem/hr)
HFBR	1.43E+04
RIAEC	1.64E+03

The QADS calculated dose rate as a function of shield thickness is given in the tables below, and is plotted in Figures 2 and 3. The dose point is located at the surface of the shield on the fuel mid-plane.

Lead Shielding

T	DOSE RATE (REM/HR)	
	HFBR	RIAEC
0	2.96E+03	3.66E+02
1	1.32E+02	1.46E+01
2	6.57E+00	7.66E-01
3	4.68E-01	5.17E-02
4	4.34E-02	5.24E-03
5	6.21E-03	8.06E-04
6	1.07E-03	1.58E-04
7	2.02E-04	3.49E-05
8	4.21E-05	8.17E-06
9	8.63E-06	1.98E-06
10	1.94E-06	4.94E-07

^f Actual dose point is located 4.1 cm from the assembly center line. This corresponds to 0.013 cm from the surface of HFBR fuel, and 0.29 cm from the surface of RIAEC fuel.

DRY MONITORED STORAGE CANISTER SHIELDING

Steel Shielding

T	DOSE RATE (REM/HR)	
	HFBR	RIAEC
0	3.50E+03	4.31E+02
1	1.10E+03	1.31E+02
2	2.92E+02	3.46E+01
3	7.91E+01	9.32E+00
4	2.00E+01	2.35E+00
5	5.30E+00	6.22E-01
6	1.37E+00	1.61E-01
7	3.52E-01	4.12E-02
8	9.34E-02	1.10E-02
9	2.37E-02	2.80E-03
10	6.43E-03	7.71E-04
11	1.74E-03	2.13E-04
12	4.79E-04	6.14E-05
13	1.36E-04	1.86E-05
14	4.00E-05	5.94E-06
15	1.22E-05	2.01E-06

It should be noted that the difference in the dose rates at zero thickness (inner surface of the shield) is due to the use on single material buildup factors in QADS. That is the lead shield case uses lead buildup factors in all regions including the fuel assembly, while the steel shield case used iron buildup factors. This difference is not significant for optically thick shields since the buildup in the shield is the controlling factor.

DRY MONITORED STORAGE CANISTER SHIELDING

The SAS3 calculated dose rate at the exit from the camera port penetration (normalized to one source photon per second) is:

ANSI standard gamma dose rate (rem per hour)				
detector	uncollided		total	
	response	fsd [§]	response	fsd
1	1.20E-17	0.0021	1.05E-14	0.08313
2	1.38E-17	0.0020	1.51E-14	0.70138
3	1.53E-18	0.0039	1.06E-14	0.03827

The dose points are located (1) on the axis of the penetration at the exit, (2) at the outer radius of the penetration at the exit, and (3) at the outer radius of the penetration near the shield wall.

The total dose rate at the exit from the camera port penetration (above values multiplied by the 2.03E13 photons per second for HFBR fuel) is:

ANSI standard gamma dose rate (rem per hour)				
detector	uncollided		total	
	response	fsd	response	fsd
1	2.43E-04	0.00216	2.14E-01	0.08313
2	2.79E-04	0.00198	3.07E-01	0.70138
3	3.10E-05	0.00387	2.16E-01	0.03827

[§] fsd is the fractional standard deviation of the result.

DRY MONITORED STORAGE CANISTER SHIELDING

Conclusion:

The dose rates as a function of lead and steel shielding have been calculated. Based on these data, it will be possible to provide shielding requirements when target dose rates are specified.

For instance, the shielding required to meet the dose limits for various occupancy areas with one HFBR assembly would be:

Zone	Designation	Dose Rate Limit ^h	Required Shielding	
		(mrem h ⁻¹)	In. Lead	In. Steel
1	General Public	< 0.05	8½	14
2		< 0.25	7¾	12¾
3	Radiation Area	< 5.0	6	10½
4	High Radiation Area	< 100.0	4½	8
5	Very High Rad. Area	< 500 rad h ⁻¹	N/A	N/A
	Design Dose Rate	< 200	4	7½

The shielding required for one RIAEC assembly would be:

Zone	Designation	Dose Rate Limit	Required Shielding	
		(mrem h ⁻¹)	In. Lead	In. Steel
1	General Public	< 0.05	7	12¾
2		< 0.25	6¼	11¼
3	Radiation Area	< 5.0	4¾	8¾
4	High Radiation Area	< 100.0	3¼	6½
5	Very High Rad. Area	< 500 rad h ⁻¹	N/A	N/A
	Design Dose Rate	< 200.0	3	6

The HFBR fuel assembly governs the shielding requirements. For the postulated design dose rate of 200 mrem/hr at the surface, it is recommended that 8 inches of steel or 4¼ inches of lead be used as the design shielding thickness to accommodate uncertainties in the shielding analysis.

The dose rate at the exit of the camera port penetration slightly exceeds the design dose rate. Administrative controls will be required to restrict access during handling of the test canister.

^h The dose rate limit is at the outer surface of the shield wall.

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DRY MONITORED STORAGE CANISTER SHIELDING

Figure 1 Homogenized HFBR Fuel Assembly

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DRY MONITORED STORAGE CANISTER SHIELDING

Figure 2 Schematic of QAD Geometry

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DRY MONITORED STORAGE CANISTER SHIELDING

Figure 3 Schematic of Actual Canister Arrangement

DRY MONITORED STORAGE CANISTER SHIELDING

Figure 4 Schematic of Simplified Canister Arrangement

DRY MONITORED STORAGE CANISTER SHIELDING

Figure 5 Plan View at Mid-Plane of Camera Port Penetration

Figure 6 Cross Section on Center of Camera Port Penetration

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Figure 7 Lead Shielding

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Figure 8 Steel Shielding

DRY MONITORED STORAGE CANISTER SHIELDING

Appendix A HFBR MATHCAD Worksheet

cc mL

HFBR FUEL

Input Data

Element Data

<u>Parameter</u>	<u>Description</u>
$l_{\text{fuel}} = 58.05 \cdot \text{cm}$	Active Fuel Length
$w_{\text{plate}} = 6.63 \cdot \text{cm}$	Width of plate (fuel and clad)
$w_{\text{fuel}} = 5.69 \cdot \text{cm}$	Width of fuel region
$t_{\text{plate}} = 0.127 \cdot \text{cm}$	Thickness of plate (fuel and clad)
$l_{\text{plate}} = 23.75 \cdot \text{in}$	Length of plate
$t_{\text{clad}} = 0.034 \cdot \text{cm}$	Thickness of Clad
$n_{\text{plates}} = 18$	Number of fuel plates per assembly
$m_{\text{Uassy}} = 377 \cdot \text{gm}$	Mass of Uranium per assembly
$m_{\text{U}} = \frac{m_{\text{Uassy}}}{n_{\text{plates}}}$	Mass of Uranium per plate
$m_{\text{U}} = 20.944444 \cdot \text{gm}$	
$m_{235\text{assy}} = 351 \cdot \text{gm}$	Mass of U-235 per assembly
$m_{235} = \frac{m_{235\text{assy}}}{n_{\text{plates}}}$	Mass of U-235 per plate
$m_{235} = 19.5 \cdot \text{gm}$	
$m_{\text{O}} = 3.8 \cdot \text{gm}$	Mass of Oxygen in fuel
$m_{\text{fill}} = 43 \cdot \text{gm}$	Mass of aluminum fill
$m_{\text{clad}} = 84.5 \cdot \text{gm}$	Mass of aluminum clad

DRY MONITORED STORAGE CANISTER SHIELDING

Assembly Data

Parameter	Description
$w_{assy} = 8.13 \cdot cm$	Width of assembly
$m_{assy} = 4.425 \cdot kg$	Mass of assembly
$t_{end} = 0.257 \cdot cm$	Thickness of end plate
$t_{assy} = 7.19 \cdot cm$	Transverse (outer) dimension of assembly
$t_{side} = 0.439 \cdot cm$	Side plate thickness
$t_{chan} = 0.1 \cdot in$	Water channel thickness

Calculated Data

Element Data

$$\begin{aligned}
 t_{fuel} &= t_{plate} - 2 \cdot t_{clad} & t_{fuel} &= 0.059 \cdot cm \\
 vol_{fuel} &= l_{fuel} w_{fuel} t_{fuel} & vol_{fuel} &= 19.487966 \cdot cc \\
 vol_{clad} &= l_{plate} \cdot 2 \cdot (w_{plate} - t_{fuel}) \cdot t_{clad} & vol_{clad} &= 27.438947 \cdot cc \\
 m_{fuel} &= m_U - m_O - m_{fill} & m_{fuel} &= 67.744444 \cdot gm \\
 m_{plate} &= m_{fuel} - m_{clad} & m_{plate} &= 152.244444 \cdot gm \\
 \rho_{fuelU} &= \frac{m_U}{vol_{fuel}} & \rho_{fuelU} &= 1.074737 \cdot \frac{gm}{cc} \\
 \rho_{fuelO} &= \frac{m_O}{vol_{fuel}} & \rho_{fuelO} &= 0.194992 \cdot \frac{gm}{cc} \\
 \rho_{fuelAl} &= \frac{m_{fill}}{vol_{fuel}} & \rho_{fuelAl} &= 2.20649 \cdot \frac{gm}{cc} \\
 \rho_{fuel} &= \frac{m_{fuel}}{vol_{fuel}} & \rho_{fuel} &= 3.476219 \cdot \frac{gm}{cc}
 \end{aligned}$$

Calculation No.	N-CLC-L-00009
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DRY MONITORED STORAGE CANISTER SHIELDING

Fraction of Uranium in homogenized fuel and bonding

$$wf_U = \frac{\rho_{fuelU}}{\rho_{fuel}} \quad wf_U = 0.309168$$

Fraction of Aluminum in homogenized fuel and bonding

$$wf_{Al} = \frac{\rho_{fuelAl}}{\rho_{fuel}} \quad wf_{Al} = 0.634738$$

Fraction of Oxygen in homogenized fuel and bonding

$$wf_O = \frac{\rho_{fuelO}}{\rho_{fuel}} \quad wf_O = 0.056093$$

Isotopic weight fractions

$$wf_{235} = \frac{m_{235}}{m_U} \quad wf_{235} = 0.931034$$

$$wf_{238} = 1 - wf_{235} \quad wf_{238} = 0.068966$$

Volume of fuel for input to SAS2

$$volume = n_{plates} \cdot vol_{fuel} \quad volume = 350.783379 \cdot mL$$

$$pitch = t_{plate} - t_{chan} \quad pitch = 0.381 \cdot cm$$

$$m_{light} = m_{assy} - n_{plates} \cdot m_{plate} \quad m_{light} = 1.6846 \cdot kg$$

 DRY MONITORED STORAGE CANISTER SHIELDING

Assembly Data

Smeared assembly without side plates

Transvers dimension of fueled region

$$w_{\text{fuelassy}} := n_{\text{plates}} \left[t_{\text{plate}} + (t_{\text{chan}}) \right] - t_{\text{chan}}$$

$$w_{\text{fuelassy}} = 6.604 \cdot \text{cm}$$

$$\text{vol}_{\text{assy}} := (w_{\text{fuelassy}}) \cdot w_{\text{fuel}} \cdot l_{\text{fuel}}$$

$$\text{vol}_{\text{assy}} = 2.181331 \cdot 10^3 \cdot \text{mL}$$

$$m_{\text{Al}} := (m_{\text{clad}} + m_{\text{fill}}) \cdot n_{\text{plates}}$$

$$m_{\text{Al}} = 2.295 \cdot 10^3 \cdot \text{gm}$$

$$m_{\text{Oassy}} := m_{\text{O}} \cdot n_{\text{plates}}$$

$$m_{\text{Oassy}} = 68.4 \cdot \text{gm}$$

$$m_{\text{fuelassy}} := m_{\text{Al}} + m_{\text{Uassy}} + m_{\text{Oassy}}$$

$$m_{\text{fuelassy}} = 2.7404 \cdot 10^3 \cdot \text{gm}$$

$$\rho_{\text{assy}} := \frac{m_{\text{fuelassy}}}{\text{vol}_{\text{assy}}}$$

$$\rho_{\text{assy}} = 1.256297 \cdot \frac{\text{gm}}{\text{mL}}$$

$$wf_{\text{Ala}} := \frac{m_{\text{Al}}}{m_{\text{fuelassy}}}$$

$$wf_{\text{Ala}} = 0.837469$$

$$wf_{\text{Ua}} := \frac{m_{\text{Uassy}}}{m_{\text{fuelassy}}}$$

$$wf_{\text{Ua}} = 0.137571$$

$$wf_{\text{Oa}} := \frac{m_{\text{Oassy}}}{m_{\text{fuelassy}}}$$

$$wf_{\text{Oa}} = 0.02496$$

Calculation No. N-CLC-L-00009
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DRY MONITORED STORAGE CANISTER SHIELDING

Smeared Cylindrical Regions

Smeared cylinder fuel region

$$r_{\text{cyl}} = \frac{w_{\text{fuel}} w_{\text{fuelassy}}}{\pi}$$

$$r_{\text{cyl}} = 3.458476 \cdot \text{cm}$$

Smeared Assembly

$$w_{\text{in}} = w_{\text{assy}} - 2 \cdot t_{\text{end}}$$

$$w_{\text{in}} = 7.616 \cdot \text{cm}$$

$$t_{\text{in}} = t_{\text{assy}} - 2 \cdot t_{\text{side}}$$

$$t_{\text{in}} = 6.312 \cdot \text{cm}$$

$$r_{\text{in}} = \frac{w_{\text{in}} t_{\text{in}}}{\pi}$$

$$r_{\text{in}} = 3.911758 \cdot \text{cm}$$

$$r_{\text{out}} = \frac{w_{\text{assy}} t_{\text{assy}}}{\pi}$$

$$r_{\text{out}} = 4.313549 \cdot \text{cm}$$

Calculation No. N-CLC-L-00009
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DRY MONITORED STORAGE CANISTER SHIELDING

Appendix B RIAEC MATHCAD Worksheet

cc = mL

Input Data

RIAEC fuel

$$\begin{aligned}
 l_{\text{fuel}} &= 25 \text{ in} & w_{\text{fuel}} &= 2.774 \text{ in} & t_{\text{plate}} &= 0.06 \text{ in} & t_{\text{clad}} &= 0.024 \text{ in} \\
 n_{\text{plates}} &= 18 & w_{\text{assy}} &= 3 \text{ in} & t_{\text{side}} &= 0.187 \text{ in} & m_{\text{assy}} &= 4.661 \text{ kg} \\
 m_U &= 7.4 \text{ gm} & m_{\text{plate}} &= 190 \text{ gm} & m_O &= 0 \text{ gm} & m_{235} &= 6.88 \text{ gm} & \rho_{\text{al}} &= 2.7 \frac{\text{gm}}{\text{cc}}
 \end{aligned}$$

