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Characterization of Radioactivity in the Reactor Vessel of the Heavy Water Component Test Reactor (HWCTR)

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INTRODUCTION

The Heavy Water Component Test Reactor (HWCTR) facility is a pressurized heavy water reactor that was used to test candidate fuel designs for heavy water power reactors. The reactor operated at nominal power of 50 MW_{th}. The reactor coolant loop operated at 1200 psig and 250ºC. Two isolated test loop were designed into the reactor to provide special test conditions. Fig. 1 shows a cut-away view of the reactor. The two loops are contained in four inch diameter stainless steel piping.

The HWCTR was operated for only a short duration, from March 1962 to December 1964 in order to test the viability of test fuel elements and other reactor components for use in a heavy water power reactor. The reactor achieved 13,882 MWd of total power while testing 36 different fuel assemblies. In the course of operation, HWCTR experienced the cladding failures of 10 separate test fuel assemblies. In each case, the cladding was breached with some release of fuel core material into the isolated test loop, causing fission product and actinide contamination in the main coolant loop and the liquid and boiling test loops. Despite the contribution of the contamination from the failed fuel, the primary source of radioactivity in the HWCTR vessel and internals is the activation products in the thermal shields, and to a lesser degree, activation products in the reactor vessel walls and liner.

A detailed facility characterization report of the HWCTR facility was completed in 1996. [1] Many of the inputs and assumptions in the 1996 characterization report were derived from the HWCTR decommissioning plan published in 1975. [2] The current paper provides an updated assessment of the radioisotopic characteristics of the HWCTR vessel and internals to support decommissioning activities on the facility.

APPROACH AND METHODOLOGY

Industry standard computational tools, MCNP5 [3] and ORIGEN-S/SCALE6 [4], were used to develop estimations of neutron flux and fluence, and consequential material activation within various components of the HWCTR reactor vessel. Previous system characterization data were used to provide validation of the methodology, assumptions, and inputs in the evaluation of the inventory of the activated products.

Assumptions

Historical data indicates that only three of the ten assemblies released solid particulate materials into the system, with the remaining assemblies releasing only gaseous fuel materials. Based upon this information, the TWNT-7, TWNT-14, and SOT-7-2 were the only failed assemblies assumed to contribute to the total activity contained within the HWCTR vessel. [5] These three assemblies released activity associated with the release of a maximum of twelve, four, and five grams of irradiated uranium, respectively. [2,5]

