WATER CHEMISTRY CONTROL SYSTEM FOR RECOVERY OF DAMAGED AND DEGRADED SPENT FUEL

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ABSTRACT

The International Atomic Energy Agency (IAEA) and the government of Serbia have led the project co-sponsored by the U.S, Russia, European Commission, and others to repackage and repatriate approximately 8000 spent fuel elements from the RA reactor fuel storage basins at the VINČA Institute of Nuclear Sciences to Russia for reprocessing. The repackaging and transportation activities were implemented by a Russian consortium which includes the Sosny Company, Tekhsnabeksport (TENEX) and Mayak Production Association. High activity of the water of the fuel storage basin posed serious risk and challenges to the fuel removal from storage containers and repackaging for transportation. The risk centered on personnel exposure, even above the basin water, due to the high water activity levels caused by Cs-137 leached from fuel elements with failed cladding. A team of engineers from the U.S. DOE-NNSA's Global Threat Reduction Initiative, the Vinca Institute, and the IAEA performed the design, development, and deployment of a compact underwater water chemistry control system (WCCS) to remove the Cs-137 from the basin water and enable personnel safety above the basin water for repackaging operations. Key elements of the WCCS system included filters, multiple columns containing an inorganic sorbent, submersible pumps and flow meters. All system components were designed to be remotely serviceable and replaceable. The system was assembled and successfully deployed at the Vinca basin to support the fuel removal and repackaging activities. Following the successful operations, the Cs-137 is now safely contained and consolidated on the zeolite sorbent used in the columns of the WCCS, and the fuel has been removed from the basins. This paper reviews the functional requirements, design, and deployment of the WCCS.

1. Introduction

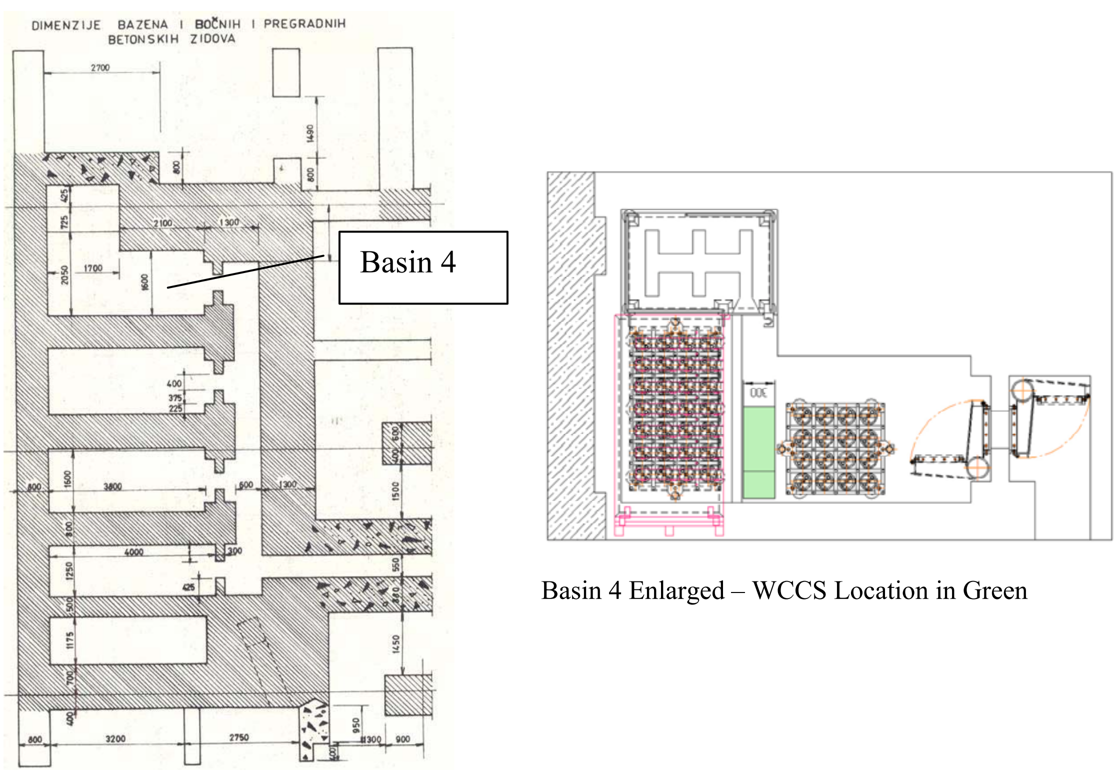
Isolation canisters to store fuel assemblies with breached cladding in basins may have significant amounts of cesium dissolved in the local water trapped inside them. Because cesium quickly diffuses into the general basin when a canister is opened, radioactivity dose rates can increase to high levels for workers in the area. One such case involved a set of isolation canisters containing pieces of fuel that leaked very large amounts of activity (up to an estimated $6x10^6$ Bq/ml) into the local water of the isolation canisters that were themselves in underwater storage in the Receiving Basin for Offsite Fuel (RBOF) at the Savannah River Site (SRS). The plan for RBOF deinventory necessitated the recovery of the fuel for transportation to the L-basin at the site. A special design of deionizer was needed to provide local deionization of the canister water without requiring large quantities of the RBOF basin water to be processed.