Calculated Data

$$\begin{aligned}
 t_{\text{fuel}} &= t_{\text{plate}} + 2 \cdot t_{\text{clad}} & t_{\text{fuel}} &= 0.03048 \text{ cm} \\
 vol_{\text{fuel}} &= l_{\text{fuel}} \cdot w_{\text{fuel}} \cdot t_{\text{fuel}} & vol_{\text{fuel}} &= 13.637319 \text{ cc} \\
 vol_{\text{clad}} &= 2 \cdot t_{\text{clad}} \cdot l_{\text{fuel}} \cdot w_{\text{fuel}} & vol_{\text{clad}} &= 54.549259 \text{ cc} \\
 m_{\text{clad}} &= \rho_{\text{al}} \cdot vol_{\text{clad}} & m_{\text{clad}} &= 147.282998 \text{ gm} \\
 m_{\text{fill}} &= m_{\text{plate}} + m_{\text{clad}} + m_U + m_O & m_{\text{fill}} &= 35.317002 \text{ gm} \\
 m_{\text{fuel}} &= m_{\text{plate}} - m_{\text{clad}} & m_{\text{fuel}} &= 42.717002 \text{ gm} \\
 \rho_{\text{fuelU}} &= \frac{m_U}{vol_{\text{fuel}}} & \rho_{\text{fuelU}} &= 0.542629 \frac{\text{gm}}{\text{cc}} \\
 \rho_{\text{fuelO}} &= \frac{m_O}{vol_{\text{fuel}}} & \rho_{\text{fuelO}} &= 0 \frac{\text{gm}}{\text{cc}} \\
 \rho_{\text{fuelAl}} &= \frac{m_{\text{fill}}}{vol_{\text{fuel}}} & \rho_{\text{fuelAl}} &= 2.589733 \frac{\text{gm}}{\text{cc}} \\
 \rho_{\text{fuel}} &= \frac{m_{\text{fuel}}}{vol_{\text{fuel}}} & \rho_{\text{fuel}} &= 3.132362 \frac{\text{gm}}{\text{cc}} \\
 vf_U &= \frac{\rho_{\text{fuelU}}}{\rho_{\text{fuel}}} & vf_U &= 0.173233 \\
 vf_O &= \frac{\rho_{\text{fuelO}}}{\rho_{\text{fuel}}} & vf_O &= 0 \\
 vf_{\text{Al}} &= \frac{\rho_{\text{fuelAl}}}{\rho_{\text{fuel}}} & vf_{\text{Al}} &= 0.826767
 \end{aligned}$$

DRY MONITORED STORAGE CANISTER SHIELDING

$$wf_{235} = \frac{m_{235}}{m_U} \quad wf_{235} = 0.92973$$

$$wf_{238} = 1 - wf_{235} \quad wf_{238} = 0.07027$$

$$pitch = \frac{w_{assy} \cdot 2 \cdot t_{side}}{n_{plates}} \quad pitch = 0.370558 \text{ cm}$$

$$m_{light} = m_{assy} - n_{plates} \cdot m_{plate} \quad m_{light} = 1.241 \text{ kg}$$

$$volume = n_{plates} \cdot vol_{fuel} \quad volume = 245.471664 \text{ mL}$$

Assembly Data

$$vol_{assy} = w_{assy} - 2 \cdot t_{side} \cdot w_{fuel} \cdot fuel$$

$$vol_{assy} = 2.984299 \cdot 10^3 \cdot \text{mL}$$

$$m_{Al} = m_{clad} - m_{fill} \cdot n_{plates} \quad m_{Al} = 3.2868 \cdot 10^3 \cdot \text{gm}$$

$$m_{Uassy} = m_U \cdot n_{plates} \quad m_{Uassy} = 133.2 \cdot \text{gm}$$

$$m_{Oassy} = m_O \cdot n_{plates} \quad m_{Oassy} = 0 \cdot \text{gm}$$

$$m_{assy} = m_{Al} - m_{Uassy} - m_{Oassy}$$

$$m_{assy} = 3.42 \cdot 10^3 \cdot \text{gm}$$

$$\rho_{assy} = \frac{m_{assy}}{vol_{assy}} \quad \rho_{assy} = 1.145998 \frac{\text{gm}}{\text{mL}}$$

$$wf_{Al} = \frac{m_{Al}}{m_{assy}} \quad wf_{Al} = 0.961053$$

$$wf_O = \frac{m_{Oassy}}{m_{assy}} \quad wf_O = 0$$

$$wf_U = \frac{m_{Uassy}}{m_{assy}} \quad wf_U = 0.038947$$

DRY MONITORED STORAGE CANISTER SHIELDING

Appendix C Input File Listing

HFBR SAS-2, ORIGENS and QADS Lead Shield

```

=sas2      parm='skipcellwt,skipshpdata'
hfbr fuel irradiation period
'
-----
'   mixtures of fuel-pin-unit-cell:
'
44groupndf5
latticecell
arbm-fuel  3.4762  2 0 0 0  92235 93.18  92238 6.82 1 .30917 656 end
al 1 den=3.4762 .63474 656 end
o 1 den=3.4762 .05609 656 end
kr-83      1 0 1-20 656 end
kr-85      1 0 1-20 656 end
y-89       1 0 1-20 656 end
mo-95      1 0 1-20 656 end
zr-94      1 0 1-20 656 end
zr-95      1 0 1-20 656 end
rh-103     1 0 1-20 656 end
rh-105     1 0 1-20 656 end
ru-101     1 0 1-20 656 end
ru-106     1 0 1-20 656 end
pa-105     1 0 1-20 656 end
pd-108     1 0 1-20 656 end
ag-109     1 0 1-20 656 end
sc-124     1 0 1-20 656 end
i-135      1 0 1-20 656 end
xe-131     1 0 1-20 656 end
xe-132     1 0 1-20 656 end
xe-135     1 0 1-20 656 end
xe-136     1 0 1-20 656 end
cs-134     1 0 1-20 656 end
cs-135     1 0 1-20 656 end
ba-136     1 0 1-20 656 end
la-139     1 0 1-20 656 end
pr-141     1 0 1-20 656 end
pr-143     1 0 1-20 656 end
ce-144     1 0 1-20 656 end
nd-143     1 0 1-20 656 end
nd-145     1 0 1-20 656 end
pm-147     1 0 1-20 656 end
pm-148     1 0 1-20 656 end
pm-149     1 0 1-20 656 end
nd-147     1 0 1-20 656 end
sm-147     1 0 1-20 656 end
sm-149     1 0 1-20 656 end
sm-150     1 0 1-20 656 end
sm-152     1 0 1-20 656 end
gd-155     1 0 1-20 656 end
eu-153     1 0 1-20 656 end
eu-154     1 0 1-20 656 end
eu-155     1 0 1-20 656 end
po-159     1 0 1-20 656 end
'
'above are ORNL typical fission products
'
-----
arbm-al6061t  2.7  6 0 0 0
              13027 95.925 12000 1.0 29000 0.275
              25000 0.700 14000 0.6 25055 1.500
              2 end
'
'.....above Aluminum alloy 6061-t6
'
-----
h2o  3 1  348 end
'
'   mixtures of larger-unit-cell:
'
-----

```

DRY MONITORED STORAGE CANISTER SHIELDING

```

h2o 4 1 343 end
-----
.....above is moderator for assembly
-----
and comp
-----
fuel-pin-cell geometry:
symmslabcell 0.4256 0.062 1 3 0.130 2 end
-----
assembly and cycle parameters:
npin/assm=18 fuelngth=60.34 ncycles=1 nlib/cyc=1
volfueltot=350.7834 printlevel=4 lightel=1
inplevel=2 numzones=4 end
500 3.4585 3 3.9118 2 4.3135 4 4.7
power=2.148 burn=55.667 down=0.01 end
al 1.6846
end
=clec_out
end
#ORIGENS
0$S All 71 E T
DECAY CASE
3$S 33 1 1 27 A33 18 E T
35$S 0 T
54$S A8 1 E
56$S A2 10 A6 1 A10 0 A13 -2 A15 3 E
57** C E T
HFBR FUEL
ASSEMBLY
60** 100 300 1000 3000 3829 4103.7 4340 4369 4643.7 4880
61** F1.e-10
65$S
'GRAM-ATOMS GRAMS CURIES WATTS-ALL WATTS-GAMMA
3Z 1 0 0 1 0 0 3Z 3Z 6Z
3Z 1 0 0 1 0 0 3Z 3Z 6Z
3Z 1 0 0 1 0 0 3Z 3Z 6Z
61$S C C C 6 1 E
62$S C C C C 2 2 2 2 2 2
63** 1.E-7 8.E+6 6.5E+6 5.E+6 4.E+6
3.E-6 2.5E+6 2.E+6 1.66E+6 1.33E+6
1.E-6 8.E+5 6.E+5 4.E+5 3.E+5
2.E+5 1.E+5 5.E+4 1.E+4
54** 2.E+7 6.434E+6 3.E+6 1.85E+6 1.4E+6
9.E+5 4.E+5 1.E+5 1.7E+4 3.E+3
5.5E+2 1.E+2 3.E+1 1.E+1 3.04999E+0
1.77E+0 1.29999E+0 1.12999E+0 1.E+0 8.E-1
4.E-1 3.25E-1 2.25E-1 9.999985E-2 5.E-2
3.E-2 9.999998E-3 1.E-5 T
HFBR FUEL TIMESTEP 5
HFBR FUEL TIMESTEP 6
HFBR FUEL TIMESTEP 7
HFBR FUEL TIMESTEP 8
HFBR FUEL TIMESTEP 9
HFBR FUEL TIMESTEP 10
56$S 0 0 A10 5 E T
56$S 0 0 A10 6 E T
56$S 0 0 A10 7 E T
56$S 0 0 A10 8 E T
56$S 0 0 A10 9 E T
56$S 0 0 A10 10 E T
56$S F0 T
END
=clec_out
end

```

DRY MONITORED STORAGE CANISTER SHIELDING

HFBR QADS Steel Shield

```

#qacs
hfbr single assembly 4369 days decay steel shield
origengp-src infhommedium
arcm-fuel 1.2563 2 0 0 0 92235 93.12 92238 6.98 1 .1376 298 end
al 1 den=1.2563 .8375 298 end
o 1 den=1.2563 .0249 298 end
,
arbm-al6061t 2.7 6 0 0 0
13027 95.925 12000 1.0 29000 0.275
26000 0.700 14000 0.6 25055 1.500
2 end
,
-----
,
.....above Aluminum alloy 6061-t6
-----
,
h2o 3 1 298 end
ss304 4 1 298 end
o 5 den=0.0012 .21 298 end
n 5 den=0.0012 .79 298 end
'air
,
-----
,
end comp
cartesian 0. flats end
' source is from origen tape
uss=1 nss=1
-- source
-- fuel assembly
rpp 1 -3.302 3.302 -2.845 2.845 -29.025 29.025
rpp 2 -3.83 3.83 -3.315 3.315 -30.17 30.17
rpp 3 -4.087 4.087 -3.722 3.722 -30.17 30.17
rpp 4 12.7 50.8 -100 100 -100 100
rpp 5 -600 600 -600 600 -600 600
end body
fue 2 +1
gap 2 +2 -1
can 3 +3 -2
shl 1 +4
air 3 -5 -4 -3 -2 -1
end zone
1 5 2 4 5
end geom
iron exp
ndetec=17
4.1 0.0 0.0 cartesian
12.7 0.0 0.0 cartesian
15.2 0.0 0.0 cartesian
17.8 0.0 0.0 cartesian
20.3 0.0 0.0 cartesian
22.9 0.0 0.0 cartesian
25.4 0.0 0.0 cartesian
27.94 0.0 0.0 cartesian
30.5 0.0 0.0 cartesian
33.0 0.0 0.0 cartesian
35.6 0.0 0.0 cartesian
38.10 0.0 0.0 cartesian
40.64 0.0 0.0 cartesian
43.18 0.0 0.0 cartesian
45.72 0.0 0.0 cartesian
48.26 0.0 0.0 cartesian
50.80 0.0 0.0 cartesian
end dose
end

```

DRY MONITORED STORAGE CANISTER SHIELDING

HFBR QADS Lead Shield

```

=qads
hfbr single assembly 4369 days decay lead shield
origengp-src infhommedium
arbm-fuel 1.2563 2 0 0 0 92235 93.12 92238 6.88 1 .1376 298 end
a1 1 den=1.2563 .8375 298 end
o 1 den=1.2563 .0249 298 end
'
arbm-al6061t 2.7 6 0 0 0
      13027 95.925 12000 1.0 29000 0.275
      26000 0.700 14000 0.6 25055 1.500
      2 end
'
' .....above Aluminum alloy 6061-t6
'
h2o 3 1 298 end
pb 4 1 298 end
o 5 den=0.0012 .21 298 end
n 5 den=0.0012 .79 298 end
'air
'
end comp
cartesian 0. flats end
' source is from origen tape
nps=6 nzs=1
end source
hfbr fuel assembly
rpp 1 -3.302 3.302 -2.845 2.845 -29.025 29.025
rpp 2 -3.83 3.83 -3.315 3.315 -30.17 30.17
rpp 3 -4.087 4.087 -3.722 3.722 -30.17 30.17
rpp 4 12.7 50.8 -100 100 -100 100
rpp 5 -600 600 -600 600 -600 600
end body
fue 2 +1
gap 2 +2 -1
can 3 +3 -2
shl 1 +4
air 3 +5 -4 -3 -2 -1
end zone
1 5 2 4 5
end geom
lead exp
ndetec=17
4.1 0.0 0.0 cartesian
12.7 0.0 0.0 cartesian
15.2 0.0 0.0 cartesian
17.3 0.0 0.0 cartesian
20.3 0.0 0.0 cartesian
22.9 0.0 0.0 cartesian
25.4 0.0 0.0 cartesian
27.94 0.0 0.0 cartesian
30.5 0.0 0.0 cartesian
33.0 0.0 0.0 cartesian
35.6 0.0 0.0 cartesian
38.10 0.0 0.0 cartesian
40.64 0.0 0.0 cartesian
43.18 0.0 0.0 cartesian
45.72 0.0 0.0 cartesian
48.26 0.0 0.0 cartesian
50.80 0.0 0.0 cartesian
end dose
end

```

DRY MONITORED STORAGE CANISTER SHIELDING

RIAEC Irradiation

```
=sas2      parm='skipceliwt,skipshipaata'
sas2 riaec fuel
```

```
-----
mixtures of fuel-pin-unit-cell:
```

```
44groupndf5      latticecell
arbm-fuel 1.386 2 0 0 0 92235 93.14 92238 6.86 1 ..233 656 end
al 1 den=1.386 .767 656 end
kr-83 1 0 1-20 656 end
kr-85 1 0 1-20 656 end
y-89 1 0 1-20 656 end
mo-95 1 0 1-20 656 end
zr-94 1 0 1-20 656 end
zr-95 1 0 1-20 656 end
rh-103 1 0 1-20 656 end
rh-105 1 0 1-20 656 end
ru-101 1 0 1-20 656 end
ru-106 1 0 1-20 656 end
pd-105 1 0 1-20 656 end
pd-108 1 0 1-20 656 end
ag-109 1 0 1-20 656 end
sb-124 1 0 1-20 656 end
i-135 1 0 1-20 656 end
xe-131 1 0 1-20 656 end
xe-132 1 0 1-20 656 end
xe-135 1 0 1-20 656 end
xe-136 1 0 1-20 656 end
cs-134 1 0 1-20 656 end
cs-135 1 0 1-20 656 end
ba-136 1 0 1-20 656 end
la-139 1 0 1-20 656 end
pr-141 1 0 1-20 656 end
pr-143 1 0 1-20 656 end
ce-144 1 0 1-20 656 end
nd-143 1 0 1-20 656 end
nd-145 1 0 1-20 656 end
pm-147 1 0 1-20 656 end
pm-148 1 0 1-20 656 end
pm-149 1 0 1-20 656 end
nd-147 1 0 1-20 656 end
sm-147 1 0 1-20 656 end
sm-149 1 0 1-20 656 end
sm-150 1 0 1-20 656 end
sm-152 1 0 1-20 656 end
gd-155 1 0 1-20 656 end
eu-153 1 0 1-20 656 end
eu-154 1 0 1-20 656 end
eu-155 1 0 1-20 656 end
co-59 1 0 1-20 656 end
```

```
-----
'above are ORNL typical fission products
-----
```

```
arbm-al6061t 2.7 6 0 0 0
13027 95.925 12000 1.0 29000 0.275
26000 0.700 14000 0.6 25055 1.500
2 end
```

```
-----
.....above Aluminum alloy 6061-t6
-----
```

```
-----
c 3 1 348 end
-----
```

```
mixtures of larger-unit-cell:
```

```
-----
c 4 den=1 1 348 end
-----
```

```
-----
.....above is moderator/reflector
-----
```

