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AEC Research and Development Report

FINAL REPORT
ON THE PERFORMANCE OF THE
VERTICAL SAFETY RODS
AT THE HIGH TEMPERATURE
LATTICE TEST REACTOR

DECEMBER 15, 1971

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ON THE PERFORMANCE OF THE VERTICAL SAFETY RODS
AT THE HIGH TEMPERATURE LATTICE TEST REACTOR

By

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December 15, 1971

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INTRODUCTION

The vertical safety rod system of the High Temperature Lattice Test Reactor has functioned properly following the most recent modification to the four poison blades. During this period of about 13 months, the safety rods have accumulated over 180 operating cycles at temperatures of 300°C and above and have functioned throughout this time without malfunction or significant distortion.

The High Temperature Lattice Test Reactor (HTLTR) is a unique critical facility in which measurements can be made of the reactor physics parameters of test lattices with the entire reactor assembly heated to a uniform temperature that can be as high as 1100°C. An extensive program of material evaluation^(1,2) and mechanical testing to select materials and devices that could function in the high temperature environment had been completed in support of the design at the beginning of the program. At that time the major thrust was to seek long term material strength and corrosion resistance in a nitrogen atmosphere at 1000°C. The vertical safety rods (VSRs), as it developed, presented an additional problem in that they were required to perform repeated movements from a temperature environment in the VSR cooling towers of ~50°C into the reactor environment of up to 1000°C, with an insertion time of less than 1 second, when scrammed, while withstanding deceleration forces of ~5 g on each scram. The poison plates which had deformed in service^(3,4) were redesigned in accord with the results of a thorough analytical program in which a successful model was developed which predicted their performance in the wide range of temperatures routinely seen.^(5,6) The design was supported by a thorough testing program in which a test section of a VSR blade successfully completed over 170 rapid cycles in and out of a 1000°C environment.⁽⁷⁾

At the same time, viewing ports were added to each VSR housing to permit visual inspection of the rods in place and a formal surveillance program was initiated in which two poison plates in each VSR assembly were routinely photographed and the film analyzed. The frequency of photographing was set at about every 20 operating cycles above 500°C.⁽⁸⁾

This paper summarizes the operating history of the VSRs during the final 13 months of reactor operation and gives their condition at the time the reactor was put in standby status in the last quarter of CY 1971.

DISCUSSION

OPERATING HISTORY

The operating history is perhaps best summarized in Figure 1, in which the experimental operating time is plotted against the temperature of the reactor since the facility was constructed. The last modification to the VSRs was completed as was the addition of the viewing ports on the VSR housings in August of 1970. There followed about 13 months of continuous experimentation during which time, three test cores were installed, charged and evaluated at temperatures up to 1000°C. The reactor was operated more at all temperatures during this period than during the previous history of the facility.

It had been concluded from prior experience and from the results of the test program completed in the summer months of 1970 that continuous deformation of the poison plates in the VSRs from cycling into and out of the high temperatures was inherent in the design and would continue. However, the modifications were expected to both reduce the rate of deformation and raise the threshold temperature, i.e., that temperature at which the deformation could be expected to occur. Reducing the number of operating cycles was an obvious additional step to longer service life for the VSRs.

Two steps accomplished the desired reduction in operational cycles. First, a modification to the reactor safety systems was completed at this time which modified the logic of the safety circuit to require two simultaneous trips from any of the four channels to scram the reactor instead of a scram from any single channel trip. All cycling of the VSRs from scrams resulting from both spurious signals and from most safety circuit equipment failures was essentially eliminated.

FIGURE 1. HTLTR Experimental History

The following tabulation shows the significant reduction in operating cycles resulting mostly from this change.

TABLE I. Comparison of VSR Operating Cycles
for Two Successive Experiments

<u>Experiment</u>	<u>Completed</u>	<u>No. of Cycles - Each VSR at</u>			
		<u>300°C</u>	<u>500°C</u>	<u>750°C</u>	<u>1000°C</u>
^{233}U , HTGR #2	March 1970	816	648	244	240
^{233}U , HTGR #3	January 1971	60	44	20	18

Note that for the ^{233}U HTGR experiment #2, 816 cycles of the VSRs occurred during the experiment completed at 300°C while only 60 cycles were required for a similar experiment at 300°C conducted about eight months later after the above change was made. The difference in the number of cycles of the VSRs between experiments at other temperatures is not as great but the improvement is still significant in each instance.

