

<Technical Note>

SIPPING TEST: CHECKING FOR FAILURE OF FUEL ELEMENTS AT THE OPAL REACTOR

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Sipping measurements were implemented at the Open Pool Australian Light water reactor (OPAL) to test for failure in reactor fuel elements. Fission product released by the fuel element into the pool water was measured using both High Purity Germanium (HPGe) detection via samples and a NaI(Tl) detection in-situ with the sipping device. Results from two fuel elements are presented.

KEYWORDS : Sipping, Gamma Spectroscopy, HPGe, NaI(Te)

1. INTRODUCTION

Sipping is a non-destructive method used to test for failed reactor fuel elements by investigating the fission product released in a fixed volume of circulating reactor cooling water. This method is commonly implemented as a way to monitor to the integrity of spent fuel elements in wet storage which can be affected by corrosion over long periods of time [1-4]. Sipping can also be employed, as it is in this work, to investigate fuel elements which are suspected to have failed during the course of operation.

The Open Pool Australian Light water reactor (OPAL), is a recently commissioned 20 MW research reactor operated by the Australian Nuclear Science and Technology Organisation (ANSTO). The OPAL reactor's key activities are the production of radiopharmaceuticals, neutron transmutation doping (NTD) of Silicon for industry and the production of neutrons for neutron scattering instruments.

In March of 2007, regular monitoring of the reactor pool water indicated the possibility of fuel element failure under normal operation. During a shutdown maintenance period, sipping measurements were undertaken on each of the elements in the reactor core to identify any problem elements.

The OPAL core is made up of 16 fuel elements. An OPAL fuel element consists of 21 aluminium fuel plates arranged with 20 water channels in between. Each fuel plate contains a quantity of low-enriched uranium meat encapsulated in aluminium alloy approximately 300 microns thick. The plates, 80 mm wide and 800 mm long,

are then laminated to give the final thickness of 3 mm. The fuel plates are swaged into two aluminium side plates to make up the main body of the fuel element. Attached to the bottom is a water nozzle which directs cooling water into each of water channels between the fuel plates.

2. EXPERIMENTAL

A sipping assembly was manufactured at ANSTO and placed in the service pool of the OPAL reactor. The assembly was designed to encase a fuel element with a fixed volume of pool water and isolate these from the reactor pool during the test. Attached to the assembly were two hoses, one at the bottom and one at the top for circulating a volume of water through the fuel element. An electric powered centrifugal pump, located at the reactor pool side (8 meters above the service pool bottom), was utilised along with polyvinylchloride hose to circulate the water.

The fuel element under investigation was placed in the sipping assembly, sealed and the water was circulated through the water cooling channels of the fuel element. The failure of the integrity of the fuel element cladding would result in a release of radioactive fission products into the circulating water. After a period of time, a significant increase of the concentration of radioactive components in the sipping water would indicate fuel element failure. The relative concentration of radioactive components in the sipping water was monitored at intervals

using two methods involving gamma spectroscopy; an external sample method and an in-situ method.

The first method required the collection of sipping water samples and measuring these samples using two High Purity Germanium (HPGe) Detectors. Samples of approximately 1 litre were collected in plastic bottles from the sipping volume by means of a tap in the return line, enabling the pump and other measurements to be uninterrupted. This will be referred to here as the external sample method.

Both HPGe detectors were ORTEC GEM series P-type HPGe detectors with relative efficiencies of 16% and 14%, crystal volumes of 431 cm² and 319 cm² and resolutions (for Co60 at 1.33 MeV) of 1.68 keV and 1.81 keV respectively.

The second gamma spectroscopy method used in this work involved the use of a 6 × 5" NaI(Tl) scintillator detector in-situ with the circulating water. This will be referred to here as the in-situ method. The detector head was wrapped several times with a section of Teflon hose connected to the sipping assembly loop.

Both types of detectors were energy calibrated by using a range of Oak Ridge manufactured point gamma sources which have activity traceability to the National Institute of Science and Technology (NIST). Additionally, both HPGe detectors were efficiency calibrated with these sources located 10cm above the aluminium detector end-cap. The point efficiency was extended to the sample bottle geometry using a semi-empirical method employed

by ETNA (Efficiency Transfer for Nuclide Activity measurements) software [5,6].

Peaks from the HPGe measured spectra were identified using data from the online Table of Isotopes provided by Lawrence Berkeley National Laboratory [7] and the online LARA nuclide information provided by the Laboratoire National Henri Becquerel [8].

