

CHARACTERIZATION OF EXTRACTION CELL 1 AT THE WEST VALLEY DEMONSTRATION PROJECT

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ABSTRACT

The West Valley Demonstration Project (WVDP) is conducting decontamination and dismantlement (D&D) of some of the most highly radioactive and contaminated cells in a former spent nuclear fuel (SNF) reprocessing plant. To help target and prioritize these D&D activities, estimates of residual radioactivity remaining in each cell in the plant are being prepared. One of the cells containing a level of residual radioactivity significant to and impacting the overall D&D strategy is Extraction Cell 1 (XC1).

During SNF reprocessing, the initial separation of fission and activation products from fuel isotopes occurred in XC1. High radiation levels prohibited personnel entry and required characterization field work to be conducted using remote tooling.

An innovative characterization approach was developed to minimize the number of in-cell measurements and also maximize the utilization of existing remote tooling. This approach ensured that limited site resources were deployed at the least cost and for the greatest effect, and provided residual radioactivity estimates for the cell floor and each of the vessels that are a key component of future D&D planning.

BACKGROUND

The West Valley Demonstration Project (WVDP) is located at the site of the former and only commercial SNF reprocessing facility to have operated in the United States. The plant was constructed in 1966 on land owned by the State of New York and operated for six years, reprocessing approximately 700 tons (636 metric tons) of SNF, and producing about 600,000 gallons (2,270 cubic meters) of liquid high-level radioactive waste (HLW).

In 1980, Congress passed the WVDP Act, authorizing the Department of Energy (DOE) to conduct a nuclear waste management demonstration project at the Western New York Nuclear Services Center near West Valley, NY. Since 1982, the DOE and its partners - the New York State Energy Research and Development Authority and the prime contractor, West Valley Nuclear Services Company - have demonstrated that the HLW can be safely and successfully placed into a vitrified waste form that provides long-term stability in the environment. In 2002, the WVDP completed its HLW vitrification mission and produced the final canister of vitrified HLW glass.

The WVDP has turned its focus to decontaminating areas in the former SNF reprocessing plant that contain significant levels of residual radioactivity, most importantly, to areas containing significant levels of long-lived radionuclides. Typical long-lived radionuclides present at the WVDP include Pu-239, Pu-240, U-233, Np-237, and Tc-99. An initial estimation of the radioactivity levels supports prioritization of the decontamination tasks, and is being undertaken for all areas within the former reprocessing plant. Due to the possible use of the estimates to support decisions on decommissioning of the site, it is imperative that the estimates be conservatively bounding (i.e., that any future decontamination work or refinement of the

estimates would only lower the source term from that established). In addition, the estimates support preparation of a performance assessment of proposed decommissioning alternatives. One of the areas expected to contain a substantial amount of the total projected for the entire former reprocessing plant is Extraction Cell 1 (XC1).

DESCRIPTION OF EXTRACTION CELL 1

Extraction Cell 1 is a shielded hot cell that housed the equipment for the partition cycle portion of the SNF reprocessing scheme, an extraction process that separated uranium (U) and plutonium (Pu) from a dissolved SNF input stream. The stream exiting the top of the first extraction column was transferred to a second extraction column to separate the U from the Pu and then on to three other extraction cells for further processing. The other streams from the separations columns containing little U or Pu were either returned to the process for rework, or sent for waste treatment. These separations steps created a number of process streams of differing radionuclide content within the cell which can be consolidated into three general categories: SNF, product streams, and waste streams.

Extraction Cell 1 is 4.9 meters wide, 5.0 meters long, and 16.8 meters tall. The concrete floor is 0.9 meters thick and lined with 304L stainless steel extending up the walls 0.5 meters. The walls are constructed of reinforced concrete coated with epoxy paint. The thickness of the cell walls ranges from 0.9 to 1.6 meters. Access to XC1 is provided through two hatches in the ceiling between the cell and the Extraction Chemical Room (XCR) above, one being 2.1 meters by 2.1 meters located at the approximate center of the cell, and a smaller 0.6 meter by 0.9 meter one located on the east side that formerly served as the personnel access path.