DRY MONITORED STORAGE CANISTER SHIELDING

```

end comp
-----
fuel-pin-cell geometry:
-----
symmslabcell 0.4233 0.0508 1 3 0.1524 2 end
-----
assembly and cycle parameters:
-----
npin/assm=18 fuelngth=63.5 ncycles=1 nlib/cyc=1
volfueltot=414.4288 printlevel=4 lightel=1
inplevel=2 numzones=1 end
500 7.62
power=0.008 burn=1792.81 down= 0.01 end
al 1.20564
end

```

RIAEC Decay

```

#origens
0$$ all 33 e t
decay case
3$$ 2i 1 1 0 a33 0 e t
35$$ 0 t
54$$ a8 1 e
56$$ a2 10 a6 1 a10 0 a13 -1 a14 5 a15 3 e
57** 0 e t
riaec fuel
assembly
60** .3 1 2 4 6 8 10 15 20 25
61** f 1.e-20
65$$
'gram-atoms    grams    curies    watts-all    watts-gamma
3z    1 0 0    1 0 0    3z    3z    6z
3z    1 0 0    1 0 0    3z    3z    6z
3z    1 0 0    1 0 0    3z    3z    6z  t
56$$ 0 0 a10 2 e t
56$$ 0 0 a10 3 e t
56$$ 0 0 a10 4 e t
56$$ 0 0 a10 5 e t
56$$ 0 0 a10 6 e t
56$$ 0 0 a10 7 e t
56$$ 0 0 a10 8 e t
56$$ 0 0 a10 9 e t
56$$ 0 0 a10 10 e t
56$$ f0 t
end

```


DRY MONITORED STORAGE CANISTER SHIELDING

RIAEC QAD (Lead Shielding)

```

=qads
riaec single assembly lead shield
origengp-src infhommedium
arbm-fuel 1.146 2 0 0 0 92235 93.12 92238 6.88 1 .0389 298 end
al 1 den=1.146 .9611 298 end
'
arbm-al6061t 2.7 6 0 0 0
      13027 95.925 12000 1.0 29000 0.275
      26000 0.700 14000 0.6 25055 1.500
      2 end
'
' .....above Aluminum alloy 6061-t6
'
h2o 3 1 298 end
pb 4 1 298 end
o 5 den=0.00125 1 298 end
'air
'
end comp
cartesian 0. flats end
' source is from origen tape
nps=4 nzs=1
end source
riaec fuel assembly
rpp 1 -3.523 3.523 -3.523 3.523 -31.75 31.75
rpp 2 -3.810 3.810 -3.810 3.810 -31.75 31.75
rpp 3 12.7 38.1 -100 100 -100 100
rpp 4 -600 600 -600 600 -600 600
end body
fz 2 -1
can 3 +2 -1
shl 1 -3
air 3 +4 -3 -2 -1
end zone
1 2 4 5
end geom
lead exp
ndetac=12
4.1 0.0 0.0 cartesian
12.7 0.0 0.0 cartesian
15.24 0.0 0.0 cartesian
17.78 0.0 0.0 cartesian
20.32 0.0 0.0 cartesian
22.86 0.0 0.0 cartesian
25.4 0.0 0.0 cartesian
27.94 0.0 0.0 cartesian
30.48 0.0 0.0 cartesian
33.02 0.0 0.0 cartesian
35.56 0.0 0.0 cartesian
38.10 0.0 0.0 cartesian
end dose
end
=qads
riaec single assembly lead shield
origengp-src infhommedium
arbm-fuel 1.146 2 0 0 0 92235 93.12 92238 6.88 1 .0389 298 end
al 1 den=1.146 .9611 298 end
'
arbm-al6061t 2.7 6 0 0 0
      13027 95.925 12000 1.0 29000 0.275
      26000 0.700 14000 0.6 25055 1.500
      2 end
'
' .....above Aluminum alloy 6061-t6
'
h2o 3 1 298 end
pb 4 1 298 end
o 5 den=0.00125 1 298 end
'air

```

DRY MONITORED STORAGE CANISTER SHIELDING

```
end comp
cartesian 0. flats end
' source is from origin tape
nps=4 nzs=1
end source
riaec fuel assembly
rpp 1 -3.523 3.523 -3.523 3.523 -31.75 31.75
rpp 2 -3.810 3.810 -3.810 3.810 -31.75 31.75
rpp 3 12.7 50.8 -100 100 -100 100
rpp 4 -600 600 -600 600 -600 600
end body
fue 2 +1
can 3 +2 -1
shl 1 +3
air 3 +4 -3 -2 -1
end zone
: 2 4 5
end geom
end exp
ndetec=7
33.10 0.0 0.0 cartesian
40.64 0.0 0.0 cartesian
43.13 0.0 0.0 cartesian
45.72 0.0 0.0 cartesian
48.26 0.0 0.0 cartesian
50.80 0.0 0.0 cartesian
27.94 0.0 0.0 cartesian
end dose
end
```

DRY MONITORED STORAGE CANISTER SHIELDING

RIAEC QAD (Steel Shielding)

```

=qads
riaec single assembly steel shield
origengp-src infhommedium
arbm-fuel 1.146 2 0 0 0 92235 93.12 92238 6.88 1 .0389 298 end
al 1 den=1.146 .9611 298 end
'
arbm-al6061t 2.7 6 0 0 0
      13027 95.925 12000 1.0 29000 0.275
      26000 0.700 14000 0.6 25055 1.500
      2 end
'
-----
'
      ....above Aluminum alloy 6061-t6
'
-----
h2o 3 1 298 end
ss304 4 1 298 end
o 5 den=0.00125 1 298 end
'air
'
-----
end comp
cartesian 0. flats end
' source is from origen tape
nps=4 nzs=1
end source
riaec fuel assembly
rpp 1 -3.523 3.523 -3.523 3.523 -31.75 31.75
rpp 2 -3.810 3.810 -3.810 3.810 -31.75 31.75
rpp 3 12.7 43.18 -100 100 -100 100
rpp 4 -600 600 -600 600 -600 600
end body
fue 2 +1
can 3 +2 -1
snl 1 -3
air 3 -4 -3 -2 -1
end cone
1 2 4 5
end geom
iron exp
ndetec=11
4.1 0.0 0.0 cartesian
12.7 0.0 0.0 cartesian
15.2 0.0 0.0 cartesian
17.8 0.0 0.0 cartesian
20.3 0.0 0.0 cartesian
22.9 0.0 0.0 cartesian
25.4 0.0 0.0 cartesian
30.5 0.0 0.0 cartesian
33.0 0.0 0.0 cartesian
35.6 0.0 0.0 cartesian
38.1 0.0 0.0 cartesian
end dose
end
=qads
riaec single assembly lead shield
origengp-src infhommedium
arbm-fuel 1.146 2 0 0 0 92235 93.12 92238 6.88 1 .0389 298 end
al 1 den=1.146 .9611 298 end
'
arbm-al6061t 2.7 6 0 0 0
      13027 95.925 12000 1.0 29000 0.275
      26000 0.700 14000 0.6 25055 1.500
      2 end
'
-----
'
      ....above Aluminum alloy 6061-t6
'
-----
h2o 3 1 298 end
ss304 4 1 298 end
o 5 den=0.00125 1 298 end
'air
'
-----

```

DRY MONITORED STORAGE CANISTER SHIELDING

```
end comp
cartesian 0. flats end
' source is from origin tape
nps=4 nzs=1
end source
riaec fuel assembly
rpp 1 -3.523 3.523 -3.523 3.523 -31.75 31.75
rpp 2 -3.810 3.810 -3.810 3.810 -31.75 31.75
rpp 3 12.7 50.8 -100 100 -100 100
rpp 4 -600 600 -600 600 -600 600
end body
fue 2 +1
can 3 +2 -1
shl 1 +3
air 3 +4 -3 -2 -1
end zone
1 2 4 5
end geom
iron exp
ndetec=7
38.10 0.0 0.0 cartesian
40.64 0.0 0.0 cartesian
43.18 0.0 0.0 cartesian
45.72 0.0 0.0 cartesian
48.26 0.0 0.0 cartesian
50.80 0.0 0.0 cartesian
27.94 0.0 0.0 cartesian
end dose
end
```

DRY MONITORED STORAGE CANISTER SHIELDING

SAS3 Input

```

=sas3
hfbr single assembly 4369 days decay steel shield
ITn-13couple infhommedium
arom-fuel 1.2563 2 0 0 0 92235 93.12 92238 6.88 1 .1376 298 end
a1 1 den=1.2563 .8375 298 end
c 1 den=1.2563 .0249 298 end
,
arom-al6061t 2.7 6 0 0 0
13027 95.925 12000 1.0 29000 0.275
26000 3.700 14000 0.6 25055 1.500
2 end
,
-----
,
....above aluminum alloy 6061-t6
-----
,
h2o 3 1 298 end
ss304 4 1 298 end
o 5 den=0.0012 .21 298 end
n 5 den=0.0012 .79 298 end
'air
,
-----
,
end comp
morse unbiased hfbr 8 in steel shield
nod=3 nst=2000 nmo=4000 nit=10000 max=45
nki=1 nsr=-1 nre=0 npa=1 ndg=1 msm=1
ran=f1bd3efbelcdc end
hfbr fuel assembly
C 0 1 0
rpp 1 -3.302 3.302 -2.845 2.845 -29.025 29.025
rpp 2 -3.83 3.83 -3.315 3.315 -30.1625 30.1625
rpp 3 -4.087 4.087 -3.722 3.722 -31.115 31.115
rpp 4 -14.605 14.605 -14.605 14.605 -35.2425 35.2425
rpp 5 -34.925 34.925 -34.925 34.925 -55.5625 55.5625
rpp 6 34.925 40.005 -19.685 19.685 -26.4524 5.2976
rpp 7 40.005 51.435 -14.605 14.605 -26.4524 5.2976
rpp 8 51.435 66.675 -17.145 17.145 -26.4524 5.2976
rcc 9 14.605 0.0 -10.5774 36.6141 0 0 4.8641
rcc 10 14.605 0.0 -10.5774 36.6141 0 0 5.08
rcc 11 46.355 0.0 -10.5774 0 -29.845 0 4.8641
rcc 12 46.355 0.0 -10.5774 0 -29.845 0 5.08
rpp 13 -600 600 -600 600 -600 600
rpp 14 -1.e4 1.e4 -1.e4 1.e4 -1.e4 1.e4
rcc 15 14.605 0.0 -10.5774 36.6141 0 0 10.
end body
fue +1
gap +2 -1
can +3 -2
air +4 -3
shl +5 -4 -15
shl +6 -15
shl +7 -15 -12
shl -8
pen +9
wal +10 -9 -11
pen +11 -9
wal +12 -11 -10
air +13 -5 -6 -7 -8 -12
exv +14 -13
shl -15 -10 -12
end
1 1 1 1 3 3 1 3 2 2 4 4 1 1 1
15*0
1 5 2 5 4 4 4 4 5 4 5 4 1000 0 4
0
6000. 0 0 -3.302 3.302 -2.845 2.845 -29.025 29.025
45rie34 45r.5 45rie34 45r.5
45r.2 45r.02 45rie34 45r.02
45r1 45r.1 45r1000 45r.1
45r0 45r.7 45r0 45r0.
27r0 18r1
27r0 18r1

```

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DRY MONITORED STORAGE CANISTER SHIELDING

```

27r0 13r1  . . .
27r0 19r1
27r0
6.17e-15  2.96e-14  1.55e-13  3.97e-13  1.38e-08  9e-08
6.83e-06  3.77e-05  0.000456  0.003273  0.005201  0.460655
0.015567  0.014295  0.020192  0.054239  0.093671  0.322416
1.
46.355  -29.9  -10.5774
51.435  -29.9  -10.5774
51.5    -23.495 -10.5774
end

```

DRY MONITORED STORAGE CANISTER SHIELDING

PICTURE Input file for Plan View

=picture

0

HFBR FUEL ASSEMBLY

C 0 1 0

```

RPP 1 -3.302 3.302 -2.845 2.845 -29.025 29.025
RPP 2 -3.83 3.83 -3.315 3.315 -30.17 30.17
RPP 3 -4.087 4.087 -3.722 3.722 -30.1625 30.1625
RPP 4 -14.605 14.605 -14.605 14.605 -30.48 30.48
RPP 5 -34.925 34.925 -34.925 34.925 -50.8 50.8
RPP 6 34.925 40.005 -19.685 19.685 -15.875 15.875
RPP 7 40.005 51.435 -14.605 14.605 -15.875 15.875
RPP 8 51.435 66.675 -17.145 17.145 -15.875 15.875
RCC 9 14.605 0.0 -10.5774 36.83 0 0 4.8641
RCC 10 14.605 0.0 -10.5774 36.83 0 0 5.08
RCC 11 46.355 0.0 -10.5774 0 -29.845 0 4.8641
RCC 12 46.355 0.0 -10.5774 0 -29.845 0 5.08
RPP 13 -600 600 -600 600 -600 600
RPP 14 -1.E4 1.E4 -1.E4 1.E4 -1.E4 1.E4

```

END BODY

FUE +1

GAP +2 -1

CAN +3 -2

AIR +4 -3

SHL -5 -4 -10

SHL -6 -10

SHL +7 -10 -12

SHL -8

pen +9

wal +10 -9 -11

pen +11 -10

wal +12 -11 -10

AIR +13 -5 -6 -7 -8 -12

EXV +14 -13

END

1 1 1 1 1 1 1 2 2 2 2 1 1

14*0

1 5 2 5 4 4 4 4 1000 4 1000 4 5 0

0

ttl= hfbr canister

irg=1 icn= -1

scr= yes

xul= -50. yul= 50 zul=-10.4775 xlr=100 ylr= -50. zlr=-10.4775

Vax= -1 udn= 1 ndn=480 end

enc

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DRY MONITORED STORAGE CANISTER SHIELDING

PICTURE Input file for Plan View

```

=picture
0
HFBR FUEL ASSEMBLY
0 0 1 0
RPP 1 -3.302 3.302 -2.845 2.845 -29.025 29.025
RPP 2 -3.83 3.83 -3.315 3.315 -30.1625 30.1625
RPP 3 -4.087 4.087 -3.722 3.722 -31.115 31.115
RPP 4 -14.605 14.605 -14.605 14.605 -35.2425 35.2425
RPP 5 -34.925 34.925 -34.925 34.925 -55.5625 55.5625
RPP 6 34.925 40.005 -19.685 19.685 -26.4524 5.2976
RPP 7 40.005 51.435 -14.605 14.605 -26.4524 5.2976
RPP 8 51.435 66.675 -17.145 17.145 -26.4524 5.2976
rcc 9 14.605 0.0 -10.5774 36.83 0 0 4.8641
rcc 10 14.605 0.0 -10.5774 36.83 0 0 5.08
rcc 11 46.355 0.0 -10.5774 0 -29.845 0 4.8641
rcc 12 46.355 0.0 -10.5774 0 -29.845 0 5.08
RPP 13 -600 600 -600 600 -600 600
RPP 14 -1.E4 1.E4 -1.E4 1.E4 -1.E4 1.E4
END BODY
FUE +1
GAP -2 -1
CAN +3 -2
AIR +4 -3
SHL +5 -4 -10
SHL +6 -10
SHL +7 -10 -12
SHL -3
pen +9
wal +10 -9 -11
pen +11 -10
wal +12 -11 -10
AIR +13 -5 -6 -7 -8 -12
EXV +14 -13
END
1 1 1 1 1 1 1 1 2 2 2 2 1 1
14*0
1 5 2 5 4 4 4 4 1000 4 1000 4 5 0
0
ttl= hfbr canister
irg=1 icn= -1
scr= yes
xul= -50. yul= -14 zul=50 xlr=100 ylr= -14 zlr=-50
wax= -1 udn= 1 ndn=480 end
end

```


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DRY MONITORED STORAGE CANISTER SHIELDING

Attachment 1

Author: Robert Sindelar at SRCCA07
 Date: 6/12/97 12:05 PM
 Priority: Normal
 TO: William Epling at SRCCC10
 TO: David Blanchard at SRCCH06
 TO: Kent Rosenberger at SRCCA04
 TO: Gerard Couture at SRCCC04
 TO: Tony Lentz at SRCCC03
 TO: Anthony Cappucci at SRCCB07
 TO: Steven Nathan at SRCCB02
 TO: John Zino at SRCCB08
 TO: William Large at SRCCC04
 TO: Trent Andes at SRCCC04
 TO: Robert Eakle at SRCCA19
 TO: Phillip French at SRCCA03
 TO: Donald Pak at SRCCA19
 TO: Jon Guy at SRCCC01
 CC: Richard Murphy at SRCCC06
 CC: Natraj Iyer at SRCCA20
 CC: S-David Burke at SRCCC04
 Subject: Test Canister Development Actions (U)

----- Message Contents -----

A planning meeting was held June 5 to discuss needed actions to design/fabricate/stage/use the Test Canister for the Alternative Treatment Technology Program.

