Summary of Studies on Fuel Cladding Failure Location Systems

by

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Presented to

IAEA Specialists' Meeting on Fuel Cladding Failure
Detection and Localization in Fast Reactors
held at C.E.N. Cadarache, France, on October, 5-6, 1970.

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1. Introduction

The following three methods are proposed for the location system of failed fuels in Japanese fast reactors:

(1) sodium sampling method,
(2) detection of fission product gas bubbles, and
(3) tagging method.

Since it is necessary, to install detectors at the outlet of fuel assemblies in the first two methods, the upper core structure should be incooperated with the CFDL (Fuel Cladding Failure Detection and Location) systems. Studies on the CFDL systems, therefore, should be initiated at the early stage of reactor design.

Evaluations, especially of the sensitivities of these three methods, have been accomplished in order to select the most suitable system for the Japanese prototype fast reactor, "MONJU", whose conceptual design is now in progress. Only the important results are summarized here and the calculational results of each system are described in Appendices 1, 2, and 3.

A brief technical specification of the MONJU is shown in Table 1.

2. A Brief Description of the CFDL Systems

Sodium Sampling Method:

The method considered here is similar to that proposed for the PFR in United Kingdom. A small volume of sodium, which contains fission products (FP) released from failed fuels, is extracted from each assembly. Detection of delayed neutrons, emitted from the fission products, indicates a failed assembly. An elaborate sodium sampling system, such as the selector valve developed for the PFR, is required to develop.

Tagging Method:

In manufacturing process, a small amount of tag-gasses is sealed in fuel pins. Upon fuel failure, these gasses will escape into the reactor cover gas. By analyzing the cover gas, the failure can be identified in which zone it occurred.

Detection of FP Gas Bubbles:

FP Gas bubbles, released upon clad failure, shall be observed by means of an appropriate detector installed at the outlet of fuel assemblies. In-core flow meters and void meters are some of the sensors possibly used for this purpose.

3. Comparison and Evaluation of Results

3.1 Sensitivities

The result of sensitivity evaluations for various CFDL systems is given in Table 2.

In doing these calculations, it was specified that the sensitivities of detectors which could be used are high enough to detect a failure in one fuel pin.

Since the principles are different in each CFDL system, direct comparisons of sensitivities are not feasible. The comparison, therefore, is made by estimating magnitudes of signals which can be obtained in case of a credible clad failure accident.

Based on the results of these calculations, the following conclusions are obtained.

Sodium Sampling Method:

(1) Sensitivities of detection is restricted by the amount of uranium impurities contained in sodium. If the impurity level is kept constant while the reactor is in operation, the detector sensitivity is independent of the fuel burnup.

(2) It is anticipated that the continuous detection of delayed neutrons might be expected even after bursting, if fission products are released continuously from damaged fuels.

(3) Present analysis is not well established because the amount of FP released from a pinhole-type failure is uncertain.

Tagging Method:

(1) Neon, instead of xenon, is investigated as tag-gasses as the first candidate because of high domestic cost of the latter. The analysis shows that ^{21}Ne is applicable while ^{22}Ne is not. One of the drawbacks of the use of neon is that natural neon is much included as an impurity in the reactor cover gas. It is therefore necessary to use a sufficient amount of tag-gasses consequently the possible reduction of gap-conductance between pellet and cladding must be well considered.

(2) The concentration of neon gas in the reactor cover gas will increase with reactor operation due to a (n, α) reaction, which is

$$^{23}Na\ (n,\ \alpha)\ ^{20}F \xrightarrow[10.7\ sec]{\beta} {}^{20}Ne.$$

However, ^{20}Ne can be discriminated in scanning for ^{21}Ne, when a mass spectrometer is used.

Detection of FP Gas Bubbles:

(1) As shown in Table 2, for the case when distributions of bubbles are uniform at outlets of assemblies, it may not be feasible to detect bubbles released upon fuel failure. Could bubbles be collected with a cyclone, for example, the bubble release can be detected.