Extraction Cell 1 contains three separation columns, three storage tanks, fifteen pots that performed various processing functions, one heat exchanger, as well as approximately 2,255 meters of process piping that connects them. The cell also contains about 50 lateral structural supports and access platforms at each of the three tanks. No remote handling capabilities were ever installed in XC1 to support reprocessing.

Extensive decontamination of both the equipment and the cell surfaces was performed in the early 1970s in preparation for enhanced reprocessing operations. Decontamination solutions and water flushes were transferred through all of the major equipment and sent either further downstream in the process or to waste processing. Line plugging and other operational problems were noted in vessels 4D-1, 4C-13A, 4C-13B, 4Y-1, 4Y-14, 7D-1, and 7Y-1, including a reported sludge layer that would not dissolve in tank 4D-1. Some of the material plugging the lines was flushed to the floor of the cell, including material flushed from tank 4D-1 that may contain SNF fines.

A radiation survey was performed in the cell in March 2000. A general area gamma probe was lowered through a hole bored through the floor of the XCR close to the center of cell XC1, passing 0.5 meters west of tanks 7D-1, 4D-1, and 4D-2. Radiation levels generally increased as the probe was lowered in the cell and ranged from 2 sieverts/hr (200 mR/hr) near the ceiling to 63 sieverts/hr (6,300 mR/hr) 1.8 meters from the floor. Localized variations in the dose rates provided evidence that the vessels adjacent to the measurement points contained significant levels of contamination.

CHARACTERIZATION STRATEGY

Introduction

The estimation of residual radioactivity levels in cell XC1 was recognized at the outset to be one of the more complex characterization tasks to be performed of the former reprocessing facility. Several factors affected the complexity of the effort. First, due to the previous radionuclide separation process, there were potentially

seven processing streams of differing radionuclide content within the cell. Second, the high radiation fields prohibited personnel entry, and therefore a remote tooling approach would be required if in-cell data gathering activities were required. Third, any equipment deployed in the cell to gather data would have its movements restricted by the presence of all the original reprocessing equipment. And fourth, the limited in-cell survey information available indicated that the reprocessing equipment and the cell floor contained significant levels of radioactivity. Therefore, to target potential future decontamination activities, any data gathering effort needed to provide information on individual components as well as the floor. An overall approach was developed to utilize dose-to-curie computer modeling with scaling factors derived from sample analysis. The dose-to-curie modeling was performed in stages, first utilizing existing information as a screening step, followed by a second modeling step using the results of additional in-cell data gathering if required based on the initial screening.

Modeling Methodology

The MicroShield™ computer modeling program used at the WVDP requires inputs on measured radiation levels or dose rates, facility configuration (i.e., source geometry), and the radionuclide(s) comprising the measured radiation. If multiple radionuclides contribute to the radiation fields, the relative proportion of each must also be defined. Non-measured radionuclides are then calculated by use of scaling factors. For the initial screening, some general area gamma dose rate information was available in addition to facility drawings that showed the configuration of equipment within the cell, therefore, the only remaining inputs needed for modeling were identifying the radionuclides contributing to the measured dose and quantifying their relative proportions. To simplify the screening process further, the entire gamma radiation dose was attributed to Cs-137/Ba-137m, an approach based on the known radionuclide content of the SNF received at the WVDP and the fact that the residual contamination has undergone 30 years of nuclear decay, a significant time period for short-lived gamma emitters. While simplifying the approach, this also ensured further conservatism for the estimate as the dose contribution from other gamma-emitting radionuclides was neglected.

Initial Screening

The scaling factors for each of the three general process categories (SNF, product, or waste) were assigned or established, and the appropriate category designated for each vessel. Scaling factors had already been developed for both the SNF and waste categories in previous facility characterization work at the WVDP. For product stream scaling factors, historical analytical information from adjoining areas serving cell XC1 was researched. While the historical data was limited, it did provide sufficient information to develop a ratio for Pu-239 (the most critical radionuclide for the performance assessment) to Cs-137/Ba-137m. This maximum ratio was used in the initial screening of the product vessels.

Each piece of equipment was placed into one of the three general categories based on its position in the former reprocessing scheme. The vessels from the dissolved SNF input stream up to and including the first separation column were deemed to have a SNF distribution. The vessels that handled the bottom stream from the first column to the point of its transfer from the cell were considered waste. All other vessels managed product streams. However, it was noted that the degree of concentration of U or Pu at any specific point in the product processing path could not be predicted. The scaling factor distribution assigned to each vessel is shown in Table I.

