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OAK RIDGE NATIONAL LABORATORY

OPERATED BY MARTIN MARIETTA ENERGY SYSTEMS, INC.
POST OFFICE BOX X, OAK RIDGE, TENNESSEE 37831

ORNL
FOREIGN TRIP REPORT

ORNL/FTR-2484

DATE: February 2, 1987

SUBJECT: Report of Foreign Travel of R. E. Maerker, Research Staff, Engineering Physics and Mathematics Division

TO: Herman Postma

FROM: Richard E. Maerker

PURPOSE: To participate in the design of an experiment using the VENUS facility located at the CEN/SCK installation in Mol, Belgium. The experiment is intended to benchmark calculational techniques that will be devised for the determination of reactor pressure vessel fluence arising from the use of one method of fluence reduction that is being implemented in several U.S. reactors.

SITES VISITED: 1/12-15/1987 CEN/SCK Mol, Belgium J. Debrue
A. Fabry
G. Minsart
C. de Raedt

ABSTRACT: A modification of the existing VENUS experimental facility has been proposed which will simulate, on a much reduced scale, the geometry and essential neutron transport features involved in the use of a partial length shield assembly that has been adopted at the H.B. Robinson-2 plant, and similar to designs also being incorporated or contemplated in other U.S. reactors, to reduce fluences at critical weld locations which may be subject to pressurized thermal shock phenomena. At the present time there are no measurements available either in PWR's or test reactors to benchmark calculational methods of these fluences, which involve transport in three-dimensional geometry. A description is presented of the design of such a benchmark experiment that introduces VENUS-3 and which will be implemented by the end of the summer of 1987. Included in this description are the basic considerations which led to the proposed modifications of VENUS-1, the measurements contemplated, and the schedule of the entire program involving both the experiment and its analysis over the time interval April 1987-December 1988.

Travel Report

The purpose of the traveler's visit to the CEN/SCK laboratory at Mol was to act as the ORNL representative of the NRC-CEN/SCK sponsored inter-laboratory agreement, and to participate in the design of an experiment to be performed by Mol using their VENUS facility. The planning discussions were held essentially with the four Mol scientists whose names appear on the summary page. During the visit, the traveler also presented a seminar on the LEPRICON code system and methodology, and its application to the analysis of cycle 9 of H.B. Robinson-2. This code system will be implemented by B. L. Broadhead of ORNL on a Belgian computer in the fall of 1987. It is anticipated that Mol will apply the code to their DOEL reactor and perhaps others in the near future.

The experiment to be designed is intended to satisfy the needs of the NRC in providing a series of measurements that can be used to validate calculational methods of pressure vessel fluence at critical weld locations using a modified core geometry for fluence reduction similar to the one presently employed for cycle 10 of H.B. Robinson-2. The PWR modification consists of replacing the uranium oxide pellets in the lower 42 inches of the 12 peripheral assemblies along the flats with stainless steel rods, replacing the upper 6 inches with natural enrichment uranium oxide, and replacing the remaining 96 inches in the middle with 1.25% enriched pellets. Gadolinium is also introduced into the reactor for proper control. This modification, along with similar modifications for other U.S. reactors, primarily reduces the fluence on the lower circumferential weld in the pressure vessel located in H.B. Robinson, 21 3/4 inches above the bottom of the active fuel, on a longitudinal weld, and on the upper circumferential weld, parts or all of which are located near the azimuth of maximum flux. The lower circumferential weld is the critical location of the three, and during the first eight cycles which all involved normal out-in-in fresh fuel loading and no low-leakage core modifications of any kind, had suffered an RT-NDT shift that if allowed to continue unchecked would result in reaching the screening criterion of 300 deg F on or slightly before 10 effective full power years. Thus, harsh measures had to be taken in order for the reactor to meet its anticipated effective full power lifetime of 32 years. Cycle 9 employed a new fuel management scheme of in-out-out for the 12 peripheral assemblies along the flats, producing a reduction of the core leakage by about a factor of two, mitigating somewhat the slope of the temperature shift vs. time. Cycle 10 used the partial length shield assembly (PLSA) and decreased fuel enrichment concept previously described and all remaining cycles will continue to do so. The result of calculations performed by TEC indicated approximately a factor of 12 reduction in the fluence over that of cycle 8.