A special underwater deionizer (UD) was designed, fabricated, and successfully deployed to process the high activity water and enable fuel retrieval from the SRS isolation canisters [1, 2]. The UD was operated as a single pass system, flushing water (for 10 hours total) from 6 large isolation canisters (416 L internal volume in each) containing fuel pieces through a column containing cation exchange media. This took less time and had less operational impact than opening the canisters and deionizing the entire basin volume (9500 m^3). This approach to fuel recovery resulted in deinventory of the basin well ahead of schedule.

A similar fuel recovery and repackaging campaign was planned at the Vinca Institute to recover aluminium-clad fuel stored in sealed aluminium barrels and stainless steel channel holders. The Vinca Institute, IAEA, U.S. NNSA/DOE, Sosny Company, Tekhsnabeksport (TENEX) and Mayak Production Association planned the overall campaign to repackage and transfer the fuel from Vinca to the Mayak facility in Russia for reprocessing. An important component of the overall operations was the need for clean up of the cesium from the Vinca basin water before and during the repackaging operations.

A Water Chemistry Control System (WCCS) based on the UD used at SRS, was designed by Savannah River National Laboratory (SRNL) personnel under U.S. Department of Energy (DOE) sponsorship. It was designed to remove cesium from the bulk basin water and trap the cesium on underwater columns containing sorbents while meeting the safety requirements at the Vinca site and also the space limitations, repackaging cycle time, and overall project schedule needs.

The Vinca fuel storage basins are arranged as shown in Figure 1 below.



Basin 4 Enlarged – WCCS Location in Green

Figure 1. Vinca Basins 1-4 and Basin 4 (enlarged) with Repackaging Equipment Locations

2. Water Chemistry Control System (WCCS) for Vinca Fuel Reprocessing

2.1 Functional Requirements

Technical requirements for the WCCS were prepared by the repackaging contractor for the SRNL design team to identify the functional and safety requirements of the WCCS. The requirements included:

- Fit in allotted underwater space (green zone)
- Reduce activity from 10^7 to $\leq 10^5$ Bq/l in a 40 m^3 volume in 24 hrs
- Filter particulates
- Upstream sample port
- Monitor fluid flow
- Repairable/replaceable parts
- Remote component replacement
- Remotely controlled
- Tools to operate/maintain WCCS
- Support safety assessment
- Avoid interference with other equipment

The repackaging equipment dimensions left limited space for the WCCS (footprint 1 m x 0.3 m x 1.5 m high) in Vinca's basin 4 (see Figure 1). Using available space and sorbent properties, SRNL maximized WCCS capacity and flow rates. Design iterations incorporated input from all parties. The selected sorbent media was ResinTech® SIR-600, an inorganic-based ion exchanger, highly selective for cesium removal and radiation-resistant. Figure 2 shows the WCCS as it was configured at Vinca installation.

