FUEL PERFORMANCE EVALUATION THROUGH IODINE ACTIVITY MONITORING

K.ANANTHARAMAN, RAJESH CHANDRA

Refuelling Technology Division
Bhabha Atomic Research Centre
Bombay-400085,INDIA

ABSTRACT

The objective of the failed fuel detection system is to keep a watch on fuel behaviour during operation. This paper describes the evaluation of fuel behaviour by monitoring the activities of various isotopes of iodine both during steady state and during a reactor shutdown. The limitations of this approach also has been explained. The monitoring of tramp uranium for different types of release, namely fixed contamination and continuous release from fuel, is also presented.

1.0 INTRODUCTION :

The fuel for nuclear power reactor is designed in such a way that the amount of structural material is kept to the minimum to achieve better neutron economy. A well designed fuel has a very low failure rate. The cladding forms the first barrier against the leaching of radioactivity. The defected fuel releases fission product iodine to the primary heat transport system. The analysis of various isotopes of iodine and their ratios in the coolant gives an indication of the type and number of failures. The activity in the coolant could be due to activity leached from the fuel and from the contamination in the reactor core. The intent of this analysis is to locate and remove the failed fuel immediately after it starts leaching out the activity. When the reactor is shut down, water enters the pellet-clad gap of the defected fuel element. Iodine being more mobile in water than in steam, there is an accelerated release of iodine called `Iodine spiking'. Two of the iodine spikes have been compared with the calculated values.

2.0 IODINE ACTIVITY

The fission gases generated widely vary in their decay times. The content of gases with very long decay time keeps on increasing with time and contributes to fission gas pressure. The radioactive isotopes of iodine reach a saturation value depending upon operating parameters like power and health of fuel like defect size.

2.1 Steady State iodine activity

The inventory of iodine in the pellet clad gap after reaching equilibrium is given by

$$N = \frac{3\sqrt{D}\,F\,Y}{\sqrt{\lambda}\,(\lambda + k)} \qquad \text{.....(1)}$$

where N - No. of atoms in the gap
D - Diffusion coefficient
F - Fission rate (Fissions/sec.)
Y - Fission Yield
λ - Decay constant (sec^{-1})
k - Escape rate coefficient (sec^{-1})

The fuel diffusion coefficient, as reported by Notley[1], is given as a function of operating power (P) in KW/m.

$$D = 10^{(P-145)/10} \qquad \text{..... (2)}$$

The above equations can be used to calculate the inventory of iodine isotopes in the pellet clad gap.

2.2 Iodine ratios

The steady state inventory of iodines reach a saturation value. The ratio of the iodine activities could be used as an indication of the leakage rate from fuel. The Release Rate (R) through the defect could be taken as a first order rate process & derived from equations (1) and (2).

$$R = kN = \frac{3\sqrt{D}\,FY\,k}{\sqrt{\lambda}\,(\lambda + k)} \qquad \text{.....(3)}$$

The ratios of the isotopes can be derived from the above equation, if one assumes the diffusion coefficient (D) and leakage rate (k) is same for both I-131 and I-133.

$$\frac{R_1}{R_3} = \frac{Y_1}{Y_3}\,\frac{\lambda_3^{0.5}\,(\lambda_3+k)}{\lambda_1^{0.5}\,(\lambda_1+k)} \qquad \text{.....(4)}$$

The subscripts 1 & 3 refers to I-131 and I-133 respectively. The equation (4) is plotted in Fig. 1. It can be seen from Fig. 1 that the ratio is around 12.5 for a leakage rate of 10^{-8}/sec and reduces to around 2 for a leakage rate of 10^{-5}/sec.

The above equations give the ratio of the number of atoms of iodine isotopes released from the defect. The plant measurements (Cm) are given as activity in microcuries/litre (μCi/l). The relation between the activity measured and the release rate depends on the contamination due to tramp uranium in the system and the purification flow. The correction for purification flow is

$$Cm = \frac{R\ \lambda\ e^{\lambda T}}{(\lambda + \beta)\ V\ (3.7\ E + 4)} \qquad \text{.....(5)}$$

where

β - Purification constant (sec^{-1})
V - Volume of the PHT coolant (litres)
T - Time elapsed between sample collection and measurement

2.3 Limitations of this approach

The analysis assumes that the equilibrium concentration of the isotopes are present in the pellet clad gap and hence the release rates. Whenever there is a power change (increase / decrease) or a new fuel is introduced during the refuelling, the ratios will change as a function of time. This happens due to

(i) the decay rates and inventories are different for different isotopes before the transient and

(ii) The generation is dependent upon the new power.