(2) The duration of bubble release is as short as 0.1 to 10 sec. It is questionable that the location can be identified during such a short period. In addition to this drawback, blips in flow rate, which indicate the release of FP gas, cannot be re-produced once the phenomenon has taken place.

(3) The duration of FP gas release depends on fuel burnups. This may make the detection of failed pins increasingly difficult in new fuels.

(4) Could the bubbles be collected by means of the cyclone method, small probe-type-flow-meters such as eddy-current-type-flow-meters or void meter are recommended as detectors.

3.2 Relationship with Reactor Structures

As mentioned previously, some modifications are required in the design of upper core structures in order to employ the sodium sampling or the FP gas bubble detection systems. Those additional complications introduced by the CFDL systems are disadvantageous in adopting these methods. In the tagging method, no such modifications are necessary. Ordinary mass spectrometers can be used in the analysis of gas sample extracted from the reactor cover gas.

Some of the advantages and disadvantages of these methods are summarized in Table 3.

4. Conclusion

It is very difficult to choose the most suitable CFDL system for fast reactors. However, the following conclusions can be made:

(1) The sampling method, if compatible with the specific upper core structures, is the most effective system in locating the failed fuels. In view of its high sensitivity, it is possible to recheck the failed fuel after its failure, while the reactor is on power.

In designing the system, it is important to estimate the background level. This is obtained from: (a) flow rate of sodium sample, (b) length and diameter of sample tubes, (c) volume of sample chambers, and (d) counting efficiency of neutron detectors. In MONJU, the background level of 30 cps is expected when (a) = 3 l/min, (b) = 15 m (1/2" I.D.), (c) = 0.3 l, (d) = 10%, as shown in Appendix I.

When the detector chamber is placed at the top of reactor shield plug, gamma and neutron levels are not prohibitive. The background can be further reduced by employing additional shieldings.

(2) The tagging method is very promissing, although being restricted by technical difficulties in fuel manufacturing. The CFDL system can be designed independent of mechanical configuration of the upper core structure.

^{21}Ne, ^{124}Xe, ^{126}Xe, ^{128}Xe, and ^{129}Xe are to be used as stable isotopes of tag-gasses. When 50% - 50% mixtures gas of two different isotopes and gas of single isotope are sealed in fuels, as many as 10 + 5 + 1 (not tagged) = 16 different zones can be labeled. When the mixing ratio is changed, the reactor core can be divided into still finer zones. For example, if tag-gasses of 30% - 70% mixtures are added, 5 x 5 = 25 more zones can be distinguished.

However, it would be almost impossible to locate the failed fuel, if fuel subassemblies in more than one zones have failed simultaneously.

(3) Clad failures will be detected if in-core flow meters are installed in future fast reactors. The short duration of FP gas release is one of the drawbacks in detecting FP gas bubbles.

In conclusion, it can be said that the sampling method is the most suitable one for the location system of fast reactors, if it could be accepted in the concept of reactor structure, because it has the high sensitivity and the re-checking possibility in reactor operation.

It can be also said that the tagging method is hopeful because it can be adopted without an undue complication of the core upper structure.

Table 1. Basic Specifications of the MONJU

Reactor Power	750 MWth
Electrical Power (net)	310 MWe
Coolant Temperature	
Reactor Inlet	400 °C
Reactor Outlet	550 °C
Primary Flow Rate	14.25×10^6 Kg/hr
Average Neutron Flux	4×10^{15} nv
Average Flow Rate per Channel	6×10^4 Kg/hr
Fuel Material	PuO_2-UO_2
Inner Zone	14% (PuO_2)
Outer Zone	19% (PuO_2)
Fuel Assembly	
Shape	Hexagonal
Distance Across Flats	110 mm
Number of Pins (Core)	169
Number of Pins (Blanket)	61
Fuel Pins	
Diameter (Core)	6.5 mm
Diameter (Blanket)	11.6 mm
Total Length	275 cm
Gas Plenum Length	108 cm
Core Diameter (Equivalent)	172 cm
Reactor Vessel Diameter	6.3 m
Reactor Vessel Height	17.0 m
Cover Gas Volume in Reactor Vessel	22 m^3