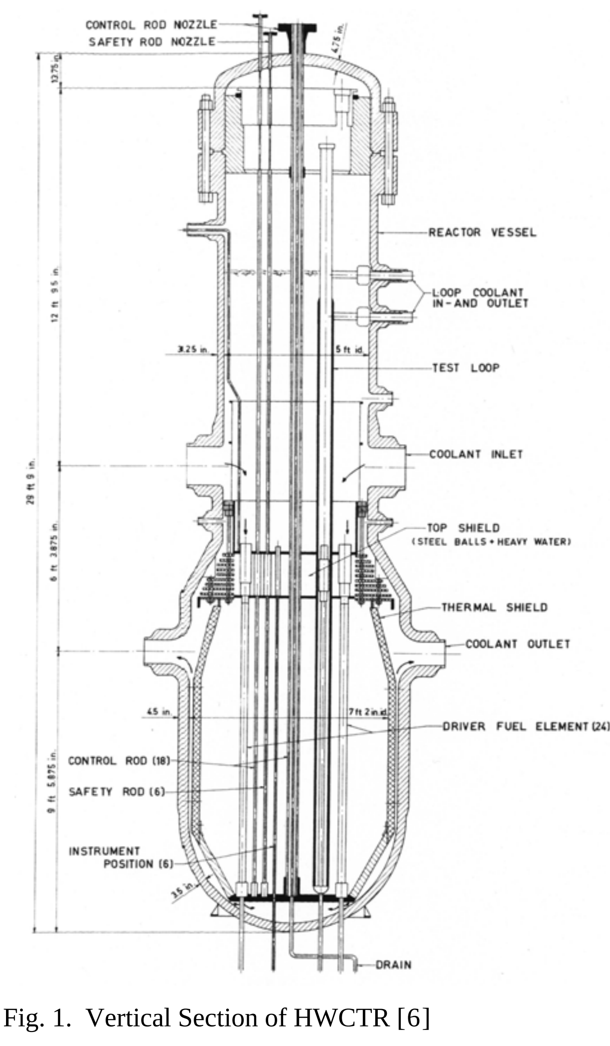

Fig. 1. Vertical Section of HWCTR [6]

The activated reactor components include the thermal shields, the reactor vessel liner, and the reactor vessel. Based upon previous characterization data, it was assumed that the average thermal neutron flux within the thermal shields was 1.0E+12 n/cm^2-s. [2] The neutron fluxes within the thermal shields and the other reactor components were those determined by the MNCP neutron transport modeling.

Determination of Activity due to Fuel Failure

The operating conditions for each of the three failed fuel assemblies, including power, exposure, and discharge date, were determined from applicable monthly site progress reports. Simulations of fuel exposure and subsequent decay were completed, using ORIGEN-S, to provide an estimate of the radioactivity characteristics of the assemblies applicable to the present day timeframe. Total released activities were then computed by multiplying the activity concentrations by the amounts of fuel that were released.

Determination of Flux Profiles and Fluence

The thermal shields account for the majority of the activity associated with the HWCTR due to neutron activation and comprise three inch thick plates of SS304L. The ¼-inch thick SS304L vessel liner and 4.25-inch thick carbon steel vessel were activated to a lesser extent. For modeling the activation products generated in these components, the neutron flux distribution as a function of the location and depth of the reactor component was projected using MCNP5.

Determination of the Activation Products

Transport of thermal, epithermal, and fast neutrons was addressed in this determination. Subsequently, ORIGEN-S was used to model the activation of the component material as a function of position and time due to the estimated flux through the component. The resulting radionuclide profiles were integrated over the total thickness of the component to yield average radionuclide concentrations applicable to the entire thickness. The total radionuclide activities were calculated by multiplying the average concentrations by the total mass of the component material.

Total System Activity Inventory

Total radionuclide inventories associated with the HWCTR vessel and internals were calculated by summing the activity contributions from the irradiated fuel releases and the activated reactor components.

RESULTS

The total radionuclide activity inventory associated with the HWCTR vessel and internals is ~3400 Ci. Approximately 99% of this inventory is due to three activation products generated in the thermal shields. Specifically, Ni-63 contributes ~93% of the inventory, Co-60 contributes ~6% of the inventory; and Ni-59 contributes ~1% of the inventory. In contrast, the total activity released from the failed fuel assemblies contributes only 2E-03% of the total inventory. Most of this 2E-03% contributed by the fuel comes from the fission products Sr-90 and Cs-137, and their daughters Y-90 and Ba-137m.

TABLE I. Radionuclide Inventories in HWCTR

Nuclide	Activity from Failed Fuel, Ci	Activity from Activation, Ci	HWCTR Total, Ci
C^{14}	6.0E-11	5.0E+00	5.0E+00
Fe^{55}	<1.0E-20	2.6E+00	2.6E+00
Co^{60}	<1.0E-20	1.9E+02	1.9E+02
Ni^{59}	<1.0E-20	3.5E+01	3.5E+01
Ni^{63}	<1.0E-20	3.1E+03	3.1E+03
Sr^{90}	1.7E-02	2.1E-12	1.7E-02
Y^{90}	1.7E-02	2.1E-12	1.7E-02
Ag^{108m}	4.3E-13	3.1E+00	3.1E+00
Cs^{137}	1.9E-02	<1.0E-20	1.9E-02
Ba^{137m}	1.8E-02	<1.0E-20	1.8E-02
Sum	7.3E-02	3.4E+03	3.4E+03

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