ENVIRONMENTAL QUALIFICATION TESTING OF TFE VALVE COMPONENTS

by

A. Eyvindson,
AECL
Chalk River Laboratories
Mechanical Equipment Development Branch
Chalk River, Ontario
K0J 1J0

W. Krasinski,
Ontario Hydro - Bruce B ND

R. McCutcheon,
Ontario Hydro - NTS

J. Aikin,
AECL
Chalk River Laboratories

ABSTRACT

Valves containing tetrafluoroethylene (TFE) components are being used in many CANDU® Nuclear Generating Stations. However, some concerns remain about the performance of TFE after exposure to high levels of radiation. Stations must therefore ensure that such valves perform reliably after being exposed to postulated accident radiation dose levels. The current Ontario Hydro Environmental Qualification (EQ) program specifies much higher postulated radiation exposure than the original design, to account for conditions following a LOCA. Initial assessments indicated that Teflon components would require replacement. Proof of acceptable performance can remove the need for large scale replacement, avoiding a significant cost penalty and preserving benefits due to the superior performance of TFE-based seals.

A test program was undertaken at Chalk River Laboratories (CRL) to investigate the performance of three valves after irradiation to 10 Mrad. Such valves are currently used at the Bruce B Nuclear Generating Station. Each contains TFE packing rings; one also has TFE seats. Two of the valves are used in the ECIS recovery system, while the third is used for instrumentation loop isolation or as drain valves. All are exposed to little or no radiation during normal use.

Based on the results of the tests, all the valves tested will still meet functional and performance requirements after the TFE components have been exposed to 10 Mrad of irradiation.

1. INTRODUCTION

Under Ontario Hydro's Environmental Qualification Assessment (EQA) program, components in safety related systems must be qualified for up to 40 years of service life under normal conditions plus a three month period under accident and post-accident conditions. Existing components must be tested for cumulative age, radiation, fatigue and seismic effects, as applicable to each component's function and location.

Bruce (A&B) Nuclear Generating Stations (NGS) EQA reports [1,2,3] for the tetrafluoroethylene (TFE) components in specified Whitey, Worcester and Jamesbury valves have qualified them for thermal aging effects of 40-years plus accident conditions. However, a major concern is the ability of TFE components to function as intended after radiation exposure. The Mechanical Equipment Development (MED) branch of AECL at Chalk River was contracted to evaluate the performance of these valves after irradiation, with no thermal aging involved.

This project evaluated three valve types, each containing one or more TFE components, for leak-free operation at accident pressure and temperature after varying degrees of irradiation. Each valve was leak-tested at simulated Loss of Coolant Accident (LOCA) conditions after 0, 2, 4, 6, 8, 10 and 12 Mrad of exposure. The dose increments were selected so the effect of increasing dose on leak rate could be monitored. After the 12 Mrad test, samples of the irradiated TFE materials were analyzed for leachable chlorides, fluorides and sulphates.

1.1 Equipment Tested

The tests evaluated specified models of Whitey, Worcester and Jamesbury valves.

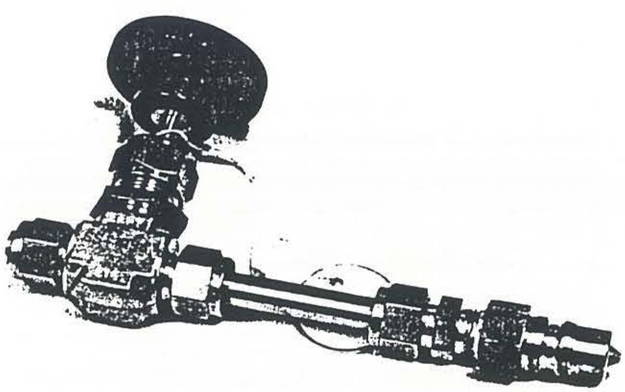

FIGURE 1: Whitey Valve

The Whitey valve (Figure 1) contains two TFE packing rings (Chevron® style). The Worcester valve (Figure 2) contains TFE packing and two TFE seats. The packing consists of two rings of polyfill (approximately 80 % TFE and the rest carbon/graphite fill) and two rings of polyetheretherketone (PEEK). The packing rings have a rectangular cross section.