Sipping of each fuel element took a total duration of 120 minutes excluding the time to load the element into the sipping assembly. Once loaded, the rotary pump was switched on and the time was used as the reference start time for the measurements. In-situ measurements were undertaken at 15, 30, 60, 90 and 120 minutes of the reference start time and each were measured for durations of 450 seconds (live time).

At 30 and 120 minutes of the start reference time, one litre samples were taken for measuring with the HPGe detectors. The samples were positioned directly on top of the HPGe detector head and a spectrum was acquired over a period of 3000 seconds (live time).

The results from two fuel elements are presented in this work. They are identified here as fuel element 005b and 003.

3. RESULTS AND DISCUSSION

A background reference sample was taken from the bottom of the service pool, before the start of the sipping

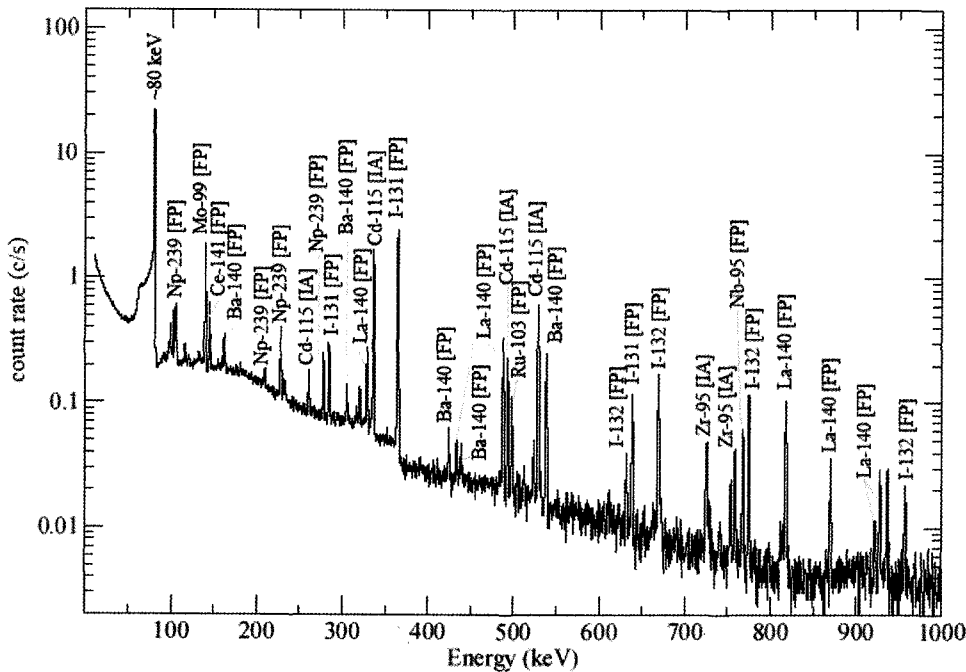


Fig. 1. Background Pool Water Spectrum Taken from the Bottom of the Reactor Service Pool, Measured Using a HPGe Detector. FP – Fission Product; IA – Impurity Activation

procedure (Fig. 1). The background pool water spectrum, measured using a HPGe detector indicates traces of pool water impurities which have been neutron activated,

indicated in the figure by IA (Impurity Activation). Also present are traces of fission products, indicated by FP (Fission Product).