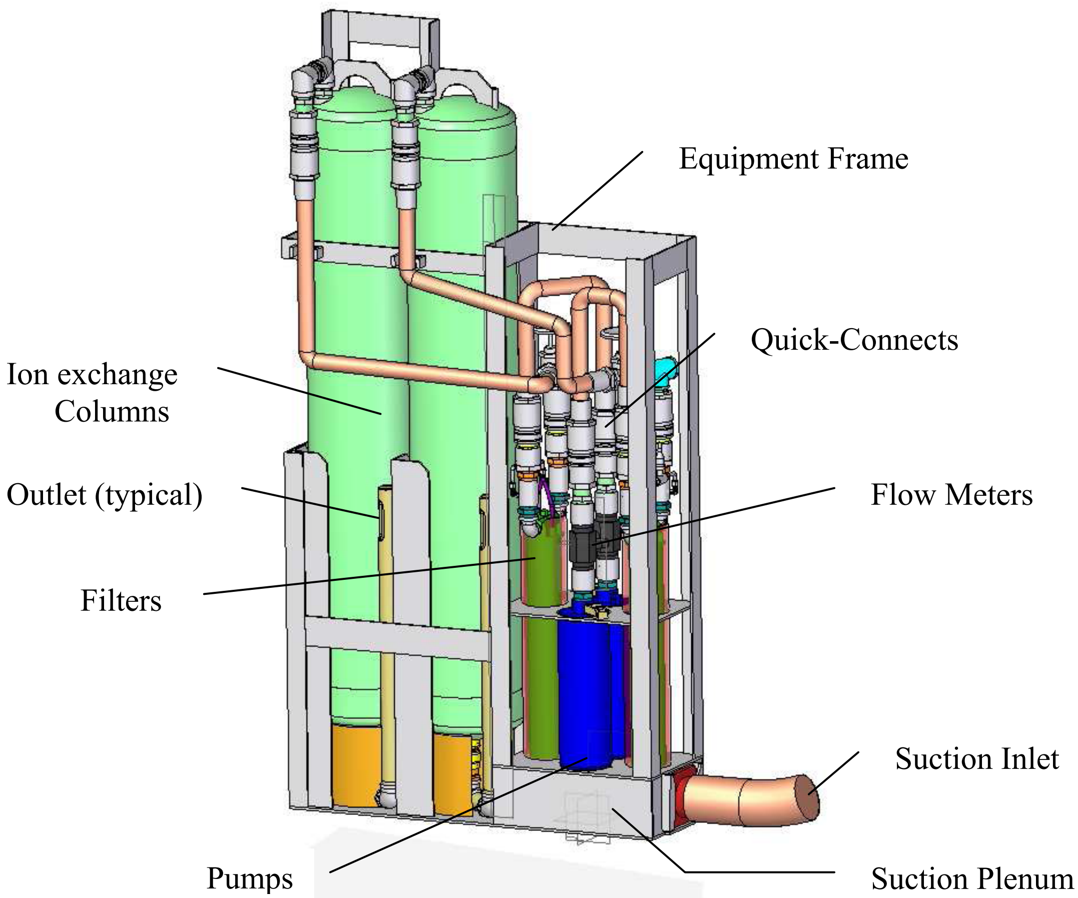


Figure 2: Water Chemistry Control System for Vinca Institute Fuel Repackaging

The unloading process was expected to release a large quantity of dissolved cesium into basin 4. Cumulative activity was expected to be 10^{12} Bq. Vinca fuel storage containers were not designed to allow purging before opening. Therefore any cesium dissolved inside the container would be mixed with basin water when the storage can was opened. Activity removal from basin water was estimated using the formula

$$C(t) = R/(Q\,\varepsilon) + [C_0 - R/(Q\,\varepsilon)]e^{-(Q * \varepsilon / V)\,t}$$

Where,

C(t) is the concentration of activity in Bq/mL in a volume of water at time t;
R is the total activity released into a volume of water in Bq/s (e.g. from all leaking fuel);
Q is the volumetric flow rate in L/s into and out of a closed loop deionization system;
V is the volume of water in the basin; and
ε is the efficiency of the deionizer system.

Figure 3 below shows an example of results for the WCCS operation to reduce the activity in the total volume of basin water (200 m^3) from the interconnected basins in comparison to the predicted (theory) activity removal results. The difference is primarily attributed to a finite release rate R that was assumed to be zero in the predicted results.

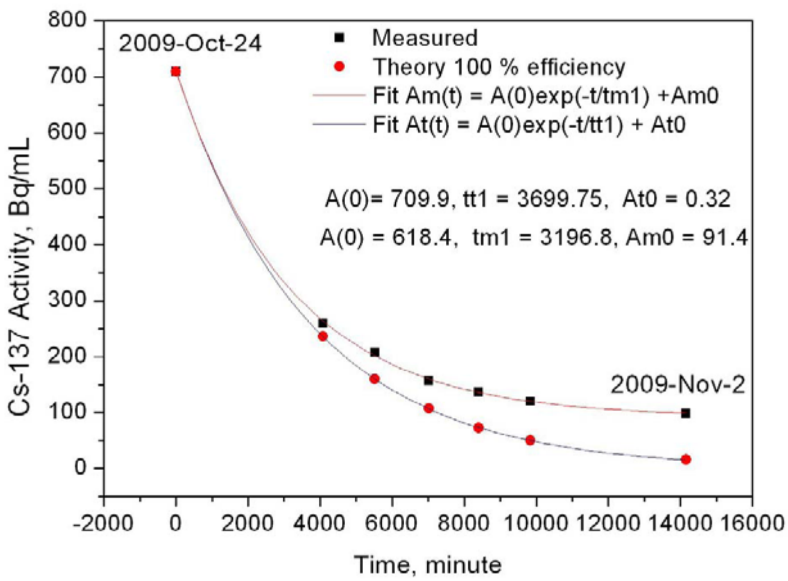


Figure 3. Activity Removal Results from the Total Water Volume (200 m^3)