The following action items capture the actions from discussions at the meeting along with other actions which have been identified. This is the latest update to the running list intended to keep the task on track to meet the PBI milestone and to keep all team members informed of the status of the activities. Please contact me for changes and updates to your item(s) or if a new item is needed. Action items will be removed from the list when fully completed.

ACTION ITEMS (Lead personnel):

****Instrumented Test Canister Design, Fabrication, Check-Out Testing Activities****

1. Modify the instrumented canister design for underwater loading (Pak/Eakle/French). Status: Complete. Drawings were reviewed at 6/5 meeting and were subsequently sent to machine shop. The shielding will be added to the canister after fabrication (see item 6 below). Refer to tolerance of Square Tube Dissolver for RBOF bundles for canister (contact Trent Andes).
2. Procure/Calibrate/Install/Check-out Sensor Equipment (Eakle/French). Status: All sensor equipment (temperature, pressure, humidity, gas analyzers) has been ordered and several items have been received and are calibrated. A change has been made to use an on-line gas chromatograph instead of separate sensors dedicated to NOx, Cs, etc gas monitoring. An existing GC system is available for use with the test canisters; new systems have been ordered.
3. Design/Fabricate Vacuum Drying Test Canister and Mock Fuel Assembly for

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DRY MONITORED STORAGE CANISTER SHIELDING

Vacuum-Drying Testing and for Check-out Testing of Instrumented, Shielded Canister (Pak/French/Large). Status: The vacuum test canister mock assembly fabrication are nearly complete and should be done by 6/17.

4. Vacuum Drying Testing (Large). Status: All equipment is nearly assembled. The balance for determined weight changes and free water measurements has been ordered and should be on site within the next week. The Works Clearance Permit is sufficient for the testing to be in L-assembly and testing should begin by 6/27. The conditions for drying of SNF loaded into the shielded instrumented test canisters will be determined through this activity. A support personnel to assist Steve Large is needed.

****Planning for Safe SNF Movement and Storage****

5. Selection of the SNF Assemblies for the Test Canister (Sindelar/Zino/Guy/Andes). Status: Based on fuel condition and with regards to availability and basin storage, the Sapphire Reactor assembly SES02 (currently unbundled in RBOF) and an assembly from the R2 Reactor (scheduled to arrive in August) have been selected. The SES02 assembly has about 0.5 in² area of exposed fuel core apparently caused when an attached T/C was removed. The fuel had 60 gm U235 initially and currently has an estimated 58 grams (data to be verified). Fuel from the R2 reactor typically had 260 gms U235 initially and is currently at 90 gms. The specific R2 assembly remains to be identified and it may have to be bundled when it arrives until just before loading into the test canister in late '97 or early '98

6. Documentation of Shielding Requirements for Test Canister (Nathan/Blanchard). Status: Initially, HFBR fuel was planned for and calculations performed by Reuben Rainisch indicated about 8+ inches of lead or steel for canister shielding would be needed to reduce to the exposure rate to 200 mR/hr outside surface of the shield for this fuel. After discussion at the 6/5 meeting, the path forward was to: 1) Use 8 inches of shielding in the test canister design regardless of the fuel selection 2) Make dose rate measurements (in water) of an assembly (e.g. SES02) at RBOF to provide confidence in the dose estimation from the SES02 assembly and the R2 assembly in shielded canisters through the calculation benchmarked for water shielding. 3) Prepare a technically-reviewed report on the required shielding for these assemblies including dose rate limits at the shielding surface and the basis for the limits. The measurements with the report are needed to be completed by 7/18. Steve Nathan should talk to Luis Canas regarding RBOF Fuel Counter Data.

7. USQ/TA/Other Safety Documentation (Couture/Guy/ et al). Status: A TA should not be prepared at this time until the testing is imminent.

8. Get SHO on board (Blanchard). Status: Completed. Kent Rosenberger is the appointed POC to support this task.

9. Review Design with Site Pressure Vessel Committee (Pak/French). Status: The maximum expected pressure in the canister is several psig. The pressure vessel committee will be contacted to evaluate need/adequacy for pressure relief capability of canister.

10. Assess Weight of Two Shielded (8") Instrumented Test Canisters with Respect

DRY MONITORED STORAGE CANISTER SHIELDING

to Floor Loading Capacity (Couture (Sharman sp?)/Pak/French). Status: Pak/French to estimate weight and give to Couture.

11. Perform Walkdown of L Area for Fuel Movement Plan (Guy/Blanchard). Status:

12. Prepare Plan of Fuel Movement (from Transfer Bay Loading into Instrumented Test Canister to Placement of Canister into L Dry Cave) (Blanchard/Guy/Pak). Status: Plan to be drafted following walkdown and used at next meeting to review handling.

13. Hold Meeting(s) to Discuss Handling/Failed-Test Contingency Plans (Sindelar/Blanchard/Pak). Status: The next status meeting for the canister team will be scheduled first week in July. Plans for handling (see item 12) and for test duration/contingencies will be discussed.

****Instrumented Test Canister Program****

14. Test Canister Report (Pak/Sindelar). Status: The extended outline for the report due as part of the PBI milestone is being prepared and will be discussed at the next status meeting.

Other Notes:

1) Please ensure that Blanchard, Couture, Pak, and Sindelar are on distribution for all reports, memos, calc sets, that are performed for this project.

2) LWT Outage starts in October and will tie up Operations.

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DRY MONITORED STORAGE CANISTER SHIELDING

Attachment 2

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Aluminum and Zinc Alloy Properties

If you are not using Netscape Enhanced or are having trouble with this chart click [here](#).

MECHANICAL PROPERTIES

*_ALLOY	*_#3 ZINC	*_#5 ZINC	*_ZA-8	*_ZA-12	*_ZA-27	*_360 AL	*_380 AL	*_384 AL	*_356	*_6061T-6
Tensile Strength (psi x 10)	41	48	54	58	61	44	48	48	33	45
Yield Strength (0.2% offset) (psi x 10)	-	-	42	46	53	25	24	24	24	40
Elongation (% in 2")	10	7	8	6	2	4	3	3	4	17
Shear Strength (psi x 10)	31	38	40	43	47	28	28	29	28	28
Hardness (Brinell)	82	91	105	105	115	85	85	85	80	30

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DRY MONITORED STORAGE CANISTER SHIELDING

PHYSICAL PROPERTIES

*

*_ALLOY	*_#3 ZINC	*_#5 ZINC	*_ZA-8	*_ZA-12	*_ZA-27	*_360 AL	*_380 AL	*_384 AL	*_356	*_6061T-6
Density (lb./ci)	0.240	0.240	0.227	0.218	0.181	0.095	0.098	0.102	0.097	0.098
Melting Point (F)	728	727	759	810	903	1105	1100	1080	1135	1206
Electrical Conductivity (%IACS)	27	26	28	28	30	30	20	30	20	43
Coefficient of Thermal Expansion (68-212F) (U in/in/F)	15.2	15.2	12.9	13.4	14.4	11.6	12.2	11.5	11.9	13.1
Die Shrinkage (in/in)	0.005	0.005	0.007	0.007	0.008	0.005	0.005	0.005	-	-

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DRY MONITORED STORAGE CANISTER SHIELDING

CHEMICAL SPECIFICATIONS (Per ASTM) (% by weight)

*

*ALLOY	*#3 ZINC	*#5 ZINC	*ZA-8	*ZA-12	*ZA-27	*360 AL	*380 AL	*384 AL	*356	*6061T-6
Al	3.5-4.3	3.5-4.3	8-8.3	10.5-11.5	25-28	Balance	Balance	Balance	Balance	Balance
Mg	.02-.05	.03-.08	.015-.030	.015-.030	.010-.020	.6	.1	.1	.20-.45	.8-1.2
Cu	.25 Max	.75-1.25	.8-1.3	.5-1.25	2-2.5	.4 Max	3-4	3-4	.25 Max	.15-.4
Fe	.10	.10	.075	.075	.075	2 Max	2 Max	1.3 Max	.6 Max	.7 Max
Cd	.004	.004	.006	.006	.006	-	-	-	-	-
Si	.003	.003	.003>	.003	.003	9-10	7.5-9.5	10.5-12	6.5-7.5>	.4-.8
Mn	-	-	-	-	-	.35	.5 Max	.5 Max	.35 Max	15 Max>
Z	Balance	Balance	Balance	Balance	Balance	.5 Max	3 Max	3 Max	.35 Max	.25 Max

INDUSTRY STANDARDS

*

*ALLOY	*#3 ZINC	*#5 ZINC	*ZA-8	*ZA-12	*ZA-27	*360 AL	*380 AL	*384 AL	*356	*6061T-6
ASTM	B86-88	B86-88	B791-88	B791-88	B791-88	SG100-B	SC84-B	SC114-A	SG70-A	B209
	AG-40	AC41A								
SAE	J468B	J468B	-	-	-	-	308	303	J4542	-
	903	925								
UNS	Z33520	Z35531	Z35636	Z35631	Z35841	A03600	A03800	A03840	A03560	A96061

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DRY MONITORED STORAGE CANISTER SHIELDING

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Appendix 2 to WSRC-TR-97-00269

Field Procedure FP-721 for Vacuum Canister Drying Tests (by P. J. French) and Data Records

SNF Instrumented Test Canister
Vacuum Drying Test Procedure (U)

Field Procedure: FP-721

Revision: 0

EES Job Number: ~~22555~~ ~~87~~ 8/4/97
22585

Effective Date: 7/16/97

Prepared by: P. French
EES Engineer

Date: 7/14/97

Reviewed by: [Signature]
EES Engineer

Date: 7/14/97

Approved by: [Signature]
EES Manager

Date: 7/16/97

Approved by: W. Z. Lange
SFS Engineer

Date: 7/16/97

Revision History Log

<u>Revision</u>	<u>Date</u>	<u>Description of Revision</u>
0	7/10/97	Initial Issue

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1.0 PURPOSE

The purpose of this testing is to demonstrate a cold vacuum drying technique for an instrumented test canister intended for dry storage of spent nuclear fuel. This procedure outlines the test plan to evaluate the performance and determine the ability of an existing vacuum pumping system to adequately dry the instrumented canister and contents.

2.0 SCOPE

This procedure covers the testing to be performed by EES and SFS in the assembly area of building 105-L.

3.0 TERMS/DEFINITIONS

- 3.1 EES - Engineered Equipment and Systems Department.
- 3.2 SFS - Spent Fuel Storage Division.

4.0 RESPONSIBILITIES

- 4.1 EES engineers shall be responsible for:
 - 4.1.1 Performing the execution of this procedure with the exception of operating the vacuum pump.
 - 4.1.2 Assisting in the coordination, scheduling, and controlling of activities associated with implementation of this procedure.
 - 4.1.3 Data documentation as specified in this procedure.
- 4.2 SFS engineers shall be responsible for:
 - 4.2.1 Operation of the vacuum pump.
 - 4.2.2 Assisting with the implementation of this procedure.
 - 4.2.3 Serving as a liaison with building 105-L Facility Operations.

5.0 PROCEDURE

5.1 Safety

- 5.1.1 All SRS safety rules will be followed. Personal protection items such as safety glasses, gloves, and safety shoes will be worn as appropriate.
- 5.1.2 Prepare the test area by installing barricade rope around the work perimeter, display appropriate safety signs, and clear work space to insure safe movement of personnel.
- 5.1.3 A safety inspection shall be performed before testing begins.
- 5.1.4 A cold walk-through shall be performed by the personnel performing the test to ensure complete understanding of the work required.

5.2 Acceptance Criteria

- 5.2.1 The vacuum level within the canister shall reach and sustain a pressure of 15 torr or less when the internal temperature is at or above 72 degrees F.

5.3 Equipment Needed

- 5.3.1 Vacuum pump
- 5.3.2 Canister frame
- 5.3.3 Canister mock-up
- 5.3.4 Thermocouple rack
- 5.3.5 Mock MTR type fuel assembly
- 5.3.6 Scale capable of reading in 0.005 lb. min. increments or equivalent.
- 5.3.7 Data acquisition system
- 5.3.8 115 vac power supply

5.4 Test Set-up

- 5.4.1 Place canister framework at desired location.
- 5.4.2 Place scale onto bottom plate of canister frame.
- 5.4.3 Install canister into frame and onto scale.

- 5.4.4 Connect vacuum hose between canister and vacuum pump.
- 5.4.5 Install thermocouple rack into canister.
- 5.4.6 Install dry mock fuel assembly into thermocouple rack.
- 5.4.7 Attach canister top flange with gasket per manufacturer's recommendations.
- 5.4.8 Ensure initial weight reading is less than 70 lbs.
- 5.4.9 Perform vacuum pump check out per reference 7.5.
- 5.5 Vacuum Test
 - 5.5.1 Observe and record initial conditions from digital display system onto data sheet (See Data Sheets).
 - 5.5.2 Start up vacuum pump and observe system for signs of leakage. See reference 7.5 on vacuum system operation.
 - 5.5.3 If leakage is indicated, shut down vacuum pump, vent system, and repair leaks before restarting .
 - 5.5.4 Slowly open isolation valve near canister to begin evacuation.
 - 5.5.5 Record maximum vacuum produced (i.e. vacuum level at which system reaches steady state) and system conditions at that point.
 - 5.5.6 Isolate pump and relieve vacuum from canister.
 - 5.5.7 Record system conditions.
 - 5.5.8 Attach any data sheets generated by the digital display system to completed procedure data sheets.
 - 5.5.9 Repeat procedure beginning with step 5.4.6 substituting the following for the dry fuel assembly:
 - 5.5.9.1 Assembly lightly sprayed with water and allowed to drip dry.