Table I Vessel scaling factor distributions

Component	Scaling Distribution	Factor
4C-1	SNF	
4C-2	Product	
4C-3	Product	
4C-13A	SNF	
4C-13B	SNF	
4D-1	SNF	
4D-2	Waste	
4Y-1	Waste	
4Y-5	Product	
4Y-6	Product	
4Y-13	SNF	
4Y-14	SNF	
4Y-15	Waste	
4Y-17	Product	
4Y-19	Product	
4Y-42	Product	
7D-1	Waste	
7Y-1	Waste	
7Y-3	Waste	

To determine whether further radiation measurements were needed for any of the vessels designated with a SNF or waste set of scaling factors, each one was modeled with three given Cs-137/Ba-137m inventories to develop the relationship between dose rate and Cs-137/Ba-137m content. Using this relationship, the Cs-137/Ba-137m content was calculated for the maximum general area dose rate anywhere in the elevation range

where the vessel is located, as measured in the March 2000 survey. This modeling scenario was extremely conservative or bounding because it neglected the dose rate contribution from other radiation sources in the cell, especially so because the measurement locations were a significant distance from all but the three large storage tanks. Applying the established scaling factors, any vessel having less than 1 percent of the total amount of Pu-239 projected for the Main Process Building as a whole was considered to be adequately characterized and no further measurements were considered necessary. This approach was successful in eliminating all of the vessels having SNF or waste scaling factors from additional measurements.

The same screening approach was then applied to the product vessels. However, when the 100:1 ratio of Pu-239 to Cs-137/Ba-137m was used, all of the vessels showed much higher values than the 1 percent threshold level. A re-evaluation of the modeling assumptions was then performed in an attempt to relieve some of their conservatism, specifically, reviewing the scaling factors and the use of the maximum measured dose rate. Those assumptions could not be modified, neither the scaling factors because of the limited nature of the information that was available, nor the use of the maximum measured dose rate because there was no way to determine how much of the measured dose was coming from the vessel and not from other sources. Therefore, additional data gathering was necessary to address both assumptions: sampling and analysis to provide the basis for new scaling factors, and radiation measurements of all the product vessels for use in modeling.

The evaluation of the March 2000 survey also indicated that the floor was a significant contributor to in-cell dose rates. While modeling of the floor contamination showed a good fit for a theoretical plane with uniform Cs-137/Ba-137m contamination, the lack of information on the radionuclide distribution of the contamination inhibited the development of a reliable initial estimate. Therefore, additional radiation measurements would be taken of the floor and a sample of the floor particulate would be collected.

Additional Measurement and Sampling Approach

As stated earlier, the radiation measurements in the March 2000 survey were obtained at significant distances from the product-containing vessels and utilized general area dose rate instrumentation. To reduce the possible contribution to measured dose rates from other sources that was probable using the previous method, the new measurements would be taken in close proximity (e.g., at contact) to each vessel using a shielded, collimated probe. While the shielded, collimated probe would measure the radiation from only a narrow slice of the vessel, a single measurement point was assumed sufficient for vessels less than two feet in length since the radiation levels were not expected to vary appreciably in such a short distance. Multiple measurements would be taken at different elevations on the larger vessels from top to bottom, and separate models prepared for each measurement point. The modeling results would then be extrapolated to the entire length of the vessel. Similarly, multiple readings would be taken of the floor and the geometric mean used for a uniformly contaminated plane model. If significant variations in the floor readings were noted, the floor area would be subdivided into sections for modeling purposes.

