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MONITORING FOR FUEL SHEATH DEFECTS IN THREE SHIPMENTS OF IRRADIATED CANDU NUCLEAR FUEL

by

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Contrôle des défauts de gaine dans trois expéditions de combustible nucléaire CANDU irradié

par

H.M. Johnson

Résumé

L'analyse des gaz radioactifs dans le château de transport Pégase a été effectuée au début et à la fin de trois expéditions de combustible nucléaire irradié provenant de la centrale Douglas Point et destiné à l'Etablissement de Recherches Nucléaires de Whiteshell. On n'a observé aucune augmentation de la concentration des gaz actifs, des substances volatiles ou des petites particules. L'activité de l'eau du bassin du WR-1 ne s'est élevée que marginalement par suite du stockage du combustible. D'autres essais ont montré que la contamination de surface était minimale. Ces données ont permis d'établir que les défauts dans les gaines des éléments combustibles ne se sont pas produits durant le transport ou la manipulation du combustible irradié. Cette constatation présente un intérêt pour les possibilités du transport et de la manipulation du combustible nucléaire irradié destiné à être stocké ou enfoui.

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ABSTRACT

Analyses of radioactive gases within the Pegase shipping flask were performed at the outset and at the completion of three shipments of irradiated nuclear fuel from the Douglas Point Generating Station to Whiteshell Nuclear Research Establishment. No increases in the concentration of active gases, volatiles or particulates were observed. The activity of the WR-1 bay water rose only marginally due to the storage of the fuel. Other tests indicated that minimal surface contamination was present. These data established that defects in fuel element sheaths did not arise during the transport or the handling of this irradiated fuel. The observation has significance for the prospect of irradiated nuclear fuel transfer and handling in preparation for storage or disposal.

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1. INTRODUCTION

The canister storage demonstration program at Whiteshell Nuclear Research Establishment (WNRE) has involved dry storage of irradiated nuclear fuel in two concrete canisters, one containing irradiated fuel from the WR-1 reactor at WNRE and the other containing fuel from the Douglas Point Generating Station (DPGS).

The DPGS fuel was transported by truck over the two thousand kilometre distance to WNRE in three successive shipments during February and March 1976. The Pegase shipping flask, illustrated in Figure 1, owned by Transnucléaire of Paris, was used for these shipments. In total 360 bundles of spent fuel, each with 19 elements, were transported. Two baskets like that shown in Figure 2, each holding 60 bundles in a vertical position, were set one above the other in the flask.

Special interest was taken in these particular shipments because they presented an opportunity of establishing the fuel sheath conditions after considerable transportation and handling. The data show that irradiated CANDU* nuclear fuel can be shipped long distances without producing fuel sheath ruptures.

2. METHOD OF TESTING

Analysis of the radioactive gases in the Pegase shipping flask was the primary method of testing for the presence of fuel sheath defects. The tests were done after the fuel was loaded at DPGS and after the arrival of the flask at WNRE using the sampling apparatus illustrated schematically in Figure 3. This apparatus consisted of a manifold, a gas sample bomb (0.25L), vacuum/pressure gauge, air supply, tritium monitor, air pump, mechanical vacuum pump and in-line filters (paper and charcoal). The tritium monitor (Canadian Admiral, Model AEP 5215) was of the double ionization chamber type incorporating ambient gamma radiation compensation and an ion

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*CANada Deuterium Uranium

trap. However, it detected all beta-emitting gases as well as tritium. A sample of flask air was drawn into a gas bomb and analyzed for ^{85}Kr content by gamma spectrometry. Particulates were collected on the paper filter, and volatiles, including iodine, were collected in the charcoal capsule. The filters were analyzed for gross beta activity and for specific gamma-emitting radionuclides.

The test procedure was as follows:

(1) The manifold was connected to the upper flask vent. All the other pieces of equipment, except the air pump, were connected to the manifold.

(2) The flask connection hose and the vacuum gauge were evacuated, then the manifold was isolated (V_1 closed), the upper flask vent opened and the internal pressure of the flask measured.

(3) The evacuation of the gas sample bomb and the tubing was verified. The bomb was opened to the flask and the lower flask vent was opened to the atmosphere. The gas sample bomb was removed and sent for ^{85}Kr analysis. Valves V_6, V_9 were closed and V_{10} opened to by-pass the bomb position.

(4) Tritium in the flask atmosphere was measured by the tritium monitor after air flowed from the flask through the in-line filters (F_1 and F_2 in Figure 3). Flask air and fresh air were alternately passed through the tritium monitor (closing V_{10} and opening V_9 permitted fresh air to flush the monitor).