- 5.5.9.2 Assembly transferred immediately from being submerged in water into dry canister.
- 5.5.9.3 Assembly transferred immediately from being submerged in water into canister containing one inch of water.
- 5.5.9.4 Other fuel assembly conditions as determined by EES.
- 5.5.10 Repeat procedure beginning with step 5.4.6 for conditions in 5.5.9.1 and 5.5.9.2. Stop vacuum pumping when the canister pressure reaches 40 torr. Record system conditions per data sheets 8.5 and 8.6.
- 5.5.11 Shut down vacuum pump and vent system.

6.0 RECORDS

- 6.1 Completed copies of this procedure shall be maintained in accordance with the SRTC records control procedure and retention schedule.

7.0 REFERENCES

- 7.1 Canister Mock-up Sketch
- 7.2 Thermocouple Rack Sketch
- 7.3 Mock Fuel Assembly Sketch
- 7.4 Canister Framework Sketch
- 7.5 Operation of Portable Vacuum Drying Equipment, EFR-RMT-95-00960.
- 7.6 Instruments and Equipment Calibration Procedure, L9.2-3848.

8.0 DATA SHEETS

- 8.1 Dry Fuel Assembly in Dry Canister
- 8.2 Drip Dry Fuel Assembly t in Dry Canister at Maximum Vacuum
- 8.3 Wet Fuel Assembly in Dry Canister at Maximum Vacuum
- 8.4 Wet Fuel Assembly with Standing Water in Canister
- 8.5 Drip Dry Fuel Assembly in Dry Canister at 40 Torr
- 8.6 Wet Fuel Assembly in Dry Canister at 40 Torr

Title: Vacuum Drying Test Canister

Title: SNF & Sensor Rack

Title: MTR SNF Mock Up

Note:
Minimum weld construction

Title: Test Canister Stand

Vacuum Drying Test Data for
Dry Fuel Assembly in Dry Canister

Step #

5.5.1 Initial system conditions.

Fuel Assembly Weight 9.1243 pounds. avg of 5 readings
Canister Weight 37.8498 pounds. " " " "
Combined Weight 46.9738 pounds. " " " "
Time 8:29am
Pressure 759 torr.
Temperature 28.4 / 28.3 degrees ~~F~~. C
Humidity 50.8 percent.

5.5.5 System conditions at maximum vacuum.

Time 8:45am
Pressure 530 milli torr.
Temperature 28.3 / 28.2 degrees ~~F~~. C
Humidity 0.1 percent.
Combined Weight 47.7468 pounds.

5.5.7 System conditions at minimum relative humidity.

Time 8:53 am
Pressure 759 torr.
Temperature 28.3 / 28.2 degrees ~~F~~. C
Humidity 46 percent.
Combined Weight 46.9743 pounds. avg of 5 readings
Canister Weight 37.8504 pounds. avg of 5 readings
Fuel Assembly Weight 9.1242 pounds. avg of 5 readings

Tester W. S. Large W. S. Large Date 8/26/97
(print / sign)

M & T E Nos. {
3-2077 Scales
7C-001 Varian 801 vacuum gage
7C-002 WV-100 gage
3-2097 Humidity sensor
3-2076 Temperature sensors
3-2075 Temperature sensor

Vacuum Drying Test Data for
Drip Dry Fuel Assembly in Dry Canister at Maximum Vacuum

Step #

5.5.1 Initial system conditions.

Dry Fuel Assembly Weight 9.1242 pounds. ^{from previous page}
Canister Weight 37.8504 pounds. avg of 5 readings
Combined Weight 46.9960 pounds. avg of 5 readings
Time 9:22 am
Pressure 759 torr.
Temperature 27.5 / 27.6 degrees ~~F~~. C
Humidity 85.1 percent.

5.5.5 System conditions at maximum vacuum.

Time 9:50 am
Pressure 510 milli torr.
Temperature 23.6 / 23.3 degrees ~~F~~. C
Humidity 0.7 percent.
Combined Weight 47.7152 pounds.

5.5.7 System conditions at minimum relative humidity.

Time 9:54 am
Pressure 759 torr.
Temperature 23.8 / 23.7 degrees ~~F~~. C
Humidity 41.8 percent.
Combined Weight 46.9743 pounds. avg of 5 readings
Canister Weight 37.8505 pounds. avg " " "
Fuel Assembly Weight 9.1243 pounds. avg " " "

Tester W.S. Large / W.S. Large Date 8/26/97
(print / sign)

M+TE Nos. { 32077 Scales
7C-001 Varian 801 vacuum gage
7C-002 WV-100 gage
3-2097 Humidity sensor
3-2076 Temperature sensor

3-2075 Temperature sensor

Vacuum Drying Test Data for
Wet Fuel Assembly in Dry Canister at Maximum Vacuum

Step #

5.5.1 Initial system conditions.

Fuel Assembly Weight	<u>9.1243</u>	pounds.	from previous page step 5.5.7 from previous page step 5.5.7
Canister Weight	<u>37.8505</u>	pounds.	
Combined Weight	<u>47.0394</u>	pounds.	
Time	<u>10:33 am</u>		
Pressure	<u>759</u>	torr.	
Temperature	<u>26.0/25.9</u>	degrees F /C	
Humidity	<u>80.0</u>	percent.	

5.5.5 System conditions at maximum vacuum.

Time	<u>11:05am</u>	
Pressure	<u>525</u>	milli torr.
Temperature	<u>18.9/18.6</u>	degrees F /C
Humidity	<u>1.1</u>	percent.
Combined Weight	<u>47.8122</u>	pounds.

5.5.7 System conditions at minimum relative humidity.

Time	<u>11:10am</u>	
Pressure	<u>759</u>	torr.
Temperature	<u>18.9/18.9</u>	degrees F.
Humidity	<u>41.4</u>	percent.
Combined Weight	<u>46.9746</u>	pounds. avg of 5 readings
Canister Weight	<u>37.8508</u>	pounds. " " " "
Fuel Assembly Weight	<u>9.1242</u>	pounds. " " " "

Tester W. S. Lange W. S. Lange Date 8/26/97
(print / sign)

M + TE Nos. {
7C-001 Varian 801 vacuum gage
7C-002 WV-100 gage
3-2097 Humidity sensor
3-2076 Temperature sensor
3-2075 Temperature sensor
3-2077 Scales

Vacuum Drying Test Data for
Wet Fuel Assembly with Standing Water in Canister

Step #

5.5.1 Initial system conditions.

Dry Fuel Assembly Weight 9.1240 pounds. avg of 8 read
Canister Weight 37.8488 pounds. " " " "
Wet Combined Weight 47.6251 pounds. " " " "
Time 8:40 am
Pressure 759 torr. ^{WSL}
Temperature 27.3 / 27.3 degrees ~~F~~. C
Humidity 93.5 percent.

5.5.5 System conditions at maximum vacuum.

Time 3:12 pm
Pressure 400 ^{milli} torr. ^{WSL}
Temperature 9.1 / 8.8 degrees ~~F~~. C
Humidity 0.7 percent.
Combined Weight 47.7525 pounds.

5.5.7 System conditions at minimum relative humidity.

Time 3:18 pm
Pressure 757 torr. ^{WSL}
Temperature 10.2 / 10.1 degrees ~~F~~. C
Humidity 29.5 percent.
Combined Weight 46.9753 pounds.
Canister Weight 37.8490 pounds.
Fuel Assembly Weight 9.1245 pounds.

Tester W-S. Large W.S. Large Date 8/25/97
(print / sign)

M+TE Nos. {
7C-001 Varian 801 vacuum gage
7C-002 WV-100 gage
3-2097 Humidity sensor
3-2076 Temperature sensor
3-2075 Temperature sensor
3-2077 Scales

Vacuum Drying Test Data for
Drip Dry Fuel Assembly in Dry Canister at 40 Torr

Step #

5.5.1 Initial system conditions.

Fuel Assembly Weight N/A pounds.
Canister Weight NA pounds.
Combined Weight NA pounds.
Time NA
Pressure NA torr.
Temperature NA degrees F.
Humidity NA percent.

5.5.5 System conditions at 40 torr.

Time NA
Pressure NA torr.
Temperature NA degrees F.
Humidity NA percent.
Combined Weight NA pounds.
Canister Weight NA pounds.
Fuel Assembly Weight NA pounds.

Tester W.S. Large W. & Large Date 8/26/97
(print / sign)

Can not perform drying test at 40 Torr
because initial steady state pressure
is ~ 25 Torr.

Vacuum Drying Test Data for
Wet Fuel Assembly in Dry Canister at 40 Torr

Step #

5.5.1

Initial system conditions.

Fuel Assembly Weight NA pounds.
Canister Weight NA pounds.
Combined Weight NA pounds.
Time NA.
Pressure NA torr.
Temperature NA degrees F.
Humidity NA percent.

5.5.5

System conditions at 40 torr.

Time NA.
Pressure NA torr.
Temperature NA degrees F.
Humidity NA percent.
Combined Weight NA pounds.
Canister Weight NA pounds.
Fuel Assembly Weight NA pounds.

Tester W.S. Large W. & Large Date 8/26/97
(print / sign)

Can not perform drying test at 40 Torr
because initial steady state pressure is
~ 25 Torr.

FP-721 Procedure

ENGINEERING COMPUTATION SHEET

Project: Canister + SNF + 689 ml of Project No. SPS
 Test: H₂O with no Heat Input Works
 Computer: W. A. Jarge Date: 8/28/97 Sheet No. 1

Time	WV 100 on Canister (Torr)	Edwards 1570 on hose (Torr)	Varian 801 on hose (millitorr)	Canister Weight (pounds)	Relative Humidity (%)	SNF thermocouples (°C)	
Zeroed scales Empty canister				0.0000 37.8488 37.8486 37.8486 37.8486 37.8486		37.8486 lbs avg	
Bare SNF				9.1240 9.1238 9.1240 9.1240 9.1240		9.1240 lbs avg	
Dry canister + SNF				46.9726 46.9726 46.9728 46.9726 46.9726		46.9726 lbs avg	
Added water (~689 ml)							
Canister + SNF + water				48.4842 48.4840 48.4844 48.4842 48.4842 48.4844 48.4844		48.4843 lbs avg	
7:30am	753	—	Room @ 82°F	49.3700	96.0	29.2/29.1	Canister exterior @ bottom 84.2°i
7:34am	753	—	—	49.3544	97.3	29.0/28.9	84.1
M+TE Nos.	7C-002	—	—	3-2077	3-2097	3-2075/3-2076	

Time	WV 100 on Canister (Torr)	Edwards 1570 on hose (Torr)	Varian 801 on hose (millitorr)	Canister Weight (pounds)	Relative Humidity (%)	SNF thermocouples (°C)	Canis Exter at bc
M+TE Nos.	7C-002		7C-001	3-2077	3-2077	3-2075/3-2076	
7:35am	Start up pump @ 92.8 hrs						
7:36am	28	4.13		49.3020	92.7	27.8/27.6	83.6
7:40	21	1.29	1300	49.2490	69.9	22.5/22.4	-
7:45	15	1.19	1300	49.2020	53.9	17.9/17.7	69.0
7:50	12	1.10	1200	49.1696	44.5	15.4/14.8	64.0
8:00	9	0.97	1000	49.1276	33.0	15.1/11.7	57.5
8:10	7	0.89	1000	49.0962	25.8	14.6/14.5	52.6
8:20	6	0.87	950	49.0726	22.5	13.6/13.5	50.4
	Visible condensate on canister exterior						
8:30 am	6	0.84	950	49.0438	20.2	12.5/12.5	47.2
8:40	6	0.84	950	49.0226	20.1	11.6/11.5	47.0
8:50	5	0.82	950	49.0012	19.2	10.7/10.6	46.5
9:00	5	0.82	950	48.9870	18.8	10.2/10.2	
9:10	5	0.82	950	48.9620	18.8	9.5/9.4	45.
9:20	5	0.81	925	48.9450	18.2	9.1/9.0	45.
9:30	5	0.80	925	48.9300	18.0	8.6/8.6	45.
9:40	5	0.80	925	48.9158	18.0	8.3/8.3	44
9:50	5	0.80	925	48.8964	18.0	8.0/8.0	44
10:00	5	0.79	925	48.8756	17.8	7.8/7.8	44
10:10	5	0.79	925	48.8660	17.5	7.7/7.7	44
10:20	5	0.79	900	48.8458	17.3	7.4/7.4	43
10:30	5	0.79	900	48.8344	17.3	7.4/7.3	43
10:40	5	0.79	900	48.8194	17.2	7.3/7.3	43
10:50	5	0.79	900	48.8036	17.1	7.3/7.3	42
11:00	5	0.79	900	48.7882	17.0	7.2/7.2	42
11:10	5	0.79	900	48.7738	17.0	7.3/7.3	42
11:20	5	0.78	900	48.7584	17.0	7.2/7.2	43
11:30	5	0.78	900	48.7424	16.9	7.3/7.2	43
11:40	5	0.78	900	48.7214	16.8	7.3/7.3	43
11:50 am	5	0.78	900	48.6970	16.7	7.2/7.2	43
12:00	5	0.78	900	48.6828	16.7	7.2/7.2	43
	Condensate on scale platform						

Canister + SNF + 689 ml of H_2O
with no Heat Input

Canister W. & Large

8/28/97

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Time	WV 100 on Canister (Torr)	Edwards 1570 on hose (Torr)	Varian 801 on hose (millitorr)	Canister Weight (pounds)	Relative Humidity (%)	SNF thermocouples (°C)	Canister exterior at bottom
M+TE Nos.	7C-002	—	7C-001	3-2077	3-2077	3-2075/3-2076	
12:20pm	5	0.78	900	48.6444	16.5	7.3/7.3	43.2
12:30pm	5	0.78	900	48.6292	16.4	7.3/7.3	42.9
12:40pm	5	0.78	900	48.6066	16.4	7.3/7.2	42.6
12:50pm	5	0.78	900	48.5770	16.3	7.3/7.3	42.6
1:00pm	5	0.78	900	48.5620	16.4	7.3/7.3	42.6
1:10pm	5	0.78	900	48.5352	16.2	7.3/7.3	42.5
1:20pm	5	0.78	900	48.5248	16.2	7.3/7.3	42.3
1:30pm	5	0.78	900	48.5070	16.2	7.4/7.3	42.2
1:40pm	5	0.78	900	48.4930	16.1	7.4/7.4	42.0
1:50pm	5	0.78	900	48.4702	16.0	7.4/7.4	41.9
2:00pm	5	0.78	900	48.4550	15.9	7.4/7.4	41.5
2:10pm	5	0.78	900	48.4388	15.9	7.4/7.4	41.5
2:20pm	5	0.78	900	48.4170	15.8	7.4/7.4	41.3
2:30pm	5	0.78	900	48.4006	15.9	7.3/7.4	41.3
2:40pm	5	0.78	900	48.3840	15.8	7.5/7.5	41.0
2:50pm	5	0.78	900	48.3712	15.9	7.3/7.3	40.8
3:00pm	5	0.78	900	48.3466	15.8	7.5/7.5	40.1
3:10pm	5	0.78	900	48.3320	15.7	7.4/7.4	40.2
3:30pm	5	0.77	900	48.2932	15.5	7.5/7.5	40.2
3:40pm	5	0.77	900	48.2774	15.8	7.4/7.4	40.1
3:50pm	5	0.77	900	48.2566	15.3	7.4/7.4	39.9
4:00pm	5	0.77	900	48.2398	15.2	7.4/7.4	40.0
4:10pm	5	0.77	900	48.2252	15.0	7.3/7.3	40.1
4:20pm	5	0.77	900	48.2046	14.9	7.4/7.4	40.1
4:30pm	5	0.77	900	48.1880	14.7	7.4/7.4	40.1
4:50pm	5	0.76	900	48.1504	14.6	7.6/7.5	39.8
5:00pm	5	0.76	900	48.1314	14.5	7.6/7.5	39.6
5:10pm	5	0.76	900	48.1218	14.4	7.6/7.6	39.7°F
5:20pm	5	0.76	900	48.1066	14.4	7.6/7.6	39.4°F
5:30pm	5	0.76	900	48.0866	14.3	7.6/7.6	39.1°F