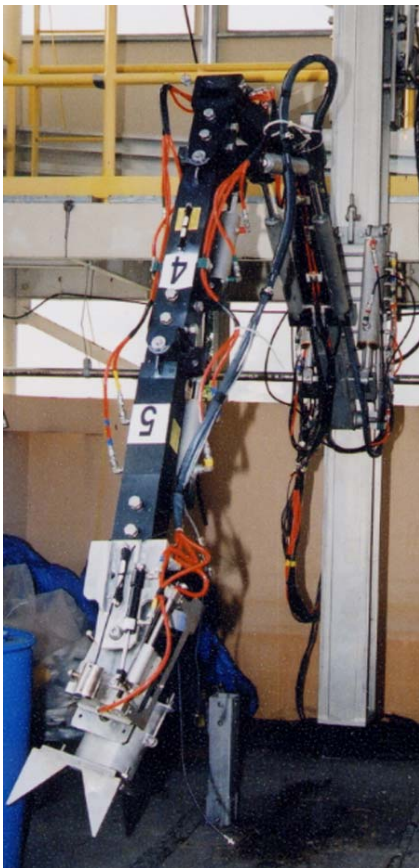
The most important factor for developing the sampling approach was the strategic identification of sample points to minimize their number due to the difficulty in performing work remotely in XC1. The former reprocessing scheme in XC1 indicated that the Pu content was concentrated to its highest level in relation to Cs-137/Ba-137m in the bottom stream of column 4C-3. Therefore, a sampling point associated with that stream was assumed to be the most conservative location and would be applied to all the product vessels. If the single set of conservative scaling factors resulted in an unacceptably high estimate, either additional sampling would be performed or alternative, technically justifiable scaling factors calculated. A pipe used to transfer the solution from column 4C-3 to the adjoining Extraction Cell 2 (XC2) for further processing was chosen as the sampling point. Further, the contamination in the pipe was assumed to be uniform along its length, or possibly even higher in a horizontal section where radionuclide deposition would more likely take

place. Therefore, a horizontal section of the pipe in cell XC2 was chosen to be the sampling point.

A single composite sample of floor particulate was identified as the appropriate means to establish the scaling factors for the floor. A composite sample would minimize the effect of any localized variability in the composition of floor particulate. The composite sample would be collected from different locations on the floor as dictated by visual evidence (e.g., staining).

EQUIPMENT DEVELOPMENT

Design of a remote tooling system was initiated to perform the required characterization, which could also be used later for equipment removal if that became necessary. This approach was taken to minimize potential future schedule impacts and possibly reduce overall costs. As design was under way on that remote tooling system, a less comprehensive system previously fabricated for use in underground storage tanks at the WVDP was identified for possible use in XC1. That system, termed the Mast Tool Delivery System (MTDS), utilized hydraulic components to operate a mechanical arm from which a radiation probe or sampling/cutting tool could be remotely deployed. In its current state, the MTDS does not provide the breadth of capabilities nor the dexterity that the new proposed system would possess; however, the WVDP proceeded with its deployment since it could be readily modified to perform the required characterization work in XC1 and accomplish it at a fraction of the cost and much more quickly than the design, fabrication, installation, and deployment of a new system.



The MTDS consists of a stainless steel mast and trolley assembly, a rotary bearing assembly connected to an electric gear motor that allows the mast and trolley assembly to be rotated either clockwise or counterclockwise, a mechanical arm and a separate camera arm, electric winches mounted above the rotary bearing that raise or lower the arms on the mast, hydraulic components for manipulating the five mechanical arm segments and end effector (e.g., radiation probe), and electrical controls. The hydraulic cylinders provide either horizontal or vertical motion to the arm sections depending on the orientation of the connecting joint. The mast is a 20-centimeter-wide flanged beam constructed in approximately 3-meter sections bolted together as it is installed in its deployment location. The hydraulic hoses and electrical cables are run along the arm segments and bundled together to minimize the likelihood of catching on cell equipment or piping during deployment. The mechanical arm sections are constructed of aluminum to ensure that load limits would not be exceeded in their worst-case deployment configurations. The camera arm contains a video camera and pan/tilt unit to provide visual capabilities during movement of the mechanical arm in the cell. The electrical and hydraulic system controls are located external to the cell for ease of maintenance and to ensure that they do not become radiologically contaminated. A photograph of the mechanical arm shown in its test location is provided in Fig. 1.

Fig. 1 Mechanical Arm Shown in the Test Tower

A radiation probe was designed and fabricated specifically for deployment in XC1. Based on the general area dose rates previously measured in the cell, 5 centimeters of lead was incorporated around the sides and back of the probe as shielding. The collimated opening was set at 2.5 centimeters and the radiation detector was placed at the front face of the probe. The detector could be pulled back within the probe up to 5 centimeters to provide additional collimation if necessary.