The Fig-2 indicates that around 20 days of steady state operation is needed to get reliable results through this procedure.

2.4 Tramp Uranium

The uranium, which is exposed to the coolant, comes mainly from three sources -

a) As fixed contamination from the fuel fabrication plant

b) Released from a defective fuel which has been discharged but the contamination on incore surfaces still remain.

c) A small but continuous release from a defective fuel.

Of all the isotopes of iodine, I-134 has a short half life ($t_{1/2}$ = 54 m). The activity of I-134 found in the coolant comes mainly from the tramp uranium and very little from diffusional release.

2.4.1 Generation of I-134: The initial composition of the contamination is identical to that of leaking rod. On the other hand its future development is different. In the very fine UO_2 layer on the outside of the cladding, the flux depression phenomenon does not intervene and the decay of U-235 and growth of Pu-239 is much faster in the contamination than in the fuel. This factor should be considered in the evaluation of I-134 activity in the coolant. Fig. 3 indicates the production rate of I-134 both in the fuel and in the contamination as a function of time. In both the cases the production rate of I-134 steadily falls.

The pattern of I-134 activity with time is different for a defect which releases continuously very minute quantity of fuel into the coolant. The released fuel particles get deposited on the down stream side of the defect. The I-134 activity continuously increases for a long time before settling down to a constant value. The behaviour of fuel for a continuous release is shown in fig. 4. This compares well with the LWR literature which shows an increase in I-134 concentration with time during a cycle.[2,3].

2.4.2 Estimation of tramp uranium: The primary process by which the fission gases are released from tramp uranium is recoil and knock-out. However, the tramp uranium being fine coating on inner surfaces, recoil is the major process. The release/birth (R/B) ratio in tramp uranium is around half[4] The birth rate is given by

$$B = F Y$$
$$R/Y = C = F/2 \qquad \text{.....(6)}$$

This ratio is constant for tramp uranium irrespective of the isotopes.

2.5 Analysis of Power Reactor Data

The release during steady state operation of a reactor could be expressed as a combination of activity release from defective fuel and from tramp uranium in the form

$$R/Y = a\ \lambda^b\ H' + C \qquad \text{..... (7)}$$

H' - a dimensionless factor which takes precursor effect into account.
b - constant varying from -0.5 to -1.5 depending upon the defect size.

The measurement and plotting of release rates of I-131, I-133, I- 134 and I-135 enables us to evaluate a, b and C in the above equation. This could be graphically or analytically solved. The fission rate (F) for tramp uranium is given by equation(6). The Fission rate/gram of tramp uranium (Fu) was calculated assuming

i) the distribution of tramp uranium in the core is same as that of fuel in the core.
ii) The contamination is assumed to be natural UO_2.

Tramp uranium in the core = F/Fu gms.

The calculated values were compared with the reported values [6.4] in literature and are given below.

Reactor	Tramp uranium (gms)	
	Reported	Calculated
Douglas Point	180	206
Point lepreau	3.528	4

The calculations and the reported values are in good agreement.

3.0 IODINE SPIKING

When the reactor is shut down, water enters the pellet-to- sheath gap of the defected fuel element. Since iodine is more mobile in water than at steam that is present in defective fuel at power, there is an accelerated release of iodine causing the so called 'iodine-spike'. The magnitude and timing of the iodine spike depends on the same parameters as that for steady state release.

3.1 Evaluation of Iodine spiking

The iodine release model during a reactor shutdown is based on the relation given by B.J. Lewis.[4] The model assumes

i) Axial diffusion of iodine in the gap to be rate determining step.

ii) Defects have been distributed uniformly so that the resistance to axial diffusion is same for all defects.

iii) Diffusion does not take place at element ends and concentration of iodine at defect size is zero.

For fuel element of length `l' with a defect at the centre, the number of atoms of a particular isotope in the coolant `Nc' at time `t' after shut down is given by

$$Nc = \{Nco + Ngo * (k / (k-\beta)) * [1-\exp(-(k-\beta)t)]\} * \exp(-(\lambda+\beta)t)$$

Nco - Initial inventory of iodine atoms in the coolant at the time of shut down.
Ngo - Initial inventory of iodine atoms in the pellet-clad gap available for release at the time of shut down.

The escape rate coefficient k, is a function of number of defects (n) and length of fuel elements (l).