Canister + SNF + 689 ml
of H₂O with no Heat Input

Computer W. & L. Large 8/28/97

Time	WV 100 on canister (Torr)	Edwards 1570 on hose (Torr)	Varian 801 on hose (millitorr)	Canister Weight (pounds)	Relative Humidity (%)	SNF thermocouples (°C)
Canister + SNF after drying with condensate ^{present} on scales / canister				47.0508		
Dried scales and rezeroed				0.0000		M+TE No. 3-20'
Canister + SNF after removing condensate on canister exterior				46.9730 46.9730 46.9730 46.9726 46.9726		46.9728 lbs avg
Cold bare SNF with condensate film				9.1256 9.1258 9.1260 9.1262 9.1264		9.1260 lbs avg
Empty canister				37.8498 37.8500 37.8498 37.8500 37.8498		37.8499 lbs avg
Checked zero				0.0000		

Canister + SNF + 689 ml of
H₂O with no Heat Input

Computer

W. & Large

8/28/97

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Time	WV 100 on Canister (Torr)	Edwards 1570 on 1/2" hose (Torr)	Varian 801 on 1/2" hose (millitorr)	Canister Weight (pounds)	Relative Humidity (%)	SNF thermocouples (°C)	Canister Exterior at bottom
5:40pm	4	0.76	900	48.0706	14.3	7.6/7.6	39.0°F
5:50	4	0.76	900	48.0556	14.2	7.7/7.7	38.8°F
6:00pm	4	0.76	900	48.0380	14.1	7.7/7.7	38.5
6:10p	4	0.76	900	48.0236	14.0	7.7/7.7	39.1
6:20pm	4	0.76	900	48.0032	13.9	7.7/7.7	39.3
6:30	4	0.76	900	47.9878	13.9	7.7/7.7	39.7
6:40	4	0.76	900	47.9738	13.9	7.7/7.7	39.3
6:50	4	0.75	900	47.9580	13.8	7.7/7.7	39.7
7:00	4	0.75	900	47.9362	13.7	7.6/7.6	39.3
7:10	4	0.75	900	47.9228	13.7	7.6/7.6	40.1
7:20	4	0.75	900	47.9070	13.6	7.6/7.6	40.5
7:30pm	4	0.75	900	47.8912	13.8	7.6/7.6	39.8
7:40p	4	0.75	900	47.8746	13.9	7.6/7.6	35.4
7:50p	4	0.75	900	47.8604	14.0	7.7/7.7	37.6
8:00pm	4	0.75	900	47.8396	14.0	7.6/7.6	38.9
8:10pm	4	0.75	900	47.8254	13.7	7.6/7.6	Room 38°F 45.3°F
8:24pm	4	0.73	900	47.8074	12.9	7.5/7.5	52.1°F
8:30pm	4	0.71	850	47.8022	11.4	7.5/7.5	54.2°F
8:32pm	3	0.70	850	47.7992	10.7	7.5/7.5	55.8
8:35pm	3	0.69	800	47.7980	9.5	7.6/7.6	57.6
8:37pm	2	0.65	800	47.7982	5.3	7.6/7.6	58.3
8:40pm	660mT	0.43	550	47.7958	1.6	7.9/7.6	Room 37°F 59.9
8:45pm	530mT	0.34	470	47.7912	1.0	7.9/7.5	62.5
8:50pm	455mT	0.30	420	47.7880	0.8	8.1/7.7	64.9
8:55pm	405mT	0.28	390	47.7866	0.6	8.2/7.9	66.7
8:56pm	Shut	down	pumps	at	106.2	hours	
9:00pm	751T	—	—	47.8556	29.1	8.4/8.6	67.4°F
M. & T.E. Nos.	7C-002	—	7C-001	3-2017	3-2097	3-2075/3-2076	
Removed 689 ml (1.45 pints) in no heat input				13.4	hours	with	

E.G. KEEPING COMP. TAT. C. 1-10-11

Canister + SNF + 46 l ml H_2O 2000
with no Heat Input 2000
Computer W. & Large 2000

8/27/97

1

[illegible]

FP-721 Procedure

ENGINEERING COMPUTATION SHEET

Canister + SNF + 461 ml of H₂O with no Heat Input
 Computer W. S. Lunge Date 8/27/97

PS
 17

Time	WV 100 on Canister (Torr)	Edwards 1570 on hose (Torr)	Varian 801 on hose (millitorr)	Canister Weight (pounds)	Relative Humidity (%)	SNF thermocouples (°C)	
Bare SNF				9.1240	avg		
Empty canister + lid				37.8498	avg		
Dry Canister + Dry SNF + lid				46.9736	avg		
Wet canister + wet SNF + lid				47.9866	avg	Room @ 82°F	Canister External at bot
6:05 am	757	-	-	48.9440	97.1	28.9/28.9°C	83.6
6:07 am	757	-	-	48.9346	97.8	28.8/28.7	83.6
6:08	Start up pump		@ 83.8 hrs				
6:08	27	7.61	-	48.8600	92.3	27.0/27.0	82.3
6:11	22	1.42	-	48.8364	77.9	24.0/24.0	77.8
6:15	17	1.31	1250	48.8052	60.4	19.5/19.6	71.7
6:20	12	1.15	1200	48.7712	46.7	18.1/18.1	64.7
6:25 am	10	1.05	1200	48.7474	38.2	16.8/16.7	59.0
6:30 am	9	1.00	1200	48.7304	32.3	16.6/16.5	55.0
6:35 am	8	0.94	1100	48.7150	28.2	16.3/16.2	53.1
6:40 am	7	0.90	1100	48.7024	26.0	15.6/15.4	51.6
6:45 am	6	0.88	1000	48.6910	23.2	14.9/14.7	49.9
6:50	6	0.87	1000	48.6804	22.1	14.2/14.1	49.3
7:00	6	0.85	1000	48.6596	20.7	13.6/13.0	47.9
7:10	6	0.84	1000	48.6396	20.2	11.8/11.7	45.0
7:20	5	0.83	1000	48.6218	20.1	10.8/10.7	41.6
Room @ 80°F		Visible	condensate	on canister	bottom	3" of bottom canister	
7:30	5	0.83	1000	48.6048	19.9	9.9/9.8	41.2
7:40	5	0.83	1000	48.5886	19.5	9.4/9.2	40.7
7:50	5	0.82	1000	48.5714	19.1	8.7/8.6	40.0
8:00	5	0.82	1000	48.5568	17.7	8.2/8.1	40.0
8:10	5	0.82	1000	48.5402	18.6	7.9/7.8	40.0
8:20	5	0.81	0.950	48.5246	18.5	7.6/7.5	40.0
8:30 am	5	0.81	0.950	48.5088	18.6	7.4/7.2	39.5
M+TE Abs	7C-002		7C-001	3-2077	3-2097	3-2075/3-2076	

THE LUBBERING COMPANY, INC. 10000

2025. 4. 2

Works

2. Der

W. E. Large

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8/27/97

Time	WV 100 on Canister (Torr)	Edwards 15 70 on hose (Torr)	Varian 801 on hose (millitorr)	Canister Weight (pounds)	Relative Humidity (%)	SNF thermocouples (°C)	Canister external at bottom °F
8:40 am	5	0.81	0.950	48.4934	18.7	7.0/6.9	39.30
Room @ 81°F	5	0.80	0.925	48.4786	18.6	6.9/6.8	38.9
9:00	5	0.80	0.925	48.4652	18.3	6.6/6.5	39.0
9:10	5	0.80	0.925	48.4502	18.3	6.6/6.5	38.5
9:20	5	0.80	0.925	48.4354	18.2	6.6/6.4	38.4
9:30	5	0.80	0.925	48.4208	18.2	6.4/6.3	38.0
9:40	5	0.80	0.925	48.4060	17.9	6.3/6.2	38.0
Room @ 82°F	5	0.80	0.925	48.3924	17.7	6.3/6.2	38.5
10:00	5	0.80	0.925	48.3796	17.7	6.2/6.1	38.0
10:10	5	0.79	0.900	48.3766	17.2	6.1/6.1	38.0
4 pieces of neoprene added on the scale							
10:20	5	0.79	0.900	48.3632	17.1	6.2/6.0	38.0
Room @ 83°F	5	0.79	0.900	48.3478	16.9	6.2/6.1	38.0
10:40	5	0.79	0.900	48.3334	16.7	6.2/6.1	38.0
10:50	5	0.79	0.900	48.3186	16.7	6.2/6.2	38.0
S/D pump @ 10:50 am							
Not Recording 11:37	12	>10.58	—	48.3028			51
Restart pump @ 88.5 hours @ 11:37 am							
11:40	10	1.00	1.100	48.2932	34.1	11.5/11.4	54.0
11:50	6	0.84	950	48.2740	20.9	11.6/11.5	45.0
12:00	5	0.82	900	48.2584	18.6	11.4/11.3	42.0
12:10	5	0.81	900	48.2408	17.5	11.0/10.9	40.0
12:20	5	0.80	900	48.2232	17.0	10.4/10.3	39.0
12:30	5	0.80	900	48.2092	16.6	10.0/9.9	39.0
12:40	5	0.79	900	48.1938	16.3	9.5/9.4	39.0
Room @ 84°F	5	0.79	900	48.1780	16.2	9.1/9.0	39.0
13:00	5	0.78	900	48.1628	15.9	8.8/8.8	39.0
13:10	5	0.78	900	48.1474	15.7	8.5/8.4	38.0
13:20	5	0.78	900	48.1326	15.6	8.4/8.3	38.0
13:30	5	0.78	900	48.1164	15.7	8.1/8.0	38.0
13:40	4	0.77	900	48.1020	15.3	8.0/7.9	38.0
M+TE Nos.	7C-002	—	7C-001	3-2077	3-2097	3-2015/3-2076	

ANALYZING COMPUTATION SHEET

Project No.

二、

Works

Summary

W. L. Lange

Date

8/27/97

11

from
@ 86°F

F P-721 Procedure

ENGINEERING COMPUTATION SHEET

Dry Fuel Assembly in Dry
Canister

Project No.

Works

Computer *W. & L. Large*

Date

8/26/97

Sheet No.

Time	WV 100 on Canister (Torr)	Edwards 1570 on hose (Torr)	Varian 801 on hose (millitorr)	Canister Weight (pounds)	Relative Humidity (%)	SNF thermocouples (°C)
Zeroed scales Bare SNF				0.0000 9.1242 9.1242 9.1242 9.1244 9.1244		9.1243 lbs avg
Empty Canister				37.8498 37.8498 37.8496 37.8498 37.8498 46.9736 46.9736 46.9738 46.9738 46.9740		37.8498 lbs avg 46.9738 lbs avg
Canister + SNF				47.8156	50.8	28.4/28.3
8:29a	759			47.7552	1.0	28.3/28.2
8:35a	S/U pump @		82.6 hrs	47.7530	0.5	28.2/28.1
8:36a	710 mT			47.7510	0.4	28.2/28.1
8:38a	598 mT	0.39		47.7490	0.2	28.2/28.1
8:40a	574 mT	0.39		47.7468	0.1	28.3/28.2
8:42a	556 mT	0.38		46.9744	46	28.3/28.2
8:45a	530 mT	0.39		46.9744		
8:46a	S/D pump @		82.8 hrs	46.9742		46.9743 lbs avg
8:53a	759T			46.9742		
Canister + SNF				46.9744		
M+TE Nos.	76-002			3-2077	3-2097	3-2075/3-2076

ENGINEERING COMPLETION SHEET

ה'תשנ"ב

Works

Computer

W. L. Large

Date _____

8/26/97

Page 2

WV 100
OR
Canister
(Torr)

Edwards 1570
on hose
(Torr)

Värjan 801
on höse
(millitorr)

Canister
Weight
(pounds)

Relative Humidity
(%)

SNF thermocouples
(°C)

Empty Canister

37,8506
37,8504
~~37,8504~~
37,8504
37,8504

37,8504 avg lbs

Bare SNE

9.1242
9.1242
9.1244
9.1242
9.1242

9.1242 avg 16s

M + TE No.

3-2077

FP-721 Procedure

ENGINEERING COMPUTATION SHEET

Title of Project:

Drip Dry Fuel Assembly in
Dry Canister

Project No

SP

Object:

Works

Computer: W. & Sarge

Date 8/26/97

Sign

Time	WV 100 on Canister (Torr)	Edwards 1570 on hose (Torr)	Varian 801 on hose (millitorr)	Canister Weight (pounds)	Relative Humidity (%)	SNF thermocouples (°C)
Empty Canister				37.8504 37.8502 37.8504 37.8504 37.8504		37.8504 lbs avg
Canister + Wet SNF				46.9962 46.9960 46.9960 46.9958 46.9960		46.9960 lbs avg
9:22am	75.9			47.8158	85.1	27.5/27.6 °C
9:24a	Start up pump @ 82.8 hrs					
9:25a	23	7.51		47.7516	72	20.0/24.8
9:26a	1.5	1.25		47.7416	48	20.1/20.9
9:27a	7	0.92		47.7334	9.7	19.2/18.7
9:28	14.13 mT	0.68		47.7320	4.2	19.7/19.1
9:29	1135 mT	0.65		47.7312	3.2	20.1/19.5
9:30	1059 mT	0.63		47.7304	2.9	20.3/19.9
9:31	952 mT	0.60		47.7292	2.4	20.8/20.3
9:32	891 mT	0.57		47.7280	2.2	21.1/20.6
9:33	805 mT	0.54		47.7268	2.0	21.5/21.0
9:34	750 mT	0.52		47.7258	1.7	21.7/21.3
9:35am	706 mT	0.50		47.7244	1.7	22.0/21.6
M&TE Nos	3-WSL 7C-002	8/26/97		3-2077	3-2097	3-2075/3-2076

FP-721 Procedure

ENGINEERING COMPUTATION SHEET

Title of Project

Drip Dry Fuel Assembly in
Dry Canister

Project No

SRS

Date

Works

Computer

W. S. Large

Date

8/26/97

Sheet 4

Time	WV 100 on Canister (Torr)	Edwards 1570 on hose (Torr)	Varian 801 on hose (millitorr)	Canister Weight (pounds)	Relative Humidity (%)	SNF thermocouples (°C)
9:36a	683mT	0.48	-	47.7236	1.4	22.1/21.7
9:37a	663mT	0.47	-	47.7228	1.4	22.2/21.9
9:40a	615mT	0.43		47.7206	1.2	22.7/22.3
9:43a	578mT	0.40		47.7188	1.1	23.0/22.7
9:45a	558mT	0.39		47.7176	1.0	23.2/22.8
9:47a	539mT	0.38		47.7166	0.9	23.3/23.1
9:50a	510mT	0.36		47.7152	0.7	23.6/23.3
9:51a	Shut	down pump @ 83.2 hrs				
9:54a	759T				41.8	23.8/23.7
Canister + SNF				46.9744		46.9743 avg lbs
				46.9742		
				46.9742		
				46.9744		
				46.9744		
Empty Canister				37.8506		37.8505 avg lbs
				37.8504		
				37.8506		
				37.8504		
				37.8504		
Bare SNF				9.1244		9.1243 avg lbs
				9.1242		
				9.1244		
				9.1242		
				9.1242		
M+TE Nos.	7C-002	-		3-2077	3-2091	3-2075/3-2076