The total weight of the probe was estimated at 80 kilograms. A schematic of the probe assembly is shown in Fig. 2.

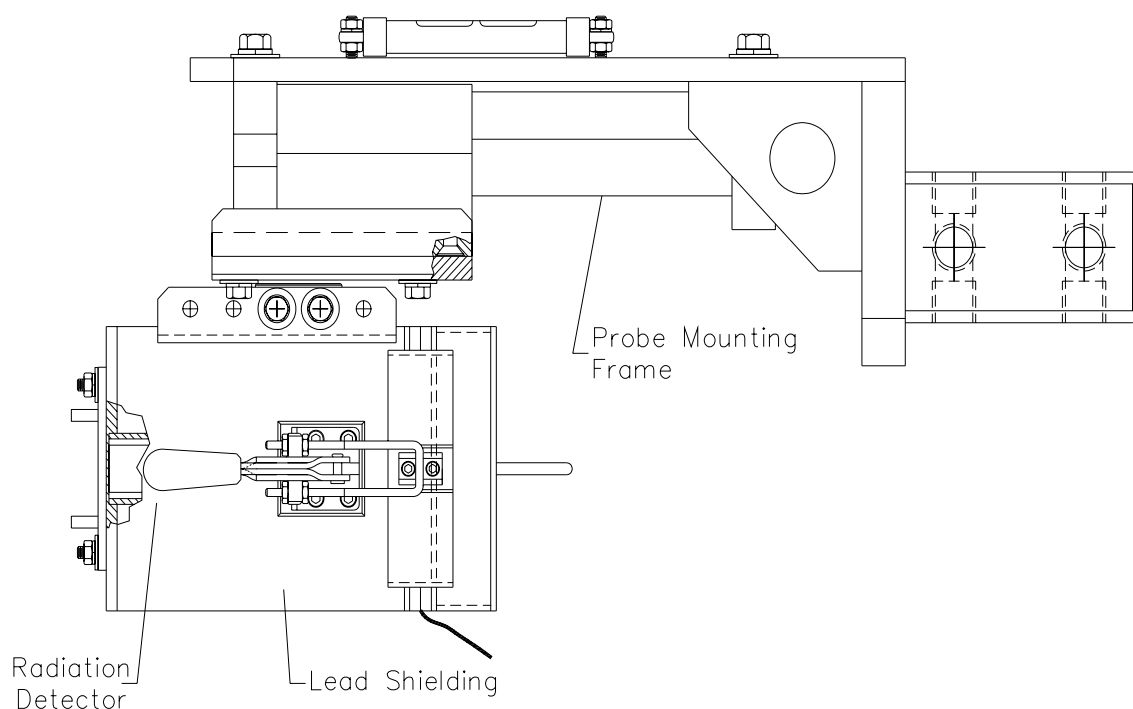


Fig. 2 Schematic of radiation probe shown in side view

The MTDS was placed in a test tower at the WVDP upon completion of modifications. The mechanical arm and radiation probe were deployed from the mast to ensure their operability and to familiarize deployment personnel with use and maintenance of the unit while it was still in a non-radiologically controlled location. The mechanical arm was tested in a three-segment and a five-segment configuration as both configurations were planned for use during actual deployment in XC1. It was discovered during the test deployment period that modifications made to two of the arm segments during previous fabrication work that were not part of the established design resulted in mechanical problems in those segments. Those two arm segments were repaired and retested. Following calibration of the radiation probe and functional check-out of the MTDS unit, the entire assembly was transferred to the XCR for installation into XC1.