The second factor in reducing the number of operating cycles of the VSRs was a change in operating procedures which was made after completing the first series of photographic examinations of the VSR poison plates at the end of the HTGR #3 experiments at 500°C. The number of cycles was reduced to 20 (see Table I) to complete an experiment at 750°C which was identical to the one just completed at 500°C in which 44 operational cycles of the VSRs were required.

The improvement is even more marked when the number of hours spent at the different temperatures for each experiment are compared:

TABLE II. Comparison of Times to Complete Experiments

<u>Experiment</u>	<u>Completed</u>	<u>Number of Hours at</u>			
		<u>300°C</u>	<u>500°C</u>	<u>700°C</u>	<u>1000°C</u>
^{233}U , HTGR #2	March 1970	192	264	186	236
^{233}U , HTGR #3	January 1971	480	372	312	340

From once and a half to twice as long was spent at elevated temperatures for the experiment completed in January 1971, as compared to the immediately preceding and similar experiment completed in March of 1970. The second experiment did take longer, all equipment including VSRs were exposed to higher temperatures for longer periods of time but at the same time, the number of operating cycles on the VSRs was reduced.

A longer service life than had been predicted⁽³⁾ will be available from the VSRs.

PRESENT STATUS

The present condition of the poison plates is excellent based both on visual inspection and on the results of the formal surveillance program for the VSRs. This program was initiated in September 1970 following the redesign of the poison plates and prior to reinitiating the experiments and was continued until October 1971 when the reactor was put on standby status.⁽⁸⁾ In this program, each of eight representative poison plates, two from the center of each VSR, has been photographed eleven different times, at each accumulation of 20 operating cycles above 500°C. Data from the film have been collected, examined and the results are given below.

Before examining the data, it is perhaps worthwhile to recall the design of the heat shields on each poison plate, as the monitoring technique actually views the heat shield and not the poison plate on each assembly. Figure 2 shows the method of construction of each of the 20 poison plate assemblies in each VSR. Note that the heat shields are spaced 0.015 inches from the poison plate and that the heat shields are fastened by 9 rivets with 8 of the rivets free floating relative to the poison plate. The center rivet (the ninth) is fastened to the poison plate and mechanically couples the heat shield to the poison plate at this point. Thus, the edges of the heat shields can move as much as 30 mils as observed by the monitoring system without any deformation occurring in the poison plate itself. At the center of the assembly at the center rivet,

FIGURE 2. Cross Section of a Modified VSR Poison Plate with Heat Shields

deflection here would include potential plastic deformation of the poison plate. Figure 3 shows an actual poison plate covered with TD nickel heat shield that is held in place with the nine rivets.

The photographic technique used in the surveillance program is illustrated in Figure 4. Here, plate 11 from VSR-2 is shown prior to operation above room temperature and the same plate after 189 cycles above 300°C. Closely spaced horizontal lines (19) were projected onto the poison plate and a photograph taken. Thirteen reference locations on these lines as marked by the small white indices on the plates in Figure 4 were selected to be measured on each film. A comparison among measurements from successive films taken on a plate would indicate developing deformation. The reference indices actually used were very fine lines scratched on the emulsion and the rather broad white markers shown in the figure are used only for visibility in the figure to illustrate the technique. The reference points are identified by location relative to the horizontal gridline on the plate. The scheme is illustrated in Figure 5, where the leading digit indicates the number of the gridlines above (+) or below (-) the center (0) gridline. The second digit indicates the number of the point on that gridline. See Figure 5 for the pattern results.

In summarizing the data, vertical sectioning was done, as follows: each of the five columns in Figure 5 is a section from top to bottom of the central part of a poison plate which is where the maximum deformation was expected to occur. For example, the center vertical section outlined in the dotted lines in Figure 5 includes the deformation measured at points +6.1, +3.2, 0.3, -3.2 and -6.1. The far left section contains the deformation occurring at only position 0.1, and so on. The deformations that developed and that were measured for the different points in each vertical section are plotted together for that section except as noted by the asterisk. Data from the five sections of a single poison plate are presented together in a single figure.