FP-721 Procedure

OSR 25.00 Rev. 8-92
Sheet 26 of 100

ENGINEERING COMPUTATION SHEET

Title of Project Submerged Assembly Transferred Project No. _____
Subject into Dry Canister Works _____
Computer W. S. Sarge Date 8/26/97 Sheet No. _____

Time	WV 100 on Canister (Torr)	Edwards 1570 on hose (Torr)	Variac 801 on hose (millitorr)	Canister Weight (pounds)	Relative Humidity (%)	SNF thermocouples (°C)
Canister + Wet SNF				47.0396 47.0394 47.0394 47.0394 47.0394		47.0394 avg
10:33am	759	-	-	47.9526	80.0	26.0/25.9
10:33am	Start	up pump	at	83.2 hrs		
10:34am	24	-	-	47.8946	76.2	25.0/24.9
10:36am	18	12.9	-	47.8714	57.2	20.6/20.7
10:40am	10	1.02	-	47.8500	29.4	18.4/18.0
10:45am	3	0.75		47.8438	9.2	18.8/18.5
10:50am	1125mT	0.62		47.8346	3.4	19.0/18.5
10:55am	665mT	0.47		47.8232	1.8	19.0/18.5
11:00am	596mT	0.41		47.8176	1.4	18.9/18.5
11:05am	525mT	0.37		47.8122	1.1	18.9/18.6
11:08am	Shut	down pump	at	83.8 hrs		
11:10am	759			47.8546	41.4	18.9/18.9
M&TE Nos.	7C-002			3-2077	3-2097	3-2075/3-2076
Canister + SNF				46.9748 46.9746 46.9748 46.9748 46.9746		46.9747 lbs avg

FP-721 Procedure

ENGINEERING COMPUTATION SHEET

Project: Submerged Assembly Transferred
 Into: Dry Canister
 Computer: W. & Long Date: 8/26/97
 SRS
 Works: _____
 Sheet No: 6

Time	WV 100 on Canister (Torr)	Edwards 1570 on hose (Torr)	Varian 801 on hose (millitorr)	Canister Weight (pounds)	Relative Humidity (%)	SNF thermocouples (°C)
Empty	Canister			37.8508 37.8508 37.8508 37.8508 37.8508		37.8508 lbs avg
Bare	SNF			9.1242 9.1242 9.1242 9.1242 9.1242		9.1242 lbs avg
M&TE No.				3-2077		

Procedure FP-721

ENGINEERING COMPUTATION SHEET

Title of Project

Canister + SNF + 297 ml of

Project No

SPS

Object

H₂O at ~4.8 watts

Works

Computer

W. S. Large

Date

8/21/97

1

Time	WV 100 on Canister (Torr)	Edwards 1570 on hose (Torr)	Varian 801 on hose (millitorr)	Canister Weight (pounds)	Relative Humidity (%)	SNF thermocouples (°C)
M+TE Nos.	7C-002	-	7C-001	3-2077	3-2097	3-2075/3-2076
Dry Canister + SNF + lid + sensor (avg)				46.9733		
Wet Canister + wet SNF + lid + sensor (avg)				47.6260		
7:50a	Heaters on @ 16 VDC * 0.3 amps =				4.8 watts	
7:58a	753			48.4894		Room @ 84°F
8:07a	5/11	pump @	70.6 hrs			
8:10a	5/11	computer				
8:10a	24	7.9	-	48.4080	74.5	25.2/25.2
8:12a	20	7.41	-		64	23.1/23.0
8:14a	16	1.35	-	48.3840	52.5	22.6/22.5
8:18	12	1.16	1200	48.3606	37.5	23.0/22.8
8:20	10	1.11	1200	48.3527	32.8	23.2/22.9
8:25	8	1.04	1100	48.3396	27.4	23.2/23.1
8:30	7	0.98	1100	48.3247	23.5	22.5/22.3
8:35	7	0.96	1000	48.3140	21.9	21.9/21.7
8:40	7	0.94	1000	48.3014	20.4	21.1/21.0
8:50	6	0.92	1000	48.2787	19.1	19.4/19.3
8:55	Visible condensate on exterior bottom 6 inches of canister					
9:00	6	0.90	1000	48.2600	18.5	18.2/18.1
9:10	6	0.89	1000	48.2400	17.9	17.1/17.0
9:20	6	0.89	1000	48.2225	17.7	16.3/16.2
9:30	6	0.88	1000	48.2010	17.5	15.6/15.5
9:40a	6	0.87	1000	48.1855	17.4	15.0/14.9
9:50a	6	0.87	1000	48.1689	17.2	14.5/14.5
10:00a	5	0.86	1000	48.1515	17.1	14.1/14.0
	Puddle on scale platform					
10:10a	5	0.86	1000	48.1352	17.0	13.9/13.7
10:20	5	0.86	1000	48.1178	16.9	13.6/13.5
10:30a	5	0.85	1000	48.1023	16.7	13.3/13.3
10:40a	5	0.85	1000	48.0862	16.7	13.2/13.1
10:50a	5	0.85	1000	48.0695	16.5	13.1/13.0
11:00a	5	0.85	1000	48.0540	16.5	13.0/12.9
11:10a	5	0.84	1000	48.0377	16.5	12.9/12.7
11:20a	5	0.84	1000	48.0111	16.4	12.8/12.8

4. KEEPING COVID-19 IN CHECK

Project No.

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Computer

Date _____

[illegible]

MATE No	7C-002	-	7C-001	3-2077	3-2097	3-2075/3-2076
11:30a	5	0.84	1000	47.942	16.3	12.6/12.6
11:40a	5	0.84	1000	47.9789	16.3	12.5/12.5
11:50a	5	0.83	1000	47.9634	16.1	12.5/12.4
12:00p	5	0.83	1000	47.9373	15.9	12.5/12.4
12:10p	5	0.83	1000	47.9211	15.9	12.5/12.4
12:20p	5	0.83	1000	47.9059	15.8	12.4/12.3
12:30p	5	0.83	1000	47.8904	15.7	12.3/12.3
12:40pm	5	0.83	975	47.8751	16.0	12.4/12.3
12:50	4	0.80	925	47.8511	13.1	12.4/12.3
1:00pm	648mT	0.44	560	47.8399	1.6	12.5/12.4
1:02p	608mT	0.41	540	47.8385	1.4	12.7/12.6
1:05pm	560mT	0.37	500	47.8367	1.2	12.8/12.7
1:07p	525mT	0.35	480	47.8357	1.0	12.9/12.8
1:10pm	495mT	0.33	450	47.8342	1.0	13.0/12.9
1:12pm	470mT	0.32	440	47.8334	0.8	13.3/13.2
1:15pm	445mT	0.31	420	47.8327	0.8	13.4/13.3
1:17pm	425mT	0.30	410	47.8320	0.7	13.7/13.6
1:20pm	410mT	0.29	400	47.8311	0.6	14.0/13.9
1:25pm	385mT	0.27	380	47.8300	0.5	14.5/14.4
1:30pm	365mT	0.26	360	47.8284	0.4	15.1/15.1
1:35pm	350mT	0.25	340	47.8270	0.3	15.7/15.6
1:36pm	S/D	pump @	76.1	hrs	0.1	

1:36 p.m.	S/D pump @ 76.1 hrs		
	Vent hose and turn off heaters		
	Removed canister from scales		
	Dried canister exterior and scale platform		
	Rezeroed scales		
	Dry canister + SNF + lid + sensor	46.9748 (avg)	or 0.7 grams higher than at start of test

Removed 29.7 ml of H_2O in 5.5 hours @ ~ 4.8 watts
SNF surface temperature dropped $\sim 2.9^\circ C$ during drying

Pretest

Procedure FP-721

8/21/91

W. & Lan

Scales as-found

-0.01105 lbs

Zeroed

0.0000 lbs

Dry canister + SNF + lid
+ sensor

46.9732 lbs

46.9733

46.9734

Avg = 46.9733

46.9733

46.9732

46.9732

Added ~ 300 ml of H₂O to canister (~1" in bottom)Wet canister + wet SNF
+ lid + sensor

47.6259 lbs

47.6260

47.6260

Avg = 47.6260 lb

47.6260

47.6259

47.6259

H₂O weight = ΔW_{AVG}

= 0.6527 lbs = 296.0 gm = 297.3

Post testDried canister + dried SNF
+ lid + sensor *

46.9747 lbs

46.9749

46.9749

Avg = 46.9748 lbs

46.9749

46.9748

46.9746

* Dried canister exterior

Dried condensate puddle on scales } Prior to readings

Zeroed scales to 0.0002 lbs

 $\Delta W_{\text{AVG}} = 0.6512 \text{ lbs} = 295.4 \text{ gms} = 296.6 \text{ m}$
cross check

Scales M+TE No. 3-2077

Title of Project

Canister + SNF + 448 ml of
H₂O at 14 watts

Project No

SRS

Object

Work

Computer

W. & Large

Date

8/20/97

Sheet

1

Time	WV 100 on Canister (Torr)	Edwards 1570 on hose (Torr)	Varian 801 on hose (millitorr)	Canister Weight (pounds)	Relative Humidity (%)	SNF thermocouples (°C)
Bare SNF (avg)				9.1239		
Dry Canister + SNF + lid + sensor (avg)				46.9735		
Wet Canister + SNF + lid + sensor (avg)				47.9562		
Heaters on @ 28VDC * 0.5 amp = 14 watts					@ 8:53 am	
Room @ 86°F						
8:53am	755			49.0114		
8:55a	5/11	pump @ 63.8 hrs				
8:56a	25	6.47		48.9480		
8:57a	18	1.42	140.0	48.9236	51.5	32.9/33.2°C 86°F room temp
9:03a	14	1.29	1300	48.8854	37.4	33.5/33.3
9:05a	12	1.24	1300	48.8742	34.9	33.3/33.1
9:10a	10	1.17	1200	48.8482	30.0	32.4/32.2
9:15a	9	1.12	1200	48.8262	27	31.1/31.0
9:20a	8	1.08	1200	48.8072	24	30.1/29.9
9:30a	7	1.02	1200	48.7714	22	27.8/27.7
9:40a	7	1.01	1150	48.7418	20.2	26.2/26.1
10:00a	6	0.97	1100	48.6832	18.8	23.1/23.77
10:10a	6	0.96	1100	48.6586	18.1	23.1/23.0
10:20a	6	0.95	1100	48.6348	18.3	22.5/22.4
		Visible condensate on exterior of canister (~5" high) and puddle on scale platform				
10:30a	6	0.94	1100	48.6084	17.8	22.1/22.0
10:40a	6	0.93	1100	48.5848	17.6	21.7/21.6
10:50a	6	0.93	1100	48.5442	17.6	21.4/21.3
		Condensate on exterior of canister continues. Puddle on scale platform is dripping off edge of scales				
11:03a	6	0.92	1100	48.5146	17.6	21.2/21.1
11:10a	6	0.92	1100	48.5000	17.5	21.1/21.0
11:20a	6	0.92	1100	48.4700	17.7	21.0/20.9
11:30a	6	0.91	1100	48.4452	17.3	20.9/20.8
11:40a	6	0.91	1100	48.4180	17.2	20.8/20.7
8/20/97 10:50a	6	0.90	1100	48.3966	17.2	20.6/20.6
M+TE Nos.	7C-002		7C-001	3-2077	3-2097	3-2075/3-2076

Procedure FP-721

ENGINEERING COMPUTATION SHEET

Title of Project

Canister + SNF + 448 ml of
H₂O at 14 watts

Project No.

SRS

Works

Computer W. & Large Date

8/20/97

Time	WV 100 on Canister (Torr)	Edwards 1570 on hose (Torr)	Varian 801 on hose (millitorr)	Canister Weight (pounds)	Relative Humidity (%)	SNF thermocouples (°C)
12:00 pm	6	0.90	1050	48.3722	17.0	20.6 / 20.5
12:12 pm	6	0.90	1050	48.3432	16.6	20.57 / 20.5
12:20 p	6	0.89	1050	48.3282	16.8	20.6 / 20.5
12:30 p	6	0.89	1050	48.3050	16.7	20.6 / 20.5
12:35 p		Scales died - no display but computer reads value				
12:40 p	6	0.89	1050		16.5	20.6 / 20.5
		Lifted canister and attempted to zero scales				
		Still no display on				
WSL 8/20/97 12:45 p	6	0.89	1000	48.0876 ⁺	16.7	20.4 / 20.3
		⁺ computer display only on all weight values				
12:50 p	6	0.89	1000	48.0578	16.6	20.4 / 20.4
1:00 p	6	0.89	1000	48.0599	16.6	20.4 / 20.3
1:10 p	6	0.88	1000	48.0395	16.4	20.4 / 20.3 shifting 0.
1:20 p	6	0.88	1000	48.0198	16.4	20.5 / 20.4 shifting 0.
1:30 p	6	0.88	1000	48.0005	16.3	20.5 / 20.5
		Still have puddle on scale platform				
1:40 p	6	0.88	1000	47.9813	16.4	20.6 / 20.5 shifting 0.
1:50 p	6	0.88	1000	47.9540	16.1	20.6 / 20.6
		Bottom 4" of canister covered in condensate on exterior and very cold to the touch				
2:00 p	6	0.88	1000	47.9355	16.0	20.6 / 20.6
2:12 p	6	0.87	1000	47.9123	15.8	20.6 / 20.6
2:20 p	6	0.87	1000	47.8971	15.7	20.7 / 20.6 shifting 0.
2:31 p	6	0.87	1000	47.8677	15.5	20.7 / 20.7
2:40 p	6	0.86	1000	47.8512	15.4	20.7 / 20.7
2:50 p	6	0.86	1000	47.8325	15.4	20.8 / 20.8
3:00 p	6	0.87	1000	47.8133	15.7	20.9 / 20.8
3:10 p	5	0.84	1000	47.7909	13.0	21.0 / 20.9
3:12 p	4	0.79	975	47.7884	10.4	21.0 / 21.0
3:13 p	3	0.73	900	47.7865	6.6	21.0 / 21.0
3:14 p	17.3 mT	0.68	850	47.7852	4.3	21.0 / 20.9
3:15 p	1000 mT	0.61	750	47.7832	2.3	21.0 / 20.9
M+TE Nos.	7C-002		7C-001	32077	32097	32075 / 32076

ENGINEERING COMPUTATION SHEET

1992

Project No.