A simple diagram illustrating the differences between cycle 8 and cycle 10 geometries that affect the fluence at the lower circumferential weld is shown in Fig. 1.

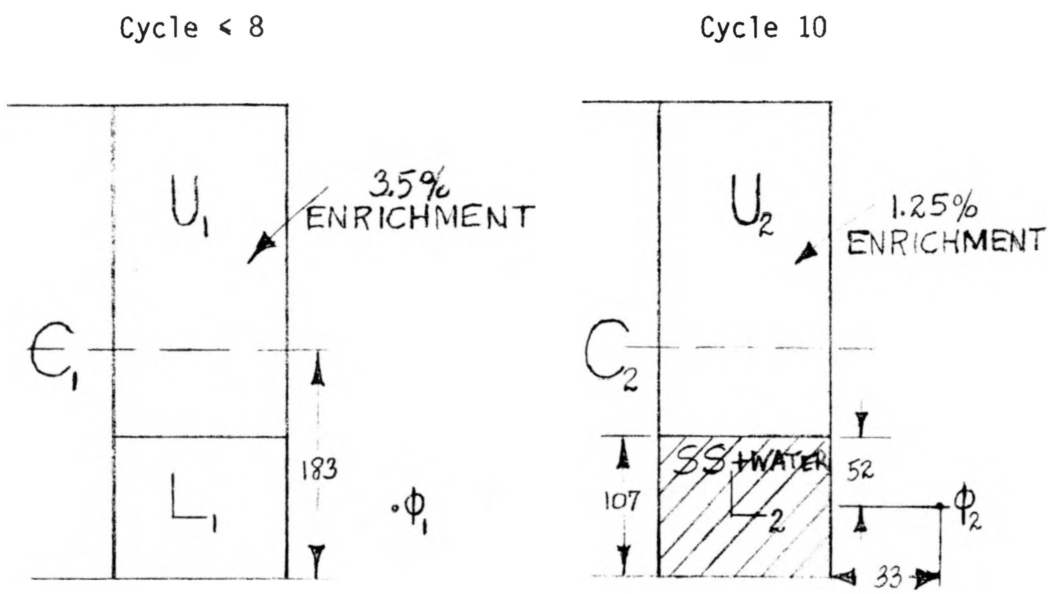

Fig. 1. Comparison of Geometries of the Peripheral Flat Assemblies Between Cycle 10 and the First 8 Cycles. All dimensions in cm.

Let us denote by ϕ_U the contribution to the flux at the weld from sources lying above the PLSA in the peripheral assemblies, by ϕ_L the contribution from sources in the PLSA region, and by ϕ_C the contribution from sources in the inner regions of the core. Let the subscripts 1 and 2 denote the cycle 8 and cycle 10 configurations respectively. Then

$$\phi_1 = \phi_{U_1} + \phi_{L_1} + \phi_{C_1} \text{ and } \phi_2 = \phi_{U_2} + \phi_{L_2} + \phi_{C_2} \quad .$$

Let us assume the following:

1. $\phi_{C_1} << \phi_{U_1} + \phi_{L_1}$

2. Attenuation through UO_2 + water ≃ Attenuation through SS + water

3. U_2 Source ≃ 1/2 U_1 Source

4. $\phi_{C_1} \simeq .05\phi_1$

The latter two assumptions are based on experience and familiarity with criticality and core leakage calculations. The first two are reasonably obvious. Thus

$\phi_1/\phi_2 \simeq 12 = (\phi_{U_1} + \phi_{L_1} + .05\phi_1)/(1/2\,\phi_{U_1} + .05\phi_1)$,

yielding $\phi_{U_1} = .066\ \phi_1$, $\phi_{L_1} = .884\ \phi_1$, $\phi_{C_1} = .05\ \phi_1$

and $\phi_{U_2} = .033\ \phi_1$, $\phi_{L_2} = 0$, $\phi_{C_2} = .05\phi_1$,

from which $\phi_{U_2}/(\phi_{L_2} + \phi_{C_2}) = 2/3$, i.e., the relative contribution to the flux at the weld location coming from sources above the PLSA to that coming through the PLSA is in the percentage $[\phi_U/\phi_L]_{\text{Cycle 10}} \approx 40/60$.

