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FAILURE LOCATION ANALYSIS FOR TAGGED REACTOR ASSEMBLIES

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FAILURE LOCATION ANALYSIS FOR TAGGED REACTOR ASSEMBLIES

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Gas tagging for the location of defective pin cladding in a liquid metal cooled fast reactor assembly consists of the addition of small amounts of xenon and krypton gases, having unique isotopic compositions, to the pins of each assembly. When a pin fails during subsequent irradiation, varying amounts of the tag gas and other gases escape to the coolant and collect in the cover gas plenum, as shown in Figure 1. A mass spectrometric analysis of a sample of the cover gas then makes possible the location of the latest one or two defective assemblies by comparing the measured ratios of concentrations of different gas isotopes to the fabricated ratios as corrected for changes due to neutron exposure.

Because values of the $^{78}\text{Kr}/^{80}\text{Kr}$, $^{82}\text{Kr}/^{80}\text{Kr}$ and $^{126}\text{Xe}/^{129}\text{Xe}$ ratios do not strongly vary with neutron exposure for either the Fast Flux Test Facility (FFTF) or Clinch River Breeder Reactor Project (CRBRP), these isotopic ratios have been designated as "primary design ratios," i.e., ratios whose values are prescribed for use in the design process. The $^{124}\text{Xe}/^{129}\text{Xe}$ also is a primary design ratio for the CRBRP even though it is more sensitive to neutron fluence. The values of the $^{128}\text{Xe}/^{129}\text{Xe}$ ratios vary much more with neutron exposure, and hence they are best used to distinguish the age of two assemblies which otherwise might have nearly identical values of the primary design ratios⁽¹⁾.

The determination of the gas tag ratios and the gases to mix them is done in three steps. The first involves an analysis for worst-case changes in the ratios with time so as to select a set of ratios that remain distinct throughout the exposure of tag gas in the reactor. More specifically,

FUEL FAILURE LOCATION - GAS TAGGING

Figure 1. Fuel Failure Location - Gas Tagging

ISOTOPIC RATIOS USED IN BASIC TAG DESIGNS

FAST FLUX TEST FACILITY

CLINCH RIVER BREEDER REACTOR PLANT

the analysis involved in this step identifies the reactor assembly with the worst case changes for a given isotopic ratio, changes produced from neutron capture by the tag gas nuclei and indirect production of new nuclei from transmutation of fission products in fuel assemblies. These worst case changes are used to determine the minimum allowable spacing between tag ratios that will still provide for unambiguous identification.

Determination of the minimum spacings is primarily a combination of three considerations: burnup of the tag gas, corrections for uncertainties in the tag ratios caused by cross section and flux uncertainties, and corrections for uncertainties associated with mass spectrometer measurements. The conservative recommended spacing factors used for the FFTF are consistent with the design philosophy that the ratios be spaced sufficiently far apart that a burnup analysis would not be necessary for identification of a single failed assembly⁽²⁾.

The second step in determining a gas tag design is selection of the configuration of the ratios in the 3- or 4-dimensional space whose orthogonal axes are the corresponding gas ratios prescribed in the design. The prescribed values of the ratios are positions in the space. Figure 2 shows the pattern of tag ratios in two of the five xenon planes which were mixed for Cores I - II of the FFTF for the three design ratios $^{78}\text{Kr}/^{80}\text{Kr}$, $^{82}\text{Kr}/^{80}\text{Kr}$, and $^{126}\text{Xe}/^{129}\text{Xe}$. A design for the CRBRP using these three design ratios is shown in Figure 3. A unique combination of ratios is assigned to each assembly, corresponding to a point in the tag space.

The third step, performed after the design ratios have been set, is to determine how the several available xenon and krypton gas mixtures with different enrichments of the tag isotopes should be mixed in order to obtain the desired ratios at minimal cost.

Figure 2. Tag Ratios for Fuel and Control Assemblies of FFTF Cores 1 and 2 (Planes 1 and 4 are shown.)

Figure 3. Tag Ratios for Fuel and Blanket Assemblies of CRBRP 3-D Design
(Planes 1 and 4 are shown.)

Age tagging consists of the use of information from tag isotopes whose isotopic ratios were not prescribed in the gas blending process because they change too much with burnup⁽³⁾. Reliance on such additional information is called for when duplicate tags exist in a given core. Such a case could occur, for example, if the two assemblies from Cores I and II of the FFTF having the same tags were in the core simultaneously, since identical gas tag ratios were fabricated for each core load.

The background concentrations of natural xenon and krypton contamination in the argon cover gas have been prescribed to be 0.25 and 0.24 vppb, respectively, for the FFTF. The escape of only 0.15% of 1 cm³ of xenon tag gas must occur before the gas concentration from the failure is as small as that of the background in the FFTF. If the same background concentration is assumed for the CRBRP, only 0.4% of the 0.75 cm³ of xenon tag gas must escape from a pin to equal the background concentration. (These considerations about tag gas concentrations in the cover gas do not take into account the possibility of entrainment of tag gas in sodium or the escape and purge rates of the tag gas; however, an estimate of the holdup is that more than 90% of the escaped tag gas will reach the cover gas within a short period of time, i.e., several minutes). When such small concentrations of tag gas occur, such background effects must be accounted for in the identification of the failure.

It is anticipated that, in the great majority of cases, identification of a failed assembly will be readily achieved. In spite of a careful design of the tag system, however, occasions may arise where a straightforward identification of which assembly has failed may be difficult. Examples of such occasions are: one assembly fails and only a very small amount of tag gas escapes; two or more assemblies fail nearly simultaneously

so the resulting gas is a mixture depending upon the relative amounts of gas leaked from each failed assembly; a small amount of tag gas escapes from one or more assemblies while the background level of tag gas is high either because of inadequate operation of the Radioactive Argon Processing System or because tag gas from a recent failure has not yet been purged from the argon cover gas. In situations such as these, the uncertainties can be compounded in such a way that the match between the original values and the measured values is open to question, and even possibly confused by other tag values.

In these cases where an analysis of leaked tag gas does not completely identify the failure, it is possible to rank the assemblies according to the relative probability of failure for each assembly.

The Tagged Assembly Failure Location Analysis (TAFLA) computer-program, developed at HEDL, automates the calculations for assigning relative probabilities of failure to the assemblies. The code provides an objective method of utilizing the information available from the gas tag system. The procedure⁽⁴⁾ is a probabilistic one which incorporates probability distributions to describe the uncertainties associated with ratio changes due to neutron capture and indirect production, and mass spectrometer measurements occurring during mixing of the tag gases during fabrication and following a tag gas escape to the reactor cover gas. The program orders all important single-assembly and double-assembly failure combinations which could have occurred, based on the measured tag gas ratios obtained after an actual failure.

The probabilistic approach is particularly appropriate in the analysis of 'simultaneous' failures - two separate assemblies leaking tag gas

within the same time interval. The isotopic ratios representing the final mixture are functions of the fraction of tag gas escaped from each assembly. Since this must be estimated, a probability distribution is useful in describing the fractional gas escape.

Since the FFTF is a test facility, it has been necessary to identify tags for assemblies designed for various fuel and absorber tests. Many of these tests, including run-to-clad-breach, will have extended residence times where distortion of the initial ratios may be substantial.

Again the tags have been assigned so that uniqueness is maintained over the time periods involved. In the FFTF, 80 sets of regular driver tags plus approximately 20 sets of tags for control assemblies have been prepared, and about 70 test tags are in the process of preparation for startup this fall. At that time the TAFLA code, with its capacity for processing concentration and burnout data, will be available when identification of failed assemblies is in question.

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