2.2 WCCS Design

The WCCS is arranged as two independent systems, each with a pump, filter, and sorbent column. Components were designed to be remotely replaceable, connected with flexible reinforced hose. Connectors are valved, push-to-connect, quick-disconnect couplings. The multi-stage centrifugal type pumps are submersible, electrically powered, and meet system head requirements and flow characteristics (up to 75 litres/min each). The pumps fit into gasketed openings in a suction plenum at the bottom of the frame, drawing water into the plenum through a single suction hose (see Figure 2).

Drilling into the "aluminium barrels" containing the fuel was necessary to remove the fuel and the activity contained within the water of the barrels. Any debris emanating from the drilling was intended to be released into basin 4 (40 m^3 volume) only. Suction nozzle placement and low fluid velocity in the suction hose keep cuttings from entering the pumps. The suction plenum slows fluid further and strainers on the pump suction keep objects from entering the pumps. A turbine-type flow meter mounted at the outlet of each pump provides reasonable flow indication although not optimally positioned due to constraints in the WCCS design to meet the requirements.

Hoses connect the flow meters to filters downstream of the pumps. Filters have stainless housings containing woven stainless cartridges with mesh openings of 100 microns. Filter housings sit in a tubular socket mounted atop the suction plenum, kept from rotating by slots accepting the filter inlet and outlet piping. Filter housings are not fixed in any other way, allowing them to be replaced as necessary by disconnecting their hoses and lifting them out of the socket using the lifting eyes attached to the top of the housings. A differential pressure transducer across the filter provides information to the control stand, allowing operators to anticipate filter replacement as the pressure differential increases.

Filtered water flows to the top of the resin column, through an internal diffuser and into the resin. Each column has a capacity of 56 litres of resin, allowing a small amount of space for resin swelling, if necessary. Non-swelling sorbent media, such as zeolite, may occupy the entire space between the column's internal baffles. The sorbent ultimately selected for the operation was a zeolite sorbent that preferentially captured cesium compared to other water impurity species that were present (e.g. Ca, Mg). The system provided for the maximum capacity in flow rate and capture volume for the space it occupied. Water exiting the column flowed to an outlet about 1 m above the base of the WCCS frame (see Figure 2).

2.3 WCCS Deployment

Fabrication of the WCCS design was contracted by the IAEA to a fabricator (VUJE) in Slovakia. SRNL designers consulted with the fabricator on questions of design and allowable part substitutions. Upon completion, team members met at the fabricator's facility to inspect the WCCS hardware, review the documentation, and observe a functional test of the WCCS.

The WCCS was shipped to Belgrade for installation in Vinca basin 4 in June 2009. Vinca operations staff modified the WCCS to meet their particular operating and maintenance needs. Following these actions, the device was installed in basin 4 (see Figure 4).

The initial flow rate through each of the two lines in was approximately 70 litres/minute, and the pressure differential across the filters was approximately 0.25 bar.

Figure 4. WCCS Installation in Vinca Fuel Storage Basin 4

2.4 WCCS Operations Summary

The activity in the entire basin water volume was reduced prior to repackaging operations from the initial value of approximately 700 Bq/ml to approximately 100 Bq/ml.

The first aluminium barrel was opened in December 2009, and the WCCS was turned on to operate intermittently, as needed. The water activity increased up to an estimated level of 3000 Bq/ml when some of the barrels were opened, but was quickly reduced by continued WCCS operation to at or below approximately 300 Bq/ml prior to resuming operations. This significantly reduced the levels of exposure to the operators, located on platforms directly over the basin water, who were performing the repackaging.

Large volumes of debris also emanated from the barrels as the fuel was retrieved, eventually causing plugging of the filters, and reduced flow rates in each of the two lines of the WCCS that were operated simultaneously. The filters were replaced when the pressure differential reached approximately 1 bar. The system was successfully returned to operation with the flow rates and pressure differential parameters in both lines at the initial, pre-operation conditions of 70 litres per minute and 0.25 bar, respectively. All the fuel from 30 aluminium barrels and 297 channel holders in the Vinca basins was safely recovered by August 2010.

3. References

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2. D.L.Fisher, N.C. Iyer, R.L. Sindelar, and T.J. Spieker, “Damaged Fuel Storage and Recovery, A Case Study”, IAEA-CN-178/09-03, International Conference on Management of Spent Fuel from Nuclear Power Reactors, June 2010.