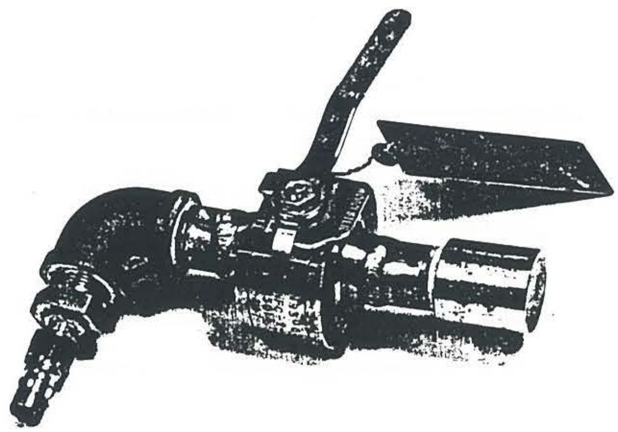

FIGURE 2: Worcester Valve

The Jamesbury valve contains 5 rings of braided TFE packing.

One each of the Worcester and Whitey valves was available from Bruce B NGS for testing. A test rig was fabricated to model the large Jamesbury valve.

1.1.1 Jamesbury Valve Test Rig

The Jamesbury Valve Test Rig (Figure 3) models the stem seal of the Jamesbury Wafer Sphere Valves at Bruce NGS, including the stem and stuffing box dimensions.

The packing configuration used in the Jamesbury test rig was a double-packed set of TFE braid (3 below the lantern ring and 2 above). This is the same packing configuration used in the valves at BNGS. The packing rings were cut on a bevel and the splits were staggered to ensure there was no continuous leak path. On installation, the packing set was live-loaded to a maximum compressive stress of 5000 psi. Since leakage through the top ring to atmosphere was the primary concern, a leak-off port from the lantern ring was not provided.

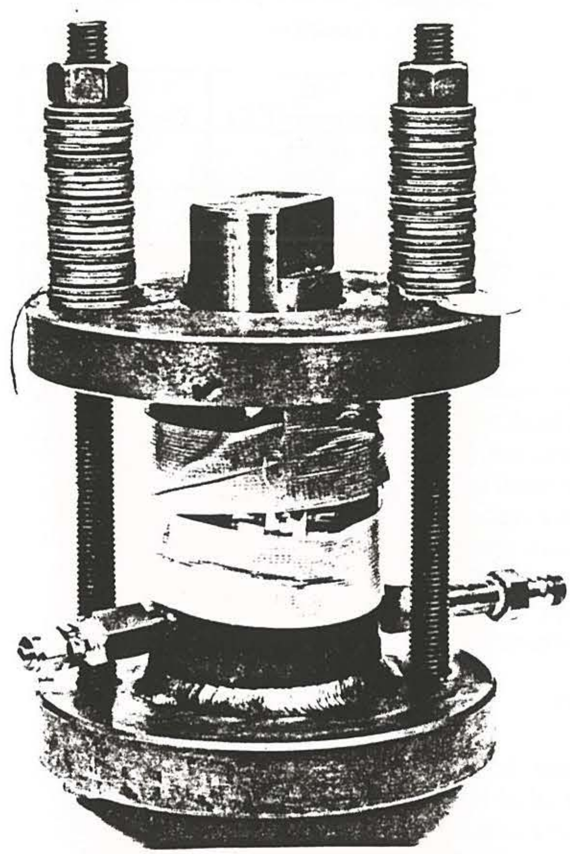

FIGURE 3: Jamesbury Valve Test Rig

2.0 TEST SETUP AND INSTRUMENTATION

2.1 Radiation Facilities

The valves were irradiated in stages to the nominal 10 Mrad total dose in a chamber approximately 1.5 ft x 1.5 ft x 1.5 ft. The chamber was shielded on all sides by lead bricks or pellets. A gamma source of ^{192}Iridium was contained in a pencil-shaped holder in the centre of the chamber. The valves were placed as close to the source as required to receive the desired dose rate.