3.2 Application to power reactor

The above equations have been used to follow the iodine transients following one typical iodine transient from MAPS-1[5] is shown for I-131. The fig. 5 shows the transient for I-131 following a reactor trip. To verify the results, the I-133 transient for the same reactor trip was followed and is given in fig. 6. The figs. 5 & 6 indicate that the agreement between theory and measurements is very close.

4.0 CONCLUSIONS

The iodine analysis has shown us that it is possible to predict the type & power of a failed fuel assembly inside the core. This data in combination with DN scans can help us to locate the failed fuel bundles. These could be further confirmed by dry sipping and Post Irradiation Examination.

We intend to continue this work to include burn up effects and the release of gaseous fission products. These along with the analysis of DN results can be a good tool for failed fuel management.

5.0 ACKNOWLEDGMENTS

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6.0 REFERENCES

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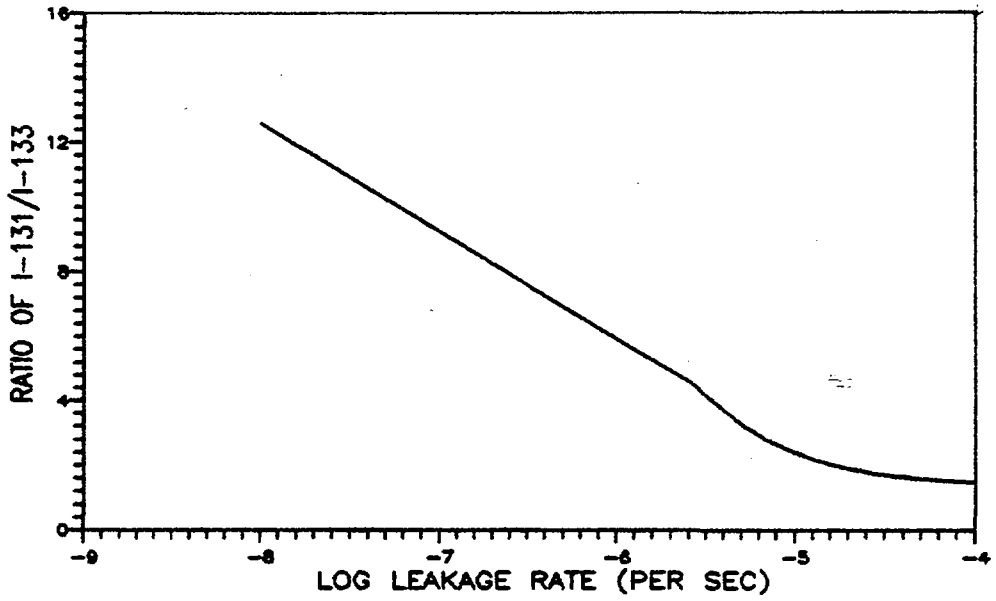