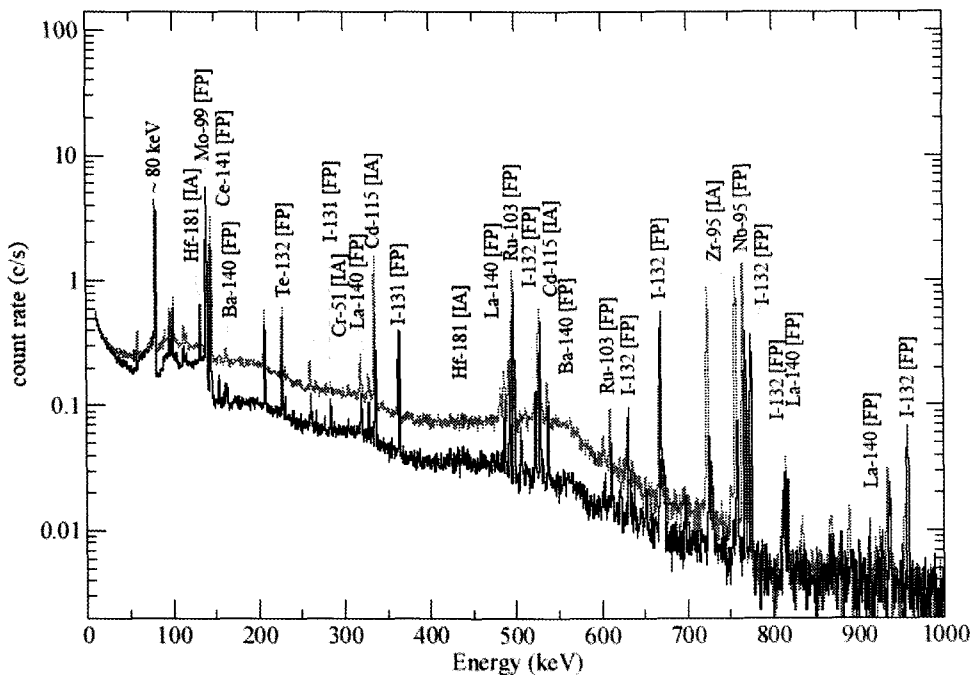


Fig. 2. Spectra of Sipping Samples from Fuel Element 005B Measured Using a HPGe Detector. Samples were Taken at 30 minutes (Black) and 120 minutes (Grey) after the Start of Sipping. FP – Fission Product; IA- Impurity Activation

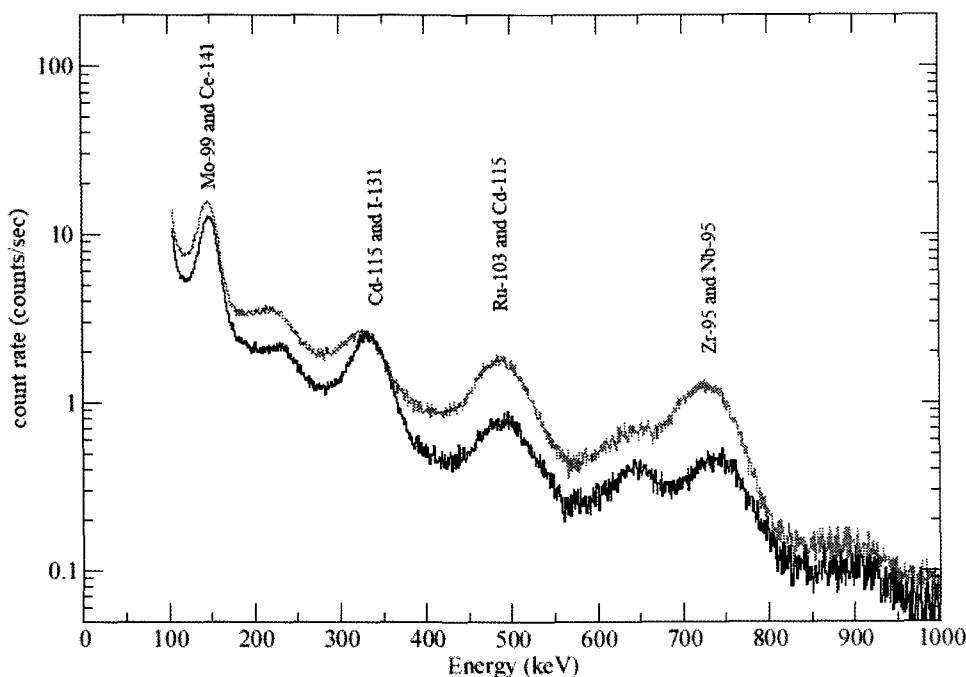


Fig. 3. In Situ Measurements of Sipping Water from Fuel Element 005b Measured Using a NaI(Tl) Detector. Samples were Taken at 15 minutes (Black) and 60 minutes (Grey) after the Start of the Sipping

Of these fission products, a significant indicator of a failed fuel element is the presence of iodine in the pool water [1]. I-131 and I-132 peaks found in the background sample originate from the use of a failed fuel element in the reactor.

Figure 2 displays the sipping sample spectra of fuel element 005b measured using the external sample method, with samples taken at 30 minutes (black) and 120 minutes (grey) after the start reference time.

Comparison of the 30 minute and 120 minute sipping samples show no significant increase in background count rate or in the count rate of the identified peaks. Many of the same peaks identified in this spectrum were identified in the background spectrum at similar count rates (Fig. 1).