(5) The tritium monitor was replaced by a Gast air pump for which the flow rate in the system had been calibrated. Flask air was drawn through the in-line filters for a considerable, measured time. The filters were removed for the gross beta analysis and gamma spectroscopy. Fresh filters were installed.

(6) Va' V_4 was closed and fresh air was passed through the flask fo. at least an hour. The exhaust from the lower flask vent was discharged into the building ventilation system.

(7) The purging air was shut off, the Pegase flask left undisturbed for at least an hour and tritium sampling was repeated.

(8) Results were evaluated (^{85}Kr, in-line filter activity and tritium activity) and the flask was unloaded.

Gross beta and tritium activity of the WR-1 storage bay water were analyzed regularly while the DPGS fuel was in storage. An initial increase in the activity of the bay water was anticipated due to the transfer of some contamination from the Pegase flask. A subsequent increase would have been related to the occurrence of fuel sheath ruptures during storage.

The final transfer of the DPGS fuel from the Pegase baskets to the canister storage baskets was made, one bundle at a time, in the WNRE hot cells facility (Figure 2). The loaded canister baskets were seal-welded and vacuum-tested. Analysis of the oil from the vacuum pump used during these tests was the final method of examination for fuel sheath defects. Gross beta contamination in the vacuum pump oil would have indicated the induction of defects at this stage. No filter was used in the vacuum pump line and the pump exhaust was vented back into the cell.

3. RESULTS

In Table 1, results of analyses of the Pegase flask atmosphere before and after the shipments are compared. Analyses performed at DPGS provided data concerning gross beta activity and ^{85}Kr activity in the flask air prior to vacuum sealing of the flask. These same measurements as well as gamma spectroscopy were performed at WNRE to identify the presence of specific radionuclides.

The internal air pressure of the flask was identical for the second and third shipments but was higher after arrival than prior to dispatch for the first shipment. This increase for the first shipment could not have been due to gaseous fission products released from defected fuel sheaths, since the activity of the flask atmosphere was low. This pressure change must have been due to a slight in-leakage of air.

The results of tritium measurements are given in Table 2. The initial tritium analyses were made prior to a lengthy flow of fresh air through the flask. The final data were obtained after flushing the flask with fresh air followed by an undisturbed period of at least one hour. Nil results for the final measurement indicated that no beta-emitting gaseous nuclides were released from defective fuel elements.

When the Pegase flask was lowered into the WR-1 bay water in preparation for unloading, water entered via the lower flask vent. The displaced air escaped through the upper vent. Airborne activity of 2×10^{-3} $\mu Ci/m^3$* was measured in the bay area adjacent to the flask. The composition of this activity is shown in Table 3.

Results of the analyses of the WR-1 bay water activity are given in Table 4. These data were averages of four analyses over a two-week period. The total increase in activity after the three shipments were unloaded was calculated to be 6 mCi.

While the tritium activity in the WR-1 bay water rose from 0.1 to 0.4 μCi/L over the storage period, these data were within the normal range of variation for this bay water and no significance was attached to the trend.

Other indirect measurements for fuel defects were performed during the handling which followed the bay water storage. The surface contamination on the Pegase baskets was measured prior to their decontamination. This contamination varied from 10^{-2} to 10^{-1} $\mu Ci/cm^2$ on external surfaces and within

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* 1 Ci = 37 GBq

bundle ports. Had a sheath rupture occurred, contamination of the baskets would have been much greater.

A second indirect measurement was performed by analyzing the vacuum pump oil. After the canister baskets were loaded by transferring fuel bundles into them from the Pegase baskets, the canister baskets were seal-welded and leak-tested. A mechanical vacuum pump was used to evacuate these baskets. No filter was used in the fore-line of the pump. Analysis of this oil revealed no radioactivity after completion of the seal-testing.

4. DISCUSSION

Key parameters have indicated that fuel sheath ruptures did not occur during the transport, handling and repackaging of the irradiated fuel.

The internal pressure of the flask remained below atmospheric pressure during the shipments. In two shipments there was no change in pressure. The sensitivity of the activity monitoring was such that had radionuclides escaped from the elements, they would have been detected.

Measurements of the radioactive gases and airborne activity in the flask proved that the radioactivity did not increase during transit. These data confirmed that no sheath ruptures occurred en route.