A radiation facility with a much higher dose rate (the Gammacell 220) was used for the final 2 Mrad dose to the Whitey and Worcester valves. This facility consists of a series of pencil-shaped ^{60}Co sources positioned circumferentially around a sample chamber.

2.1.1 Dose Monitoring

While in the ^{192}Ir chamber, the dose to the TFE components was estimated using a Microshield computer model. Model inputs included source strength and halflife, distance from the source to the component, the amount of shielding due to the valve body and the exposure time. The dose to the internal TFE components from their exposure in the Gammacell 220 was calculated based on the same variables. The accuracy of the dose is estimated to be ±20%.

2.2 Leak Test Facility

The leak test facility (Figure 4) consisted of two adjacent water columns, an oven, a compressed air cylinder and associated tubing. The two water columns were connected through tubing containing an isolating valve. The primary water column was open to atmosphere while the second was connected to the valve in the oven and, when the isolating valve was closed, could be pressurized by the compressed air cylinder.

The accuracy of leakage measurement depends on tube inner diameter, water temperature, and the water column height, and is ± 0.7 mL. Measurement accuracy of the pressure and temperature are ± 3 psig and ± 3 °C, respectively.

2.3 Chemical Analysis

Chemical analysis of TFE samples, both unirradiated and irradiated to maximum dose, was contracted off-site to an approved laboratory.

3. TEST PROCEDURE

3.1 Packing Installation

In preparing the Jamesbury Valve Test Rig, the first three packing rings and the lantern ring were installed in the stuffing box, then loaded to 5000 psi packing stress by compressing the calibrated Belleville washers. The load was then removed and the top two packing rings installed, followed by the gland follower. The Belleville washers were again compressed to give 5000 psi packing stress.

The Whitey Valve and the Worcester Valve were tested as received.

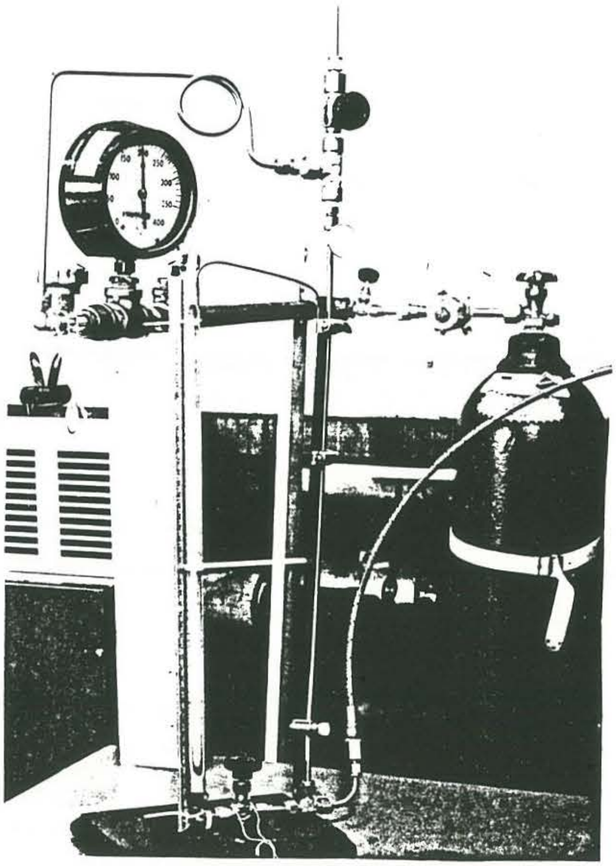

FIGURE 4: Leakage System

3.2 Leak Tests

All valves were leak tested at the start of the test program and after each 2 Mrad increment of irradiation. The leak test temperature and pressure were the predicted Loss of Coolant Accident (LOCA) conditions for the particular valve [1,2,3]. Table 1 shows the temperature and pressure of each valve during the leak test.

The valve to be tested was placed in the oven and connected to the leakage testing system. The system was then pressurized and heated. When temperature and pressure were at the LOCA levels for the valve being tested, temperature, pressure and time were recorded. These values were monitored for the next four hours to ensure that the test was progressing according to plan.