U D U

Notes

Computer

W. & Large

Date:

8/20/97

3

Time	WV 100 on Canister (Torr)	Edwards 1570 on hose (Torr)	Varian 801 on hose (millitorr)	Canister Weight (pounds)	Relative Humidity (%)	SNF thermocouples (°C)
3:17pm	740mT	0.51	675	47.7810	1.5	20.9/20.9
3:20pm	640mT	0.43	575	47.7770	1.1	21.0/21.1
3:22pm	600mT	0.40	550	47.7755	1.0	21.2/21.2
3:25pm	560mT	0.37	525	47.7735	0.8	21.5/21.5
3:27pm	540mT	0.35	500	47.7724	0.7	21.7/21.7
3:30pm	495mT	0.33	470	47.7710	0.5	22.0/22.0
3:32pm	480mT	0.32	460	47.7700	0.5	22.2/22.4
3:35pm	455mT	0.30	440	47.7690	0.4	22.6/22.8
3:37pm	445mT	0.30	430	47.7683	0.4	23.0/23.1
3:40pm	425mT	0.28	420	47.7673	0.3	23.3/23.7
M+TE Nos.	7C-002		7C-001	32077	32097	32075/32076
S/D	vacuum pump @ 70.6 hours @				3:41 pm	and vented hose
	S/D heaters					
	Restarted scales and restored display					
	Removed canister and dried exterior and dried scale platform with towels					
	Placed dried canister back on dried scale platform					
	Dried Canister + SNF + lid + sensor			46.9741 lb		
				46.9743		
				46.9742		
				46.9742		
				46.9740		
				46.9740	Avg = 46.9741 lbs or	
						0.3grams higher than at start of t
	SNF dry cold and dry			per visual inspection		
	Canister interior dry			per visual inspection		
	Removed 448ml H ₂ O (0.95 pint) in 6.77 hours @ 14 watts					
	SNF surface temperature dropped ~ 13.1°C during drying					

Prestartup

Procedure FP-721

8/20/97
sheet 4
W. & Lai

Scales as found

0.0002 lbs

Zeroed scales

0.0000 lbs

Bare SNF

9.1238 lbs

9.1240

9.1240

9.1240

9.1238

Avg = 9.1239 lbs

Dry canister + dry SNF
+ lid + sensor

46.9734 lbs

46.9736

46.9734

46.9736

46.9734

Avg = 46.9735 lbs

Scales M+TE No. 32077

Added ~ 475 ml H₂O (1 $\frac{3}{4}$ " water in bottom of canister)

8:33am Aborted pump startup when scales lost power

Wet canister +
wet SNF + lid
+ sensor after
aborted startup

47.9562 lbs

47.9562

47.9562

47.9564

47.9560

47.9562

47.9562

47.9562

Avg = 47.9562 lbs

Post test
H₂O weight = $\Delta W_{\text{avg}} = 0.9827 \text{ lbs} = 445.7 \text{ gms} = 447.7 \text{ ml}$

Dried canister + dried

46.9741 lbs

SNF + lid + sensor

46.9743

after drying canister
exterior, scale platform
and rezeroing scales

46.9742

46.9742

46.9740

46.9740

Avg = 46.9741 lbs

 $\Delta W_{\text{check}} = 0.9821 \text{ lbs} = 445.5 \text{ gms} = 447.4 \text{ ml}$

8/19/97

Field Procedure FP-721

Canister + SNF + 291. ml of H_2O
 (1" in bottom of canister)
 at 14 watts. Heat Input

Page 1

W. S. Large

Time	WV100 on canister (Torr)	Edwards 1570 on 1 1/2" hose (Torr)	Vacum 801 on 1 1/2" hose (millitorr)	Canister Weight (pounds)	Relative Humidity (%)	SNF thermometer (°C)
7:50am	75.5T	-	-	48.3710	86%	31.9/32.1
7:58	3/U	pump @ 59.15 hrs		48.2990	68%	Haltian @ 28VDC + 0.5amp = 14 watts Audible "popping" as water boils
7:58	26T	6.22T	-	48.2860	-	
8:00	21T	6.22	-	48.2462	32.3	
8:06	Booster on 12 -	1.28	1300	48.2200	25.2	34.0/33.9
8:12	9	1.17	1250	48.1874	20.4	33.2/32.9
8:22	7	1.07	1200	48.1566	18.6	30.9/30.8
8:33	7	1.04	1200	48.1260	17.7	28.9/27.7
8:45	6	1.02	1150	48.1106	17.7	27.2/27.1
8:51	6	1.01	1150	48.0922	17.4	26.5/26.4
9:03	6	1.00	1100	48.0606	17.3	25.3/25.2
.12	6	0.99	1100	48.0448	17.3	24.5/24.3
9:20am	6	0.99	1100	48.0222	16.9	24.0/23.9
9:30am	6 Vac. Pump skid	0.97 Pump Circ Wtr Inlet = 77°F	1100 Tank (Pump Outlet) = 90°F	C.W. inlet = 22psig, 76°F	C.W. outlet = 80°F	88°F Pump inlet @ ~ 2 psig, Pump Inlet Vac = 29.5" Hg
9:40am	6	0.97	1100	47.9996	16.7	23.5/23.3
9:50am	6	0.96	1100	47.9586	16.7	23.0/22.9
10:00am	6	0.96	1100	47.9234	16.4	22.6/22.5
10:16am	6	0.94	1100	47.9164	16.4	22.5/22.3
10:20am	6	0.94	1100	47.8970	16.3	22.0/21.9
10:30am	6 Vac. Pump skid	0.93 Pump Circ Wtr Inlet = 76°F	1100 Tank (Pump Outlet) = 90°F	C.W. inlet = 22psig @ 76°F	C.W. outlet = 80°F	21.9/21.8
10:40am	6	0.93	1100	47.8770	16.1	21.8/21.7
10:52am	6	0.93	1100	47.8506	16.0	21.6/21.5
11:00am	6	0.92	1100	47.8370	15.9	21.5/21.4
11:10am	6	0.92	1100	47.8140	16.0	21.4/21.4
M & TE Nos.	7C-002		7C-001	32077	32097	21.4/21.3
						32075/32076

Field Procedure FP-721
8/19/97 Canister + SNF + 29 ml of H₂O continued Page

Canister + SNF + 291 ml of H_2O

continued

Page

SNF Thermocou

(°C)

[illegible]

Prestartup

Field Procedure FP-721
W.S. Large

8/19/97
Page 3

Zeroed scales

0.0000 lbs @ 7:12am

Dry canister + dry SNF
+ lid + sensor

46.9740
46.9738
46.9736
46.9738
46.9738

Avg = 46.9738 lbs

added ~ 300 ml H_2O (1" water in bottom of ~~canister~~ ^{ws Large})

Wet canister + SNF
+ lid + sensor

47.6134
47.6134
47.6132
47.6132
47.6132
47.6132

Avg = 47.6133 lbs

$\Delta W_{Avg} = H_2O \text{ weight} = 0.6395 \text{ lbs} = 290.05 \text{ grams} = 291.3 \text{ ml}$
 $= 0.61 \text{ pints}$

Post test

Dry canister + SNF
+ lid + sensor

47.0118
47.0120
47.0118
47.0120
47.0118

Avg = 47.0119 lbs

Scales M+TE No. 32077

ONR 25 100 100 100
100 100 100 100

Title of Project

Project No. _____

Subject

Works

Computer

Date _____

$$\overline{8} \overline{18} \overline{97}$$

Sheet No.

SR

Time	WV100 on Canister (Torr)	Edwards 1570 on hose (Torr)	Varian 801 on hose (millitorr)	Canister Weight (pounds)	Relative Humidity (%)	SNF thermocouples (°C)
MTE Nos.	7C-002	-	7C-001	3-2077	3-2097	3-2075/3-2076
Bare SNF				9.1239	(avg)	
Empty canister + lid + sensor				37.8509	(avg)	
Dry canister + SNF + lid + sensor				46.9738	(avg)	
Wet canister + SNF + lid + sensor				47.0072	(avg)	
Heaters on @ 28 VDC * 0.5 amp =				14 watts		
1:54pm S/U pump @			58.5 hrs			T/C data not valid
1:57pm 14		9.43				due to cross
1:58pm Booster on 9		2.51				wiring
2:00pm S/D pump @			58.6 hrs			
Canister + SNF + lid + sensor				46.9758	(avg)	W. & Lane 8/18/9
Removed 14.3 ml H ₂ O in 6 minutes						
2:14pm S/U pump @			58.6 hrs			
2:15pm 3		2.45	2000	47.8458		
2:19pm S/D pump @			58.7 hrs			
Vented canister + SNF + lid + sensor				46.9738	(avg)	
Removed 0.9 ml H ₂ O in 5 minutes						
No visible water inside canister						
Wet canister + SNF + lid + sensor				47.0084	(avg)	NO HEAT t
2:49pm S/U pump @			58.7 hrs			
2:50pm 28		8.26		47.7510		
2:52pm Booster On 13		1.30	1300	47.7402		
2:56 3		0.88	975	47.7394		Removed 15.5 ml
3:02pm 758mT		0.56	650	47.7240		H ₂ O in 27 min
3:10 610mT		0.44	560	-		
3:15pm 562mT		0.40	525	47.7074		
3:16pm S/D pump @			59.1 hrs			
Canister + SNF + lid + sensor				46.9744	(avg)	

FP-721 Procedure

ENGINEERING COMPUTATION SHEET

Canister + SNF + 297 ml of
H₂O with no Heat Input

Computer W. S. Large Date

8/25/97

Time	WV 100 on Canister (Torr)	Edwards 1570 on hose (Torr)	Varian 801 on hose (millitorr)	Canister Weight (pounds)	Relative Humidity (%)	SNF thermocouples (°C)
Zeroed Scales				0.0000		
Empty Canister				37.8488		
				37.8488		37.8488 lbs avg
				37.8486		
				37.8488		
				37.8488		
				37.8488		
				37.8488		
				37.8488		
Base SNF				9.1240		
				9.1240		
				9.1240		9.1240 lbs avg
				9.1240		
				9.1242		
				9.1240		
				9.1240		
				9.1240		
Dry canister + SNF				46.9738		
				46.9740		46.9741 lbs avg
				46.9739		
				46.9740		
				46.9741		
				46.9743		
				46.9744		
				46.9746		
Added H ₂ O			(297ml)			
M+TE No.				3-2077		

ENGINEERING COMPUTATION, 1997, 14, 101-110

W. L. Large

8/25/97

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[illegible]

Procedure FP-721

ENGINEERING CONSULTANTS

Canister + SNF + 297 ml of
H₂O with no Heat Input

W. S. Lange

8/25/97 (Mon)

18

Time	WV 100 on Canister (Torr)	Edwards 1570 on 1/2" hose (Torr)	Varian 801 on 1/2" hose (millitorr)	Canister Weight (pounds)	Relative Humidity (%)	SNF thermocouples (°C)	
Dry Canister + SNF + lid + sensor (avg)				46.9741			Canister exterior wall
Wet Canister + wet SNF + lid + sensor (avg)				47.6251			1" above bottom
after test	Dry canister + SNF + lid + sensor + puddle			47.0205			
8:39 am	Start computer		data acquisition				Room @ 80°F
8:40	759			48.9530	93.5	27.3/27.3	80.5°
8:44	5/10 @ 16, 1 hour						
8:44	26			48.3950	88.2	26.3/26.2	79.6
8:47	20			48.3693	72.8	23.0/22.8	74.1
8:48	Booster On	1.35	1300	48.3549	62.7	21.0/20.8	70.3
8:50	15	1.28	1250	48.3470	56.6	19.7/19.5	67.2
8:55	11	1.10	1100	48.3190	40.3	18.0/17.9	58.7
9:00 am	9	1.03	1100	48.3035	33.6	18.3/18.2	53.7
9:05	7	0.96	1000	48.2836	27.1	17.8/17.7	48.3
9:10	7	0.93	1000	48.2712	24.4	17.2/17.1	46.6
9:15	6	0.91	950	48.2585	22.9	16.4/16.3	45.1
9:20	6	0.90	950	48.2475	21.9	15.6/15.4	44.2
9:30 a		Visible	condensate on				lower canister wall
9:30 am	5	0.87	950	48.2267	19.9	14.1/14.0	42.6
9:40 am	5	0.86	925	48.2067	18.9	12.7/12.6	42.3
9:50 a	5	0.85	925	48.1885	18.5	11.6/11.4	41.8
10:00 am	5	0.85	925	48.1720	18.1	10.7/10.6	41.5
10:10 am	5	0.84	925	48.1545	17.5	9.8/9.7	41.7
10:20 am	5	0.84	925	48.1376	17.7	9.1/9.0	41.7
10:30 am	5	0.83	925	48.1215	17.6	8.6/8.5	41.5
10:30 am		Small puddle	of condensate				on scales
10:40 a	5	0.83	925	48.1060	17.4	8.2/8.1	41.1
10:50 am	5	0.82	925	48.0895	17.3	7.8/7.7	41.2
11:00 am	5	0.82	925	48.0745	17.2	7.5/7.4	40.8
M+T E No.	7C-002	-	7C-001	3-2077	3-2097	3-2075/3-2076	

Procedure FP-721

Canister + SNF + 297 ml of
H₂O with no Heat Input

Operator *W. J. Large*

Date 8/25/97

Time	WV 100 on Canister (Torr)	Edwards 1570 on hose (Torr)	Varian 801 on hose (millitorr)	Canister Weight (pounds)	Relative Humidity (%)	SNF thermocouples (°C)	Canis Exter
11:10am	5	0.81	925	48.0585	17.0	7.2/7.1	40.
11:20am	5	0.81	925	48.0430	17.0	7.0/7.0	39
11:30am	5	0.81	900	48.0285	16.9	6.8/6.7	38
11:40am	5	0.80	900	48.0144	16.7	6.6/6.5	38.
11:50am	5	0.80	900	47.9998	16.7	6.5/6.4	38
12:00pm	5	0.80	900	47.9858	16.4	6.4/6.4	38.
12:10pm	5	0.80	900	47.9719	16.3	6.4/6.3	38
12:20pm	5	0.80	900	47.9571	16.2	6.3/6.3	3
12:30pm	4	0.80	900	47.9428	16.1	6.2/6.2	4.
12:40pm	4	0.79	900	47.9290	15.9	6.2/6.2	4.
12:50	4	0.79	900	47.9153	15.7	6.1/6.1	4
1:00pm	4	0.79	900	47.8980	15.6	6.2/6.1	4.
1:10pm	4	0.79	900	47.8855	15.4	6.2/6.2	4.
1:20pm	4	0.78	900	47.8720	15.3	6.2/6.2	4.
1:30pm	4	0.78	900	47.85	15.2	6.1/6.0	4
1:40pm	4	0.79	900	47.8423	15.2	6.1/6.1	4
1:50pm	4	0.78	900	47.8285	15.1	6.2/6.2	4.
2:00pm	4	0.78	900	47.8150	15.0	6.2/6.2	4.
2:10pm	4	0.78	900	47.7995	15.0	6.2/6.2	4
2:20pm	3	0.74	800	47.7855	11.6	6.2/6.2	4
2:22pm	3	0.71	800	47.7834	9.8	6.3/6.2	4
2:24pm	3	0.70	800	47.7820	8.8	6.4/6.3	50
2:26	3	0.69	800	47.7800	8.4	6.3/6.2	5
2:28	3	0.68	800	47.7780	8.1	6.3/6.2	52
2:30	2	0.68	800	47.7760	7.8	6.4/6.3	53
2:31	1955mT						
2:32	1870mT	0.67	775	47.7743	7.1	6.4/6.4	54
2:34	1760mT	0.65	750	47.7720	6.3	6.5/6.4	54
2:36	1625mT	0.64	750	47.7695	5.5	6.7/6.6	55
2:38	1515mT	0.63	750	47.7682	5.0	6.7/6.6	56
2:40pm	1400mT	0.61	725	47.7665	4.6	6.8/6.7	56
M & TE Nos.	7C-002	-	7C-001	3-2077	3-2071	32075/32076	

Ed 1570
started
dropping
2:15pm

Rm
85°F

CLASSIFICATION SHEET

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WZKS

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3

Canister
Exterior
2" above

0-1414-1-27-1

500

2275

Conc 37

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4

[illegible]

WESTINGHOUSE SAVANNAH RIVER CO.
Report WSRC-TR-97-00269

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