To illustrate the sensitivity of these activity analyses, consider the situation for ^{85}Kr alone. By calculation for this specific fuel, each element of the DPGS bundles contained 8.8 curies of ^{85}Kr. Had a fuel sheath rupture occurred, 12 percent of this ^{85}Kr would have been released to the free space of the flask (W.C. Harrison and M.J.F. Notely, unpublished information). In the event of a fuel sheath rupture, 1.0 Ci of ^{85}Kr would then be available for escape into the 140 L free-space volume of the loaded Pegase flask. Thus, the ^{85}Kr activity in the flask atmosphere could have been 7.4 mCi/L from the rupture of the sheath of a single fuel element. This potential concentration is seven decades greater than that observed for ^{85}Kr.

Therefore, not only is the ^{85}Kr parameter a sufficiently sensitive test, but the data obtained have confirmed that no fuel sheath defect arose during transit.

The tritium monitor used here incorporated means for removal of ionized air and prefiltering for particulate and volatile radionuclides. Initial measurements of the gaseous beta activity in the flask gave a positive indication. However, these measurements decreased to zero after fresh air flushing followed by a period during which the flask air was undisturbed. The initial measurements were considered to have been a real detection of beta-emitting gas. This was considered to be due to ^{85}Kr and ^{3}H in the flask. Because of the much greater energy of the betas from ^{85}Kr relative to those from ^{3}H, a tritium monitor of this type would give an apparent ^{3}H reading in the presence of ^{85}Kr which was more than an order of magnitude greater than that from an equal concentration of tritium. If the origins of these gases had been other than on surfaces in the flask, further evolution would have occurred during the hour-long undisturbed period prior to the final ^{3}H measurements. Thus, the data of Table 2 confirm that ^{3}H and ^{85}Kr had not originated from defective fuel sheaths.

That no fuel sheath ruptures arose after the shipment, during storage and hot cells handling, was supported by the bay water activity and the vacuum pump oil activity measurements.

5. CONCLUSION

Dry, irradiated DPCS fuel (360 bundles, comprising 6 840 elements) has been transferred 2 000 km by road without the induction of a single fuel sheath defect. The re-immersion and underwater storage of this fuel followed by the bundle-by-bundle transfer into baskets for dry storage was also accomplished without sheath ruptures. This was proven by several techniques, of which the analysis for ^{85}Kr in the flask air was considered a very sensitive, single parameter.

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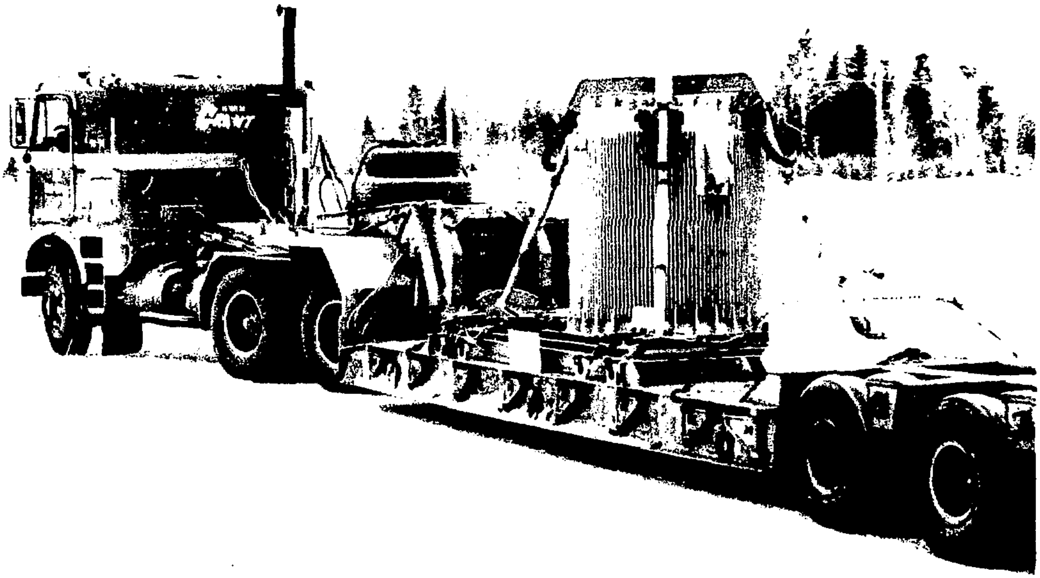

FIGURE 1

THE PEGASE FUEL TRANSFER FLASK ON THE TRANSPORT WHICH CARRIED IT BETWEEN DPGS AND WNRE.

FIGURE 2

A PEGASE BASKET POSITIONED ON A "SPIKE-BOARD" IN THE HOT CELLS FACILITY. BUNDLES OF DPGS FUEL ARE SHOWN RAISED TO DIFFERENT HEIGHTS PRIOR TO TRANSFER INTO THE CANISTER STORAGE BASKETS.