Table 1: Leak Test Temperatures and Pressures

Valve	Oven Temperature (^{o}C)	Valve Fluid Pressure (psig)
Worcester Valve	100 ± 5	190 +5,-8
Whitey Valve	ambient (20-30)	50 +5,-8
Jamesbury Valve Rig	100 ± 5	190 +5,-8

After four hours, the oven was turned off, the system depressurized, and the change in water column height measured. Except for the Whitey valve test, where the test temperature was ambient, a second water column height measurement was made after a minimum of four hours, after the water in the system had returned to ambient conditions. The top of the primary water column tube was clamped to minimize evaporation.

3.3 Valve Irradiation

After the initial leak tests, the valves were installed in the irradiation chamber at the desired distance from the source. The chamber lid was installed and covered with bags of lead pellets and the source was wound into the chamber. After a time sufficient for the centre of the TFE components in each valve to have received 2 Mrad of dose, the source was rewound into its shielded container and the valves removed from the chamber.

After each 2 Mrad dose increment, the valves were leak tested again.

3.3.1 Dose Rate

The target dose rate was 10 Mrad in 90 days but the actual dose rate was slightly lower than this. The ^{192}Ir source (74 day half life), saw a significant decay in its strength over the course of testing. Interference between the three valves in the chamber prevented them from being moved closer to the source as its strength decreased. Instead, the exposure period was increased for each successive 2 Mrad dose.

3.3.2 Total Dose

On achieving the nominal 10 Mrad dose, each valve was irradiated an extra 2 Mrad, to ensure that 10 Mrad had been exceeded. The Whitey and Worcester valves underwent the final irradiation in the Gammacell 220, while the Jamesbury rig remained in the ^{192}Ir chamber.

The total irradiation times for the three valves ranged from 118 days to 139 days.

3.4 Post-Irradiation Inspection

After the final functional tests, each valve and its TFE components were carefully examined for changes in appearance, cracks and colour. In addition, internal components of similar, non-irradiated components were inspected for comparison with the irradiated components.

3.5 Chemical Analysis

Samples of irradiated and non-irradiated TFE components from the valves was sent to an approved off-site laboratory for testing of leachable chlorides, fluorides and sulphates.

4. TEST RESULTS

4.1 Radiation Dose

Comparison of the predicted dose from the model with dosimeter readings resulted in a correction factor of 0.82 being applied to the nominal dose. Therefore, an additional nominal 2 Mrad irradiation period was applied to ensure that the total corrected dose exceeded 10 Mrad. Table 2 shows the nominal and corrected doses for the TFE components.

Table 2: Nominal and Corrected Dose of the TFE Components

Nominal Dose	Corrected Dose		
	Whitey Packing	Worcester Packing and Seat	Jamesbury Packing
Mrad	Mrad	Mrad	Mrad
2	1.5	1.5	1.2
4	3.2	3.3	2.9
6	4.9	4.9	5.0
8	7.0	7.0	6.1
10	8.6	8.6	8.2
12	10.6	10.6	10.0

4.2 Leakage

Table 3 shows the leakage for each valve as a function of nominal dosage, from the baseline leak test to the 12 Mrad leak test.

Table 3: Valve Leakage* Over 4-Hour Leak Test

Nominal Dosage, Mrad	Whitey Valve Leakage, mL	Worcester Valve Leakage, mL	Jamesbury Rig Leakage, mL
0	0.6	0	9.8 12.6**
2	0.3	0.3	0
4	0.5	20.0	4.7
6	0.4	24.7	7.5
8	3.3	3.1	2.6
10	0.2	6.6	3.4
12	0.6	4.3	4.1

* The accuracy of the leakage measurements was estimated at $\pm$ 0.7 mL.

** This test was repeated after stem movement was observed.

4.2.1 Whitey Valve (Chevron Style TFE Packing)

The leakage from this valve remained below 1 mL per 4 hours, for all tests except the 8 Mrad test, which had 3.3 mL leakage. There is no evidence of increasing leakage with increasing total dose.