This is a very important parameter and should be approximately duplicated in the VENUS experiment since it corresponds closely to the most difficult situation to calculate, i.e., about equal contributions from both components, and hence is representative of a real three-dimensional effect. The major contributor to the attenuation produced by the core modification is obviously the replacement of the fission source by the steel rods.

The VENUS-1 and proposed VENUS-3 assemblies are illustrated in a simple fashion in Figs. 2 and 3 respectively.

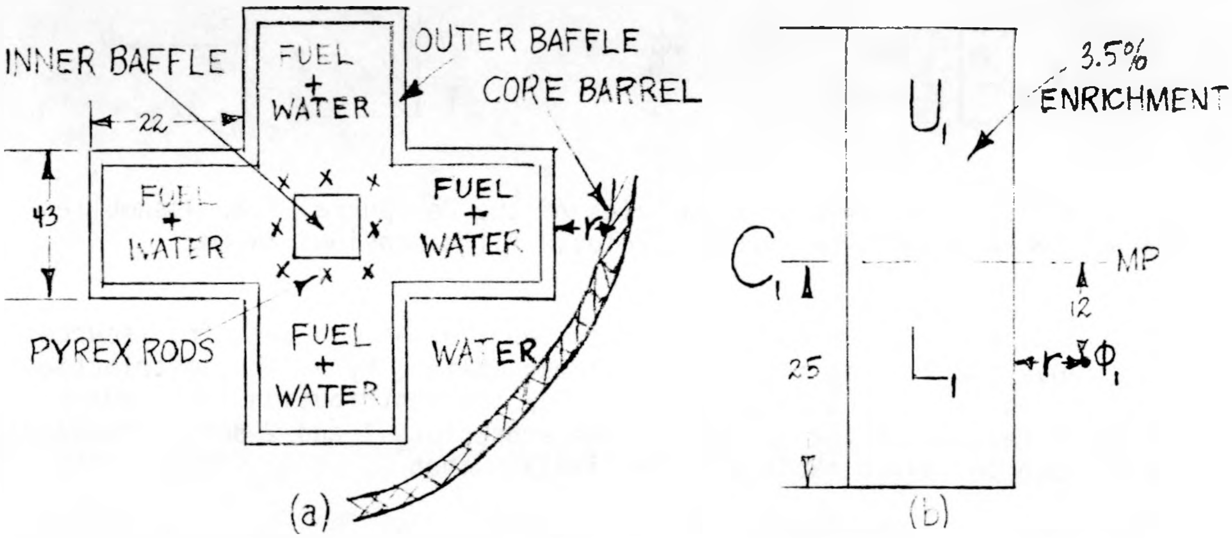

Fig. 2. Essential Features of VENUS-1: (a) Plan View; (b) Elevation View. All dimensions in cm.