Figure 3 shows the results of the in-situ measurements of fuel element 005B, taken at 15 minutes (black) and 60 minutes (grey) after the start of the sipping procedure using a NaI(Tl) detector. Although the peaks are not resolved, the overall rate of change as a function of energy is indicated by this technique, giving similar results as the HPGe measured data.

Figures 2 and 3 indicate that there was a minimal change in the fission product radionuclides detected in the sipping samples when compared to the background, for both the external sample and the in-situ methods.

Figure 4 displays the spectra acquired using HPGe detectors of element 003 samples collected at 30 minutes (black) and 120 minutes (grey) after the start of the sipping test.

There is a significant increase (approximately 4 times) in the count rate between the 30 and 120 minute samples for this fuel element. A similar increase is found when comparing the 30 minute sample to the background. The majority of the peaks identified from this element were present in the background spectrum, only in much reduced count rates. Both samples from element 003 show a higher proportion of fission product radionuclides. Prominent among these are I-131 and I-132, which are often used as indicators of fuel element failure [1].

Figure 5 shows the in-situ measurements of the fuel element 003 at 15 (black) and 60 (grey) minutes after the start of the sipping. From this information we can see the same increase of 4 times between the two measurements.

The in-situ measurements indicate two major peaks at around 670 keV and 770 keV, corresponding to two of the more intense peaks of I-132 (667.7 keV – 99% and 772.6 KeV – 75.6%) as shown in figure 4. Results from both figures 4 and 5 indicate failure of the cladding for fuel element 003.

Table 1 gives the activity concentrations for each of the HPGe detector samples collected, with reference to the I-131 and I-132 indicators. These were determined from the efficiency calibration of both HPGe detectors and the sipping samples.

The activity concentrations from fuel element 005B are of the same magnitude for the 30 minute and 120 minute samples, this is in contrast to fuel element 003 showing a significant increase in both the I-131 and I-132 activity

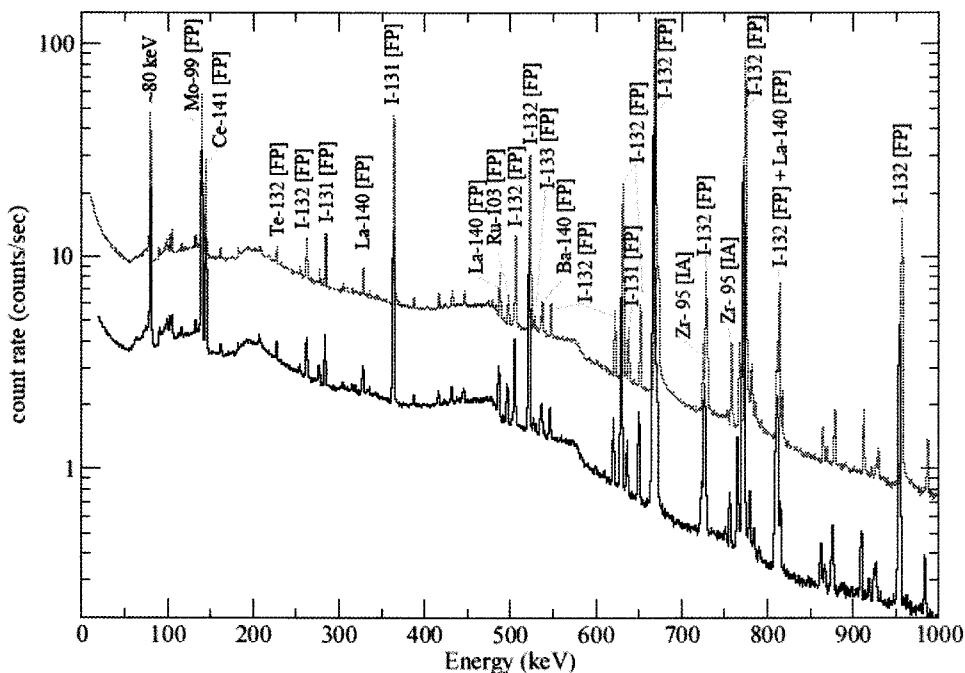


Fig. 4. Spectra of Sipping Samples from Failed Fuel Element 003 Measured Using a HPGe Detector. Samples were Taken at 30 minutes (Black) and 120 minutes (Blue) after the Start of Sipping. FP – Fission Product; IA- Impurity Activation