Table 2. Comparisons of Numerical Analysis

<table>
<tr><th colspan="2"></th><th colspan="2">Sodium Sampling Method</th><th colspan="2">Tagging Method</th><th colspan="2">Detection of FP Gas Bubbles</th></tr>
<tr><td colspan="2">Nature of FP Release</td><td colspan="2">Continuous Release or Burst</td><td colspan="2">Burst</td><td colspan="2">Slow Leak</td></tr>
<tr><td colspan="2">Basis of Calculation</td><td colspan="2">(1) Background level is determined by uranium impurities in sodium (50 ppb)
(2) Amount of Release: 10 mg (PuO_2-UO_2)
(3) 100% mixing of FP with coolant in a subassembly</td><td colspan="2">(1) Tag-gasses: ^{21}Ne or ^{22}Ne
(2) Amount of sealed gas per fuel element: 27 ml</td><td colspan="2">(1) Area of Pinhole: 1 mm^2 or 3 mm^2
(2) Location of Failure: Middle of fuel pins.
(3) 100% mixing of bubbles with coolant at the outlet of subassembly.</td></tr>
<tr><td rowspan="5">Results of Calculations</td><td rowspan="2">Initial</td><td>Continuous Release</td><td>Burst</td><td>^{21}Ne</td><td>^{22}Ne</td><td colspan="2">Area of Pinhole
1 mm^2 | 3 mm^2</td></tr>
<tr><td>S/N = 1.3</td><td>S/N = 40</td><td>S/N = 0.25</td><td>S/N ≅ 0.01</td><td>α = 2
τ = 0.5</td><td>α = 3
τ = 0.3</td></tr>
<tr><td>10^4 MWD/T</td><td>ditto</td><td>ditto</td><td>ditto</td><td>ditto</td><td>α = 2
τ = 0.7</td><td>α = 3
τ = 0.5</td></tr>
<tr><td>10^5 MWD/T</td><td>ditto</td><td>ditto</td><td>ditto</td><td>ditto</td><td>α = 2
τ = 3</td><td>α = 3
τ = 2</td></tr>
<tr><td colspan="2">Minimum level of signals necessary for detection</td><td colspan="2">S/N > 1</td><td colspan="2">S/N > 0.1</td><td colspan="2">$\alpha \geq 5$
α: Void fraction (%)
τ: Duration of release (sec)</td></tr>
</table>

Table 3. Comparison of Advantages of Various CFDL Systems

(O) Advantages
(X) Disadvantages

	Sodium Sampling Method	Tagging Method	Detection of FP Gas Bubbles
Detection Systems and Their Compatibilities with Core Upper Structures	(X) Elaborate sampling systems are required for each fuel assembly.	(O) No special modifications are required for the core upper structures. Sample gas can be extracted from the reactor cover gas system.	(X) Detectors are required at each subassembly. Introduces additional complications in core upper structures.
Compatibilities with Reactor Structures	(X) Elaborate components, such as a selector valve, an EM pump, penetrations (through shield plugs) are required.	(O) No additional complication	(X) Detectors must be made interchangeable because of their limitted life.
Problems in Manufacture of Fuels	(O) None	(X) Technical problems of sealing tag-gasses and reduction of gap conductance due to tag-gas.	(O) None
Economical Considerations	Increase in capital cost needed for modification of core upper structures.	Small additional cost for instrumentation and control system. A few per cent increase in fuel cost by tagging.	Same as the sampling method. Detectors must be replaced every 1 - 3 years.