FIG.1 EFFECT OF LEAKAGE RATE ON IODINE RATIOS

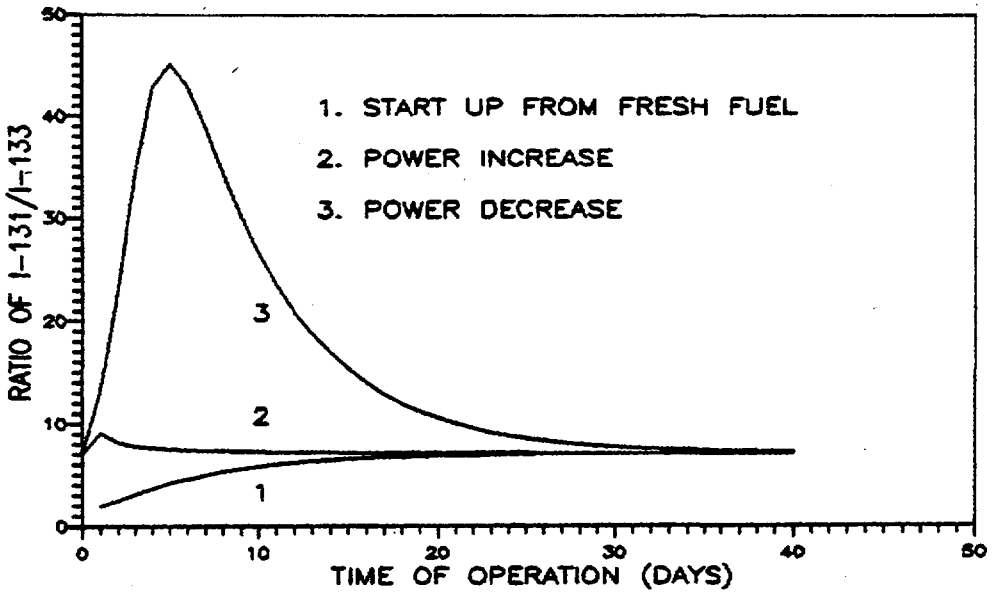

FIG.2 VARIATION OF IODINE RATIOS DURING TRANSIENTS

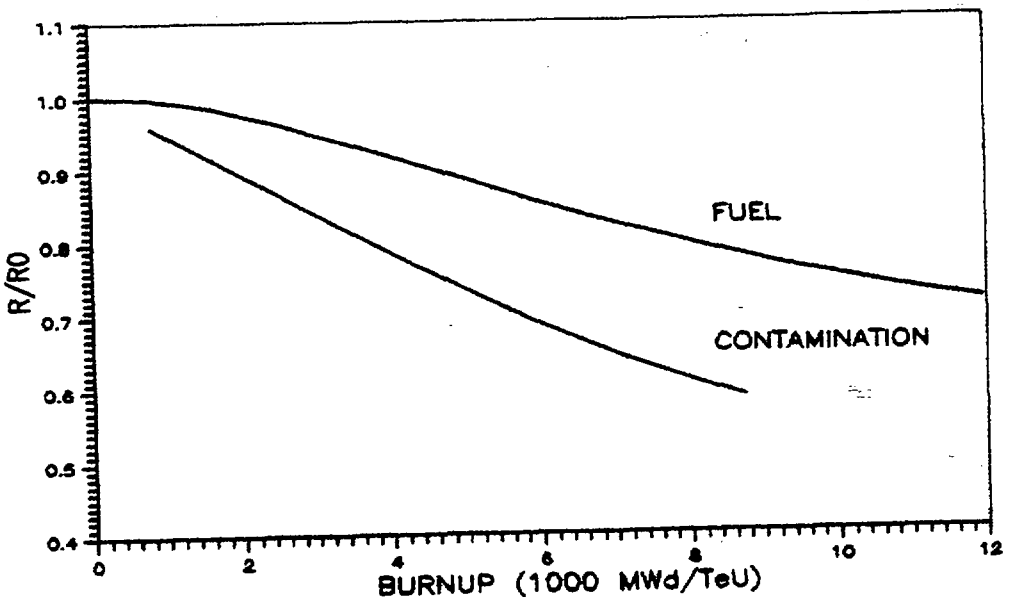

FIG.3 I–134 GENERATION