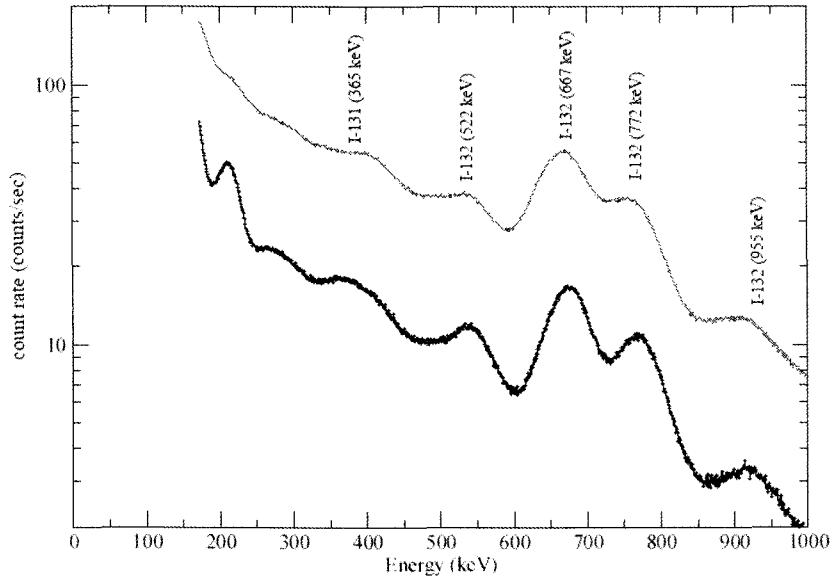


Fig. 5. In Situ Measurements of Sipping Water from Failed Fuel Element 003, Measured Using a NaI(Tl) Detector. Samples were Taken at 15 minutes (Black) and 60 minutes (Grey) after the Start of the Sipping

Table 1. Activity Concentrations Measured in the Sipping Samples from Fuel Elements 005B and 003 and a Background Sample. All Measurements are Given in Bq L^{-1}

Nuclide	Background	005B		003	
		30 mins	120 mins	30 mins	120 mins
I-131	5.9×10^2	2.0×10^2	1.8×10^2	8.6×10^3	2.6×10^4
I-132	1.6×10^2	5.4×10^2	1.6×10^2	5.1×10^4	1.3×10^5

concentrations. The rate of increase is $193 \text{ Bq L}^{-1}\text{min}^{-1}$ and $877 \text{ Bq L}^{-1}\text{min}^{-1}$ for I-131 and I-132 respectively, at the sipping rate used in these measurements. These values confirm the failure of fuel element 003.

We observed a gradual increase in the background count rate from sample to sample with the in-situ method. This was believed to be from a slow contamination of the Teflon tubing that wrapped the NaI(Tl) detector. A future improvement to this method could be the introduction of a Marinelli shaped reservoir to replace the Teflon hose. This would produce a larger sample volume for the NaI(Tl) detector to measure and allow better definition of the sample size if some quantitative measurements are required. It would also be suggested to change or flush the sample reservoir after each fuel element.

Due to the limitations in the resolution of the NaI(Tl) detector, we were unable to identify the radioactive components of the sipping water by this detector alone. The in-situ method does have the advantage of achieving higher detection efficiency and obtaining results without the need to take samples and count at a later time. Although unresolvable, the spectral information can be sufficient to identify increases in particular energy regions, such in

the case of I-132. This technique is satisfactory for an in-situ indicator of failed fuel elements, but should be used in conjunction with HPGe to identify the particular fission products.

An improvement to the in-situ method could be in the form of a higher resolution detector, which could eliminate the necessity for two detection methods. This detector would need to have an efficiency similar to that of NaI(Tl), which eliminates the use of HPGe as a financially achievable in-situ detector. $\text{LaBr}_3:\text{Ce}$ scintillator is a possible candidate and will be the topic of future work on this subject [9,10].

4. CONCLUSION

A sipping method was implemented at the OPAL reactor in Australia, to test for reactor fuel element failure. This involved using two gamma spectroscopy methods, one in-situ with the sipping assembly, the other by taking 1 litre samples. Results from two fuel elements, element 005B and 003 were presented from this work, using these methods.

Both methods were sensitive enough to identify fuel element failure of element 003 conclusively. It was found

that the significant identifiers of fuel element failure are the rate of increase in I-131 and I-132 fission product released into the sipping water.

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