RADIATION MEASUREMENTS

The smaller 0.6 meter by 0.9 meter hatch in the ceiling of XC1 was chosen as the easiest deployment location for the MTDS. The hatch had served as the personnel access path during SNF reprocessing and consequently no equipment was located below the hatch opening. To access the cell, the concrete shield plugs installed in

the hatch were removed and placed into retrievable storage. A temporary hatch cover was then installed to help prevent the spread of contamination. Steel platforms associated with the ladder mounted on the east wall of the cell had to be removed from two locations to allow access to all cell elevations. The bolts securing the two platforms to structural supports were removed using long-reach tools from the open hatch and the platforms relocated within the cell. The MTDS was installed in the hatch and a video inspection was performed from ceiling to floor. The inspection showed that component 4Y-42, which was indicated on the partition cycle piping and instrumentation diagram but nowhere else in the facility drawing system, did indeed exist in the cell. To quickly gain additional information on cell radiation fields, a general area gamma dose probe was lowered through the hatch from the XCR approximately 18 meters to a point close to the XC1 floor, with radiation measurements taken every 1.5 meters. These measurements confirmed the conclusions from the March 2000 survey that the floor was a major contributor to in-cell dose rates, and that individual vessels also showed significant residual radioactivity.

The MTDS and mechanical arm were then deployed to perform radiation measurements on each of the product vessels and the floor. Soon after starting deployment with the mechanical arm with all five segments in place, cracked welds were noted in the two arm segments that were not previously repaired. The arm was withdrawn from the cell and reconfigured with three segments in place and measurements continued while new arm segments were fabricated. The three-segment mechanical arm configuration was successfully deployed within the cell and radiation measurements were taken of the product vessels within its reach, along with two of the large storage tanks. Due to the actual configuration of XC1 equipment and structural supports being in slight variance with the facility drawings, additional platform removal was necessary to allow access to some of the measurement locations. These removal activities were conducted using tools deployed from the mechanical arm. Once measurements with the three-arm configuration were completed and the new arm segments were fabricated and tested, the two new segments were installed on the mechanical arm. Measurements are currently under way in the five-segment configuration on the last vessel, 4Y-5, and additional measurements of column 4C-1. The collimated radiation readings ranged from 0.06 to 1.25 sieverts/hr (6.5 to 125 mR/hr) on the vessels.

Throughout deployment, the intertwined maze of XC1 reprocessing equipment and structural supports made gaining access to many of the vessels with the mechanical arm extremely difficult, and completely prevented the arm from gaining access to the floor. Cutting tools deployed from the arm to remove obstructions may have eased access in some locations, but they were not utilized for several reasons: 1) there was no capability to remotely change the end effectors, therefore installation of cutting tools would have required multiple transfers between XC1 and the XCR, causing delays and adding to personnel exposure during tool change outs; 2) the radiological containment area in the XCR may have itself become contaminated, which may have required additional work effort and personnel exposure to decontaminate it; and 3) the safety of potential future decontamination work may have been impacted if process fluids were released to the XC1 floor, or by leaving the piping or structural supports partially cut.

Since the floor measurements could not be taken using the mechanical arm, a separate deployment method was developed. A small, wheeled cart was designed large enough to hold the existing radiation probe. The cart was only 0.3 meters tall, so its access to measurement locations was restricted only by piping that was less than that height from the floor. The radiation probe was oriented vertically downward, with the face of the detector being only 2.9 centimeters from the floor. A schematic of the cart is shown in Fig. 3. The remotely controlled cart will be lowered to the cell floor and driven to the measurement locations. The number of measurement locations using the cart is expected to be significantly more than that planned using the mechanical arm. In addition, the cart is able to traverse the entire floor, rather than being restricted to two small areas that were considered accessible by the arm.