FIGURE 3. Close-up Photo of a Modified VSR Poison Plate with Heat Shields

AT 25° ON 9-29-70
FOLLOWING MODIFICATION AND PRIOR TO OPERATION

AT 1000°C ON 6-11-71
AFTER 189 CYCLES ABOVE 300°C

FIGURE 4. Photographic Data, Poison Plate #11 -
HTLTR Vertical Safety Rod #2

		+6.1		
	+3.1	+3.2*	+3.3	
0.1	0.2*	0.3	0.4*	0.5
	-3.1	-3.2*	-3.3	
		-6.1		

*These points are not included in the plots.

FIGURE 5. Projected Grid for Measurements of Deformation

The data from photographs from just the eight plates (two on each VSR) that were routinely examined are summarized in Figures 6 through 13.

Temperatures at which the cycles were accumulated are indicated by the shaded areas in the figures. No filming was done for cycling of the VSRs that occurred during experiments completed at room temperature (25°C) and 150°C. The latter temperature is believed to be far below the threshold temperature at which deformation could develop.

In the figures, the center rivet appears as the heaviest line in the plot in the center section, and the final deformation of this point that occurred after 281 cycles is indicated separately for each VSR. When compared to the reference condition, this deformation for any plate shown is not greater than 18 mils and when compared to that measured after the first 44 cycles at 500°C is insignificant. That is, in every case there seemed to be slight deformation after the first 44 cycles, but thereafter little deformation if any is indicated.

Further examination of the data shows that the maximum deformation occurred after 257 cycles and was about 51 mils (Figure 8). It occurred at point -3.3, about a third of the distance from the center rivet to the edge of the plate. The center rivet and presumably the poison plate for this same assembly show movement in the same direction of about 18 mils after 281 cycles (Figure 8). Presumably this plate has deformed slightly.

FIGURE 6. Deformation History. Poison Plate 10 on VSR 1.

FIGURE 7. Deformation History. Poison Plate 11 on VSR 1.

FIGURE 8. Deformation History. Poison Plate 10 on VSR 2.

FIGURE 9. Deformation History. Poison Plate 11 on VSR 2.

FIGURE 10. Deformation History. Poison Plate 10 on VSR 3.

FIGURE 11. Deformation History. Poison Plate 11 on VSR 3.

FIGURE 12. Deformation History. Poison Plate 10 on VSR 4.

FIGURE 13. Deformation History. Poison Plate 11 on VSR 4.

The maximum rate of deformation was about 3.1 mils per operating cycle which occurred to plate 11 on VSR #4 during the 123rd to 142nd cycles as shown on Figure 13. However, this was both preceded and followed by similar apparent rates of deformation in the opposite direction. The average rate of movement of this point over the total operating life (281 cycles) is quite small. Figures 8 and 11 show points with similar apparently high rates of deformation over 20 to 40 operating cycles, but correspondingly low rates when averaged over the total operating cycles involved.

A total of 225 mils of deformation could accumulate on a poison plate before some additional control over the routine operation of a VSR could continue and approximately 333 mils of deformation could develop before the VSR would be physically restrained in its movement.⁽⁸⁾ The small figure drawn in the upper right hand corner of the figures compares these limits with typical deformation of the center rivet observed to date. On this scale the relatively small amount of deformation that has occurred is apparent.

No striking trends were observed. Operation at 1000°C produced no observed tendency to deform at this temperature and in most cases, the measured deformation was slightly less after operation at 1000°C than before.

CONCLUSIONS

The poison plates of the VSRs have deformed very little since the last modification. The present design will apparently permit many hours of experimentation.

The frequency of photographing the poison plates that had been established when the formal surveillance program was adopted was more conservative than that required based on the measurements.

The viewing ports, and the optical measuring technique have provided a fully acceptable monitoring program, assuming, of course, that the side of the poison plates not capable of being viewed function no differently than those being examined.

RECOMMENDATIONS

- The frequency of photographing the plates should be extended to once every 75 operating cycles.
- Each of the VSR blades should be removed and visually inspected prior to being used again at temperature. This will permit an examination of the side of the blade not being viewed
- The procedures and techniques used to reduce the number of operating cycles should be continued if reactor operation is resumed.

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