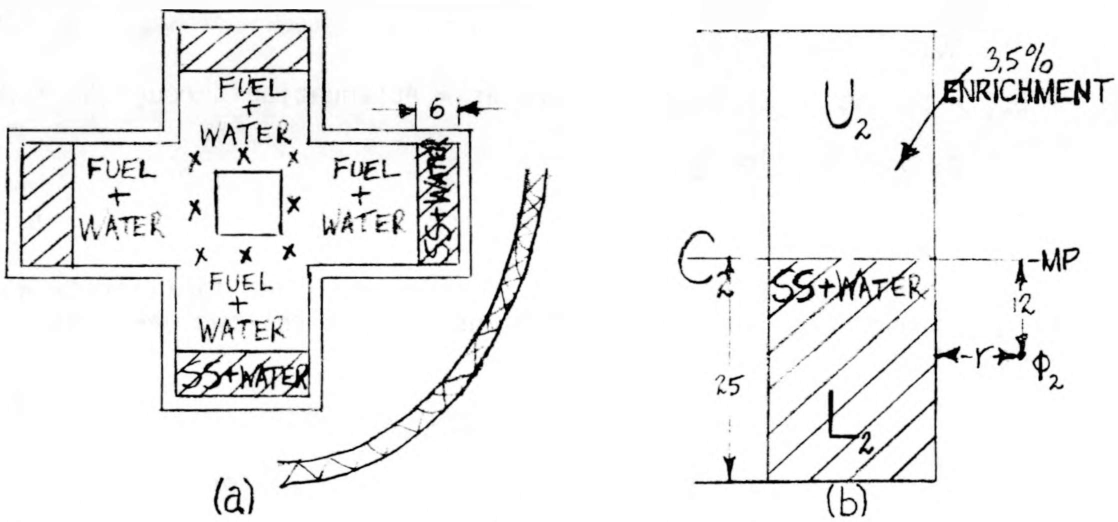

Fig. 3. Modifications for VENUS-3: (a) Plan View; (b) Elevation View. All dimensions in cm.

In VENUS-3, Mol was convinced the PLSA should extend a full half-height of the core, and estimated 5±1 rows of fuel pin replacement by the PLSA. These conclusions were based on their past experience with the facility, which suffers from effects of poor resolution because of its small dimensions. Since the facility would have to purchase or rent the 1.25% enriched pellets used in the H.B. Robinson-2 modification because it has none in stock, it was also decided to try and make do with the existing 3.5% enrichment pellets to match the desired 40/60 ratio estimated for ϕ_U/ϕ_L. For this reason, r in Fig. 3b will be allowed to take on values between the approximate limits of 5.5 cm (water measurement) to 7.5 cm (measurement in the core barrel), and axial profiles will be measured at ϕ_2 as well (i.e., the 12 dimension in Fig. 3b will be allowed to vary). Taking advantage of the fact that past calculations indicate that removal of the outer five rows of fuel pins in the arms of the cross (Fig. 3a) decreases the neutron leakage into the water by about a factor of 3, one can obtain for VENUS-3:

$$[\phi_U/\phi_L]_{VENUS-3} = \phi_{U_2}/(\phi_{L_2} + \phi_{C_2}) = \phi_{U_1}/(\tfrac{1}{3}\phi_{L_1} + \phi_{C_1}).$$

Writing $\phi_{L_1} = \alpha\phi_{U_1}$, where α is a function of radial and axial location, and again assuming $\phi_{C_1} \simeq \phi_{C_2} \simeq .05\phi_1$,

$$[\phi_U/\phi_L]_{VENUS-3} \simeq \frac{\phi_{L_1}}{\alpha} /(\frac{1}{3}\phi_{L_1} + .05\phi_1) = 1/(\frac{\alpha}{3} + \frac{\alpha+1}{19}).$$

Locating the point for which $\alpha \simeq 4$ in VENUS-1 would produce a ϕ_U/ϕ_L value in VENUS-3 of about 40/60. This can be effected by proper choice of r in Fig. 3b (and perhaps the axial location).

In summary, the simple analysis presented allows one to reproduce in VENUS-3 the most important geometric features in cycle 10 for the flux calculations at the critical lower circumferential weld. These essential features may be duplicated without modifying the fuel enrichment in the region above the PLSA in VENUS-3.

Mol is reasonably certain that replacement of the first 5 or 6 rows of fuel pins by the steel will not present any difficulties in obtaining criticality, which can be effected most easily by maneuvering the pyrex rods located outside the inner baffle.

Once the problems of criticality and ensuring the three-dimensional nature of the transport have been solved in VENUS-3, two remaining criteria must still be met. The first is that it is desirable that the flux point ϕ_2 be located in a region of relatively small axial gradient in order that the flux synthesis principle that constitutes part of the calculational procedure can be confidently applied; this condition is satisfied by both the H.B. Robinson-2 and Doel reactors, and probably many others as well. The second is that the attenuation of VENUS-3 relative to VENUS-1 should not be so large as to cause measurement difficulties at ϕ_2 because of low flux levels. Plots of the source axial profiles in VENUS-1 indicate they are not steep, thanks in large measure to the presence of the plexiglass at either end of the fuel rods which acts as an effective vertical reflector. The ratio of the flux 12 cm below the midplane to the flux at midplane is about 0.85--very similar to the shape during cycle 8 in H.B. Robinson-2. Since VENUS-3 will use fuel of the same enrichment as VENUS-1 in the region above the PLSA whereas cycle 10 uses a decreased enrichment there, in order to maintain the same relative contributions from above and through the PLSA for both the VENUS and H.B. Robinson-2 situations, we have seen the PLSA must be thinner in VENUS than its PWR counterpart. Thus the flux attenuation afforded by VENUS-3 over VENUS-1 is considerably less than the value of 12 calculated by TEC for H.B. Robinson-2 between cycles 10 and 8. A calculation of this attenuation may be made:

$$[\phi_1/\phi_2]_{VENUS} = \frac{\phi_{U_1} + \phi_{L_1} + \phi_{C_1}}{\phi_{U_2} + \phi_{L_2} + \phi_{C_2}} \simeq \frac{\phi_{U_1} + 4\phi_{U_1} + .05\phi_1}{\phi_{U_1} + (4/3)\phi_{U_1} + .05\phi_1}$$

$$= \frac{.19\phi_1 + .76\phi_1 + .05\phi_1}{.19\phi_1 + .24\phi_1 + .05\phi_1} \simeq 2.$$

Thus the flux levels in VENUS-3 should not present an intensity problem.

The measurements contemplated include the following:

Axial profiles at 0 deg covering the complete 50 cm range of the fuel for each of three locations r in Fig. 3b ranging between a location in the outer baffle to one in the core barrel with a third in the water at about 5.5 cm. These profiles constitute the major effort and should consist of ^{237}Np and ^{238}U miniature fission chamber measurements as well as ^{115}In(n,n') and ^{58}Ni(n,p) foil measurements and possibly ^{27}Al(n,α) as well.

Additional fission chamber and ^{115}In(n,n') foil measurements will be made at 11, 21, 34, and 45 deg, the first and last on the midplane only and the others over complete axial traverses in order to determine the locations of the new maxima.

A complete three-dimensional distribution of the source in VENUS-3 by gamma-scanning techniques will be obtained. Special attention will be paid to the first several rows of pins next to the PLSA. Approximately 700 data points are envisaged for this task. This measured source will be used in the analysis.

The time schedule for the entire program of calculations and measurements appears below:

July 1, 1987:	Verification of VENUS-3 design with criticality calculations and source sensitivity two-zone RZ calculations to be completed by Mol;
Oct. 1, 1987:	Construction of VENUS-3 completed;
Mid Dec., 1987:	Final irradiations to determine the source distributions and $^{58}Ni(n,p)$ activities at the ex-core detector locations will be completed;
April 1, 1988:	Counting of the gamma-scans and $^{58}Ni(n,p)$ foils will be completed, and the results will be communicated to ORNL immediately;
July 1, 1988:	All ex-core detector measurements will be completed in preliminary phase;
Sept. 1, 1988:	All measurements finalized;
Oct. 1, 1988:	All transport calculations of VENUS-3 results to be completed by ORNL;
Dec. 31, 1988:	Final report on the ORNL calculations and the Mol measurements to NRC due. This report will probably be prepared in two parts under separate cover.

A strong recommendation is made by the traveler for future ORNL calculations of the measurements performed in cycle 10 of H.B. Robinson-2 using the techniques that are to be validated by the VENUS-3 experiment. At present, these PWR results have not been analyzed, but they should soon be available.

APPENDIX

Itinerary

1/9/87	Knoxville to J.F.K.
1/9-10/87	J.F.K. to Brussels via London
1/10/87	Brussels to Antwerp
1/10-15/87	Antwerp
1/12-15/87	Commuting to CEN/SCK Mol from Antwerp
1/16/87	Antwerp to Brussels
1/16-17/87	Brussels
1/18/87	Brussels to Knoxville via London and Atlanta

Persons Contacted

J. Debrue	CEN/SCK Mol	Department Head
A. Fabry	CEN/SCK Mol	Scientist, Research Staff
G. Minsart	CEN/SCK Mol	Scientist, Research Staff
C. de Raedt	CEN/SCK Mol	Scientist, Research Staff