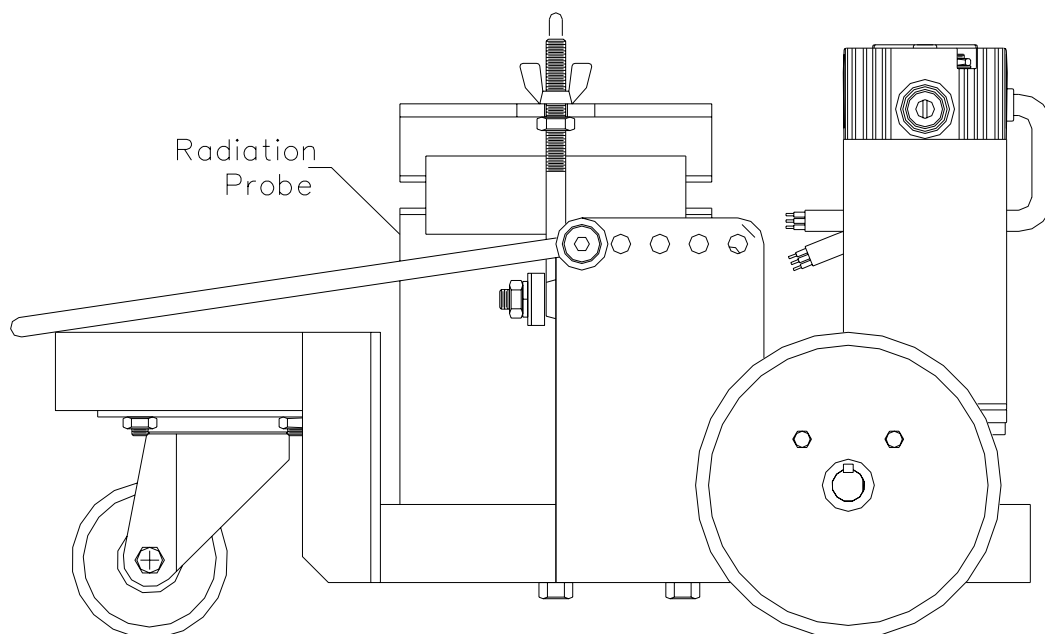


Fig. 3 Schematic of radiation probe assembly modified for floor measurements

SAMPLING AND ANALYSIS

A sampling tool that combined a vacuum and rotating wire brush within the vacuum head was lowered to the XC1 floor from the hatch to collect particulate in three locations. The material collected in the three locations was composited into a single sample. This was performed as soon as access was gained to the cell to allow sufficient time for sample preparation and analysis and for an evaluation of the results to occur. The rotating brush scoured the stainless steel floor liner to a bright, shiny finish in each of the sampling locations in marked contrast to the surrounding area, giving some evidence that much of the residual contamination was removed in those locations. Analysis of the sample indicated that the floor particulate resembled SNF in its radiological composition rather than product.

Sampling the pipe in XC2 that originates at the bottom of column 4C-3 was a straightforward effort, primarily because personnel entry in XC2 is possible in contrast to the remote operations that would have been required in XC1. The pipe was first checked for the presence of liquid. Once it was determined that no liquid was present, four approximately 2.5-centimeter slices of the pipe were collected using a hand-held saw (the four samples were needed due to different laboratory sample preparation procedures for the tests that were performed). The analysis results from the pipe sample were similar to those from pipe and vessel samples collected in the other extraction cells at the WVDP. This indicates that the extensive decontamination efforts of the 1970s served to remove contamination to a similar low level in product lines throughout those areas, regardless of the composition of the process liquids they previously contained.

MODELING

Each vessel radiation measurement was modeled separately using MicroShield™. To simplify the modeling, the conical field of view was approximated to a right circular cylinder whose height was the same as the diameter of the cone at the closest side of the vessel. This was the first level of conservatism applied to the

results as the cylinder encompasses a smaller volume than the conical section. The vessels were modeled as either an internally contaminated hollow cylinder, or in the case of vessels with internal components, as a volumetrically contaminated cylinder whose apparent density was calculated based on the weight of the internal components. Contamination was modeled as uniform within the field of view. This limitation of the MicroShield™ program is not expected to create significant error as the contamination is not expected to vary appreciably in the small distances involved. For vessels with single readings, the modeling results were extrapolated to the entire length of the vessel. For vessels with multiple readings, the geometric mean of the modeling results was calculated and then extrapolated to the entire length.

The floor will be modeled using the measurements collected with the new floor cart. The geometric mean of the measurements will be placed in the center of a planar surface and the results extrapolated over the entire floor area. If significant variations are evident among the different measurement locations, the floor will be separated into subsections and the results extrapolated accordingly.

CONCLUSION

The characterization approach for Extraction Cell 1 at the WVDP was tailored to provide a technically sound residual radioactivity estimate for use in decontamination planning. The approach maximized the use of reasonable, bounding assumptions on the composition of residual contamination in conjunction with limited existing radiation survey data to minimize the scope of new data gathering efforts. To accomplish the collection of additional in-cell information, existing equipment was adapted to meet the challenges of remotely characterizing individual components in a facility with high radiation fields, and resulted in an approximately 25 percent acceleration in the schedule and 66 percent reduction in the projected overall cost.

FOOTNOTES

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