4.2.2 Worcester Valve (Solid TFE Rings & Ball Seat)

The baseline and 2 Mrad tests for the Worcester valve showed little or no leakage through the packing or the seat. However, after 4 Mrad, 20 mL of leakage was measured. No water was observed in the downstream end cap and there was no obvious sign of leakage through the packing. A second, one-hour leak test was performed, this time at 190 psig but ambient temperature. The leakage measured was 3 mL and approximately this amount of water was found in the downstream end cap after this test, indicating that the leakage was through the seat. It is suspected that during the four-hour leak test, the water in the downstream end cap evaporated through a slight leak to atmosphere.

The 6 Mrad leak test confirmed the results after 4 Mrad. The leakage was 24.7 mL, and this time water was noted in the downstream end cap after the test. However, the leakage dropped below 7 mL for the final three leak tests; again, there is no evidence of increasing leakage with increasing total dose.

A previous test performed at CRL on the same valve model, but at a lower temperature and pressure, also showed no evidence of decreased performance with increasing dose [4].

4.2.3 Jamesbury Rig (Braided TFE Packing)

The initial baseline leak test resulted in a 9.8 mL loss in the water column. This was believed to be a result of the relatively porous packing "soaking up" the water. This test was repeated after stem movement was observed, and the second baseline test showed 12.6 mL loss. Again, this was felt to be due to the packing "soaking up" the water. The valve was irradiated to 2 Mrad and leak tested again. Leakage remained below 8 mL for all subsequent leak tests and did not increase with increasing total dose.

4.3 Jamesbury Test Rig Packing Stress

The packing load was applied with two stacks of calibrated Belleville washers. Initial and final packing stresses were determined from the gland gap and spring stack heights with associated spring calibration curve. Table 4 shows the initial and final packing stress and consolidation.

Table 4: Jamesbury Test Rig - Packing Stress

Total Nominal Dosage (Mrad)	Packing Stress (psi)	Packing Consolidation During Tests (inches)
0	5000	0
12	3170	0.060

4.4 Post-Irradiation Visual Inspection

After the final leak test, the TFE components were examined. Apart from very slight extrusion of the upper Jamesbury packing ring and of the Whitey packing, there was no evidence of any packing deterioration in any of the valves. The slight extrusion of the Jamesbury and Whitey packing is normal for TFE packing at high stresses and is not considered as caused by the radiation. There was also no obvious difference between the packing from the front (nearest the radiation source) and back sides of the valves.

The front and back TFE seats of the Worcester valve were examined. Although there was no difference in colouration, the front seat had a single crack that went right through. This crack was located at one of six small notches in the outer edge of the seat. At least one leak test must have been performed after the break, because the crack faces were dirty from exposure to water containing rust particles. No other cracks were visible on either seat. Figure 5 shows the front seat with the crack.

It is possible the crack developed between the nominal 2 Mrad and 4 Mrad tests when the leakage for this valve increased substantially. However, the leakage dropped again for the last three leak tests, although not back to the levels at 0 and 2 Mrad. Regardless of when the crack developed, it did not result in drastic failure of the valve.

Components from an identical but unirradiated Whitey valve were compared to the irradiated components. The irradiated packing was slightly dirtier than the unirradiated packing due to contact with the water during the leak tests. No other differences were noticeable. The same was true for irradiated and unirradiated components of the Worcester and Jamesbury valves.

4.5 Post-Irradiation Chemical Analysis

A chemical analysis for leachable chlorides, fluorides and sulphates was performed for samples of the irradiated TFE components and non-irradiated components. The detection limit for all the analyses was 1 µg/g. Table 5 lists the results of the analysis.