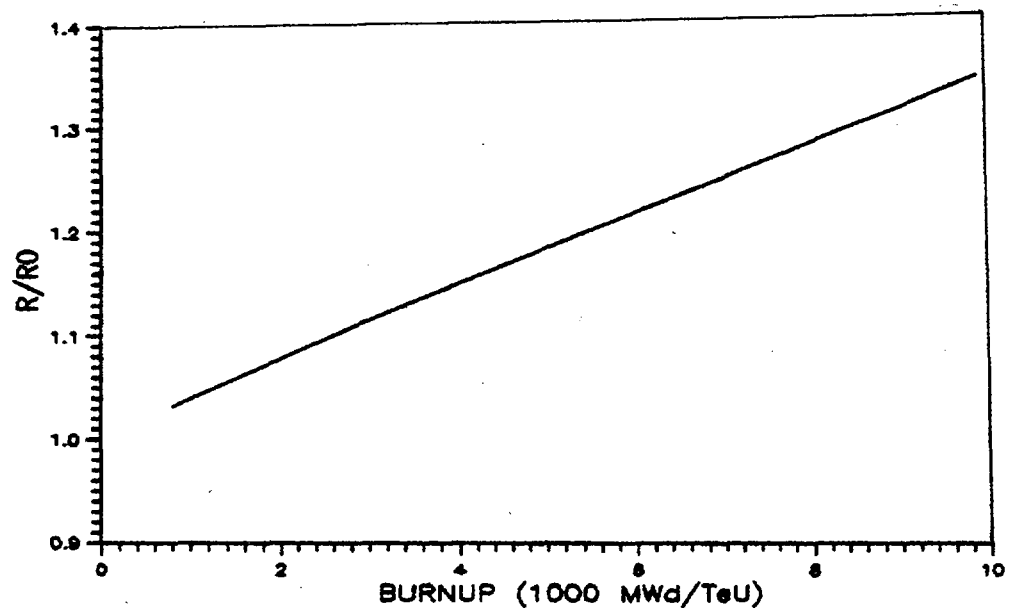

FIG.4 I–134 GENERATION – CONTINUOUS RELEASE

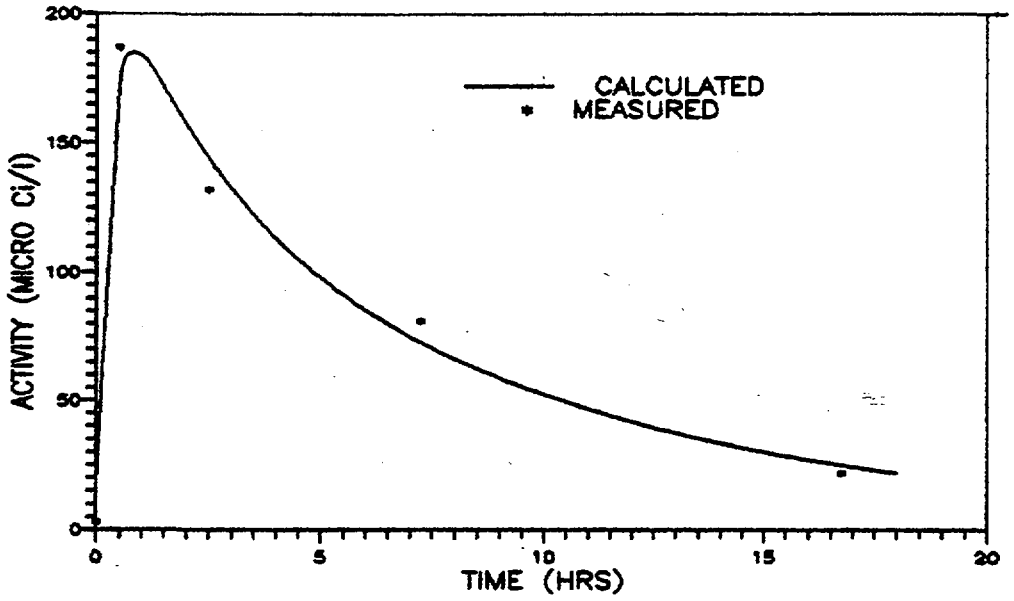

FIG.5 MAPS–1 IODINE TRANSIENT (I–131)

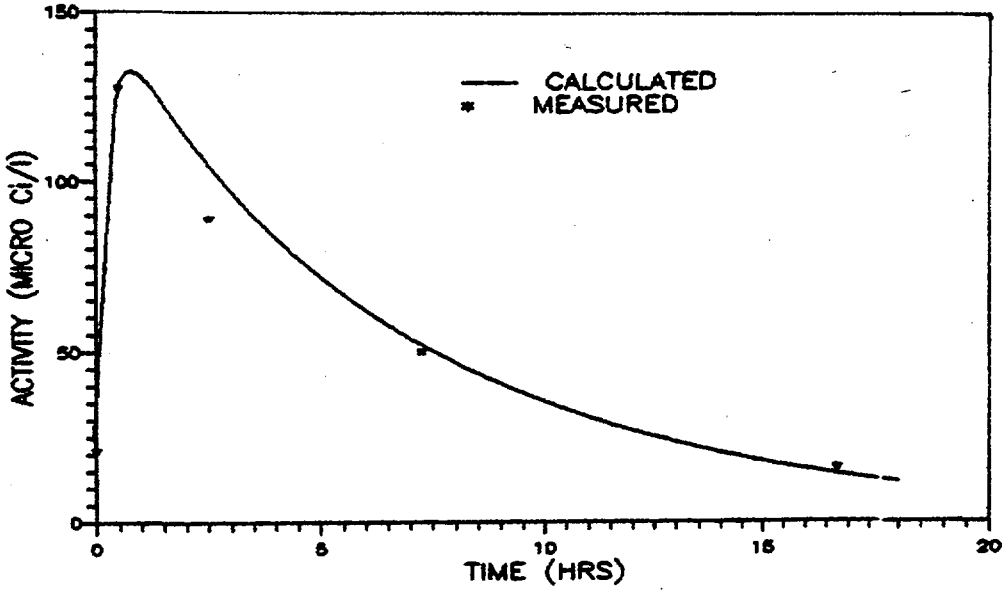

FIG.6 MAPS–1 IODINE TRANSIENT (I–133)