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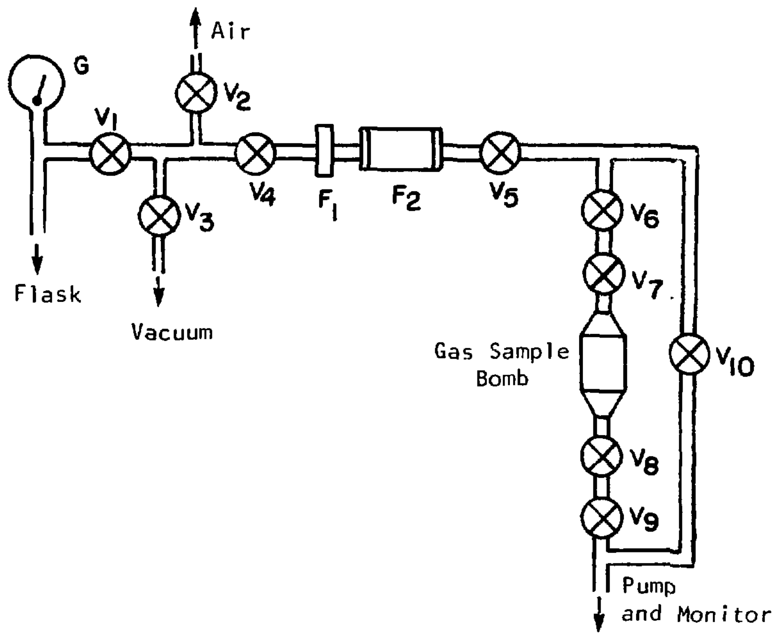

FIGURE 3

SCHEMATIC REPRESENTATION OF THE APPARATUS USED TO SAMPLE RADIOACTIVE GASES AND AIRBORNE RADIOACTIVITY IN THE FLASK AIR.

TABLE 1

COMPARISON OF FLASK AIR PARAMETERS BEFORE AND AFTER SHIPMENT

MEASURED QUANTITY	SHIPMENT I		SHIPMENT II		SHIPMENT III	
	DPGS	WNRE	DPGS	WNRE	DPGS	WNRE
Pressure	-85 kPa	-70 kPa	-85 kPa	-85 kPa	-85 kPa	-85 kPa
^{85}Kr	1×10^{-8} Ci/L	n.d.	1×10^{-8} Ci/L	n.d.	1×10^{-8} Ci/L	2×10^{-10} Ci/L
Gross-Beta	7×10^{-10} Ci/L	3×10^{-12} Ci/L	$<10^{-10}$ Ci/L	8×10^{-11} Ci/L	$<10^{-10}$ Ci/L	4×10^{-13} Ci/L
SPECIFIC NUCLIDES*						
^{60}Co	n.a.	50%	n.a.	n.d.	Trace	n.d.
$^{95}Zr/^{95}Nb$	n.a.	Trace	n.a.	n.d.	n.d.	n.d.
^{129}I	n.a.	n.d.	n.a.	n.d.	n.d.	n.d.
^{131}I	n.a.	50%	n.a.	70%	Trace	Trace
^{134}Cs	n.a.	n.d.	n.a.	n.d.	n.d.	n.d.
^{137}Cs	n.a.	n.d.	n.a.	30%	Trace	n.d.

NOTES:
- * - The percentage of the total gamma activity attributable to specific nuclides has been given.
- n.d. - Measurements were made but nothing was detected.
- n.a. - No specific analysis was made.
- 1 Ci = 37 GBq.

TABLE 2

RESULTS OF MEASUREMENTS OF TRITIUM IN FLASK A1

Shipment	Initial	Final
1	0.06 µCi/L	0
2	0.2 µCi/L	0
3	6 µCi/L	0

TABLE 3

DISTRIBUTION OF RADIONUCLIDES IN AIR DISPLACED FROM THE PEGASE FLASK AS IT ENTERED THE WR-1 BAY WATER, IDENTIFIED BY GAMMA SPECTROSCOPY

Nuclide	Percentage
^{60}Co	53
^{125}Sb	19
^{131}I	7
^{137}Cs	21

TABLE 4

GROSS BETA ACTIVITY OF WR-1 BAY WATER

Time Period	Average Activity (μCi/L)
Prior to first shipment	$< 2 \times 10^{-3}$
After first shipment	2×10^{-3}
After second shipment	1×10^{-2}
After third shipment	2×10^{-2}

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