In every case, the irradiated components show higher leachables than the unirradiated components. In many cases, the changes are quite small and within the error of the analysis. However, the increase in leachable fluorides in the Jamesbury packing from below the detection limit to 143 µg/g may be of concern. The Whitey packing also showed a large increase in

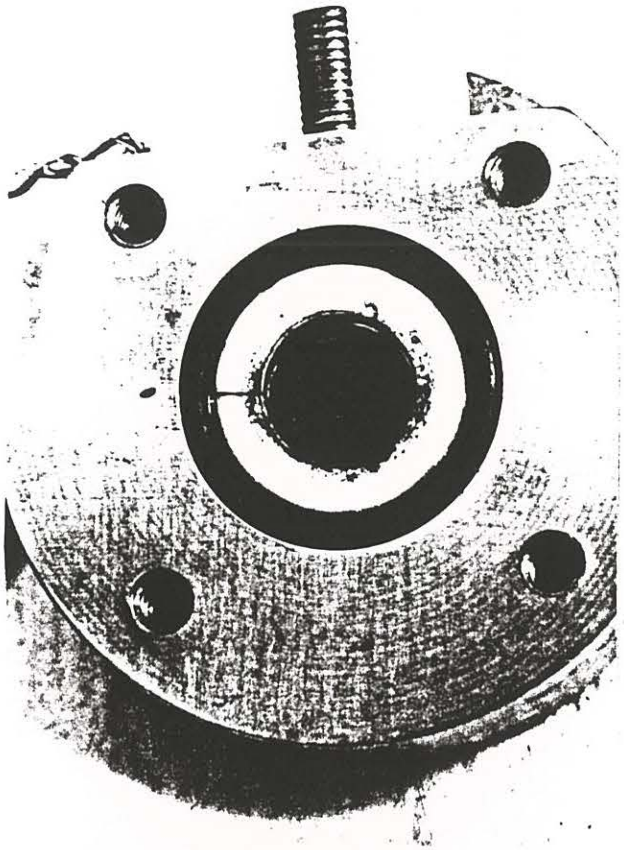

FIGURE 5: Cracked Worcester Seat (dark line @ 9:00 o'clock)

fluoride after irradiation, while the Worcester packing had a moderate increase in all three leachables.

The current Ontario Hydro specification for graphite valve packing materials [5] specifies maximum allowable values for leachable chlorides, fluorides and sulphates. In new condition, all the materials pass the maximum leachables requirement. Only the Worcester seat satisfies all three requirements after irradiation to 10 Mrad. The Whitey packing is just out of range for leachable fluorides. Since these valves are not exposed to radiation under normal operating conditions, excursions beyond the specified allowable levels of leachates after 10 Mrad exposure will likely be considered minor issues relative to other post-LOCA conditions.

5. DISCUSSION

Other than the Worcester seat, there is no visible evidence of radiation damage to the TFE

Table 5: Chemical Analysis of Irradiated and Unirradiated Components

Sample	Chloride µg/g		Fluoride µg/g		Sulphate µg/g	
	0 Mrad	**12 Mrad***	**0 Mrad**	**12 Mrad**	**0 Mrad**	**12 Mrad**
Whitey Packing	10	19	1	28	7	22
Worcester Packing	40	86	5	17	30	76
Worcester Seat	5	8	<1	9	3	9
Jamesbury Packing	3	4	<1	143	2	3

*The nominal total dose is referred to as 12 Mrad for this report.

components. It is unclear when and why the crack developed in the Worcester seat but the most likely time is between the 2 Mrad and 4 Mrad leak tests. Despite the crack, the valve did not leak catastrophically.

Previous research [6] has shown that high irradiation rates can result in less damage for a given total dose than low rates. Oxygen is required for the damage to occur, so for a given oxygen supply rate, there is a radiation dose rate that fully utilizes this oxygen to drive the damage process. If the dose rate is increased, the rate of damage will not increase unless extra oxygen is made available. Therefore, the slower radiation rate is considered to give conservative data. Since the total irradiation period for each valve exceeded 90 days, the results are considered conservative.

During a reference accident, the outside of the valve is estimated to receive a maximum of 10 Mrad. Interior components would receive less because they are shielded by the valve body. During these tests, the TFE components received at least 10 Mrad, so that the conditions were harsher than expected in the reference accident.

Despite the conservatism resulting from the dose rate and total dose, there is no evidence of increasing leakage with increasing radiation dose for any of the valves tested, indicating that they should be able to perform acceptably during a LOCA event.

ACKNOWLEDGMENTS

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