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OVERBORING HANFORD REACTORS
(Condensed Version)

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PRELIMINARY HAZARDS REVIEW
OVERBORING HANFORD REACTORS
(Condensed Version)

R. Nilson and P. A. Carlson

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INTRODUCTION

The Hanford overbore proposal as applied to the six 8 3/8-inch lattice reactors has been reviewed from a hazards standpoint in the expanded version of this report¹. The review was intended to satisfy the specifications for a Preliminary Hazards Review as adopted at the third meeting of the General Electric Technological Hazards Council at New York City on June 15-16, 1961. This supplement is a tabular condensation of the information in the previous document. One departure is made from the specifications for such a review: since the overbore proposal is a modification to existent production reactors, those items which will not be changed by the modification are not as a rule included. Complete hazards summary reports of all the Hanford production reactors are soon to be issued^{2,3} and will include all information related to nuclear safety.

Although the report is relevant to all six old reactors, in those places where particular items are listed C is the reactor used as the example. Statements and conclusions for the five other reactors (B,D,F,DR and H) differ only in degree.

¹R. Nilson and P. A. Carlson, Preliminary Hazards Review Overboring Hanford Reactors, HW-72374, July 25, 1962 ([REDACTED]).

²Staff, Irradiation Processing Department, Hazards Summary Report - Six Oldest Hanford Reactors, HW-74094 Volumes 1, 2, and 3, to be issued ([REDACTED]).

³Staff, Irradiation Processing Department, Hazards Summary Report - Hanford K Reactors, HW-74095, Volumes 1, 2, and 3, to be issued ([REDACTED]).

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SUMMARY AND CONCLUSIONS

It is concluded that the over-all nuclear safety of the 8 3/8-inch lattice reactors will be materially improved by the overbore modification. This conclusion is based on the following changes in the basic physics and engineering features of the reactor:

- 1) The overbore lattice will be "fail-safe" upon loss of coolant. Instead of gaining up to 3.5% in the reactivity upon total loss of coolant (as is the case in the present C lattice and fuel geometry), the overbore reactor will lose reactivity (one to two per cent depending on conditions).
- 2) The prompt, negative, fuel temperature coefficient of reactivity in the overbore reactor will be nearly double that in the reactor at present.
- 3) The positive temperature coefficient of reactivity associated with heating the moderator is smaller in the overbore reactor by at least 20 per cent.
- 4) The maximum excess reactivity (non-accident) is less in the overbore reactor than in the present reactor.
- 5) The overbored lattice will gain reactivity in the event the core is flooded. However, the maximum conceivable reactivity gain due to flooding would occur in the hot core and would be less than one per cent. In the flooding calculation, the entire reactor is assumed flooded, no water is assumed flushed to steam and all the water is assumed to collect in the position of maximum reactivity effect. This maximum calculation thus describes a physically impossible event.
- 6) The net reactivity effect associated with increasing core temperatures to the melting point of uranium is considerably more negative in the overbore reactor than in the present reactor.
- 7) The effective nuclear strengths of the control systems will be reduced in the overbore reactor. In spite of the reductions, either vertical control system will individually meet accident control requirements. This is not the case in the present reactor; under certain conditions, only the Ball-3X System is strong enough to hold the dry reactor subcritical.
- 8) The reduction in the strength of the horizontal control rods will result in increased use of the poison splines now utilized to supplement the horizontal rods.
- 9) The potential for fuel melting following a flow-loss or power-surge transient will be no greater in the overbore reactor than in the present reactor and will probably be less due to the greater heat capacity of the fuel elements.

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- 10) Assuming the same equilibrium power levels, the emergency coolant flow rate required to maintain satisfactory cooling in the event of a loss of primary and secondary pumping power will be less in the overbore reactor during the early period when flywheel decay and high tank flow are the major sources of water. During the later period (greater than an hour following power loss) when the export system flow alone is available, the flow demand for the overbored reactor will be slightly greater than that for the present reactor.

The types of accidents to which a Hanford production reactor is potentially subject are not significantly changed by the overbore project though the changes outlined above will affect the probabilities and severities. A complete meltdown of the core would release fission products to the reactor building and eventually to the environs. The inventory of fission products will in general be increased by the modification of the overbore project. A useful comparison with a Hanford K Reactor can be made. The fuel inventory in an old reactor is currently about half that of a K Reactor and will be increased to approximately equal the K inventory. If the thermal power level of the reactor is unity, that of the K Reactor is about two and the overbore project will increase the reactor power to at most 1.2. Over-all then, the long-lived fission product inventory is expected to approximate that in a K Reactor today, while the short-lived products, being primarily power level dependent, will remain substantially below the level currently carried in a K Reactor. The consequences of a meltdown accident in an overbored reactor are thus expected to be somewhat less severe than those from a similar accident at current K-Reactor operating conditions.

In total, the modifications to the old reactors under the proposed overbore modification improve the safety status of these reactors. The increase in fission product inventory, though undesirable in itself, is more than balanced by the improved lattice characteristics. It therefore is judged that the nuclear hazards associated with reactor operation will not be increased, but will in fact be reduced by the proposed modification.

SPECIFICATIONS

The specifications follow in tabular form. The reactor illustrated is C Reactor. *

	<u>Present</u>	<u>Overbore</u>
1. Site	No change	
2. Reactor		
2.1 Type	Thermal	
2.2 Service	Production	
2.3 Prototype Experience	1953	- -
2.4 Rating ^a	2175 MW	2310 MW

*Footnotes are at end of specifications section.

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	<u>Present</u>	<u>Overbore</u>
2.5 Lattice	8 3/8" □	8 3/8" □
2.6 Power Density ^b	3.3 kw/liter	3.5 kw/liter
2.7 Moderator	Graphite	
2.7.1 Temperature Limits	460 to 650 C	
2.7.2 Structural Support?	Yes	
2.7.3 Design Basis	Zone II Earthquake ^c	
2.8 Coolant	Light Water	
2.8.1 Temperatures		
2.8.1.1 Inlet	13 C	13 C
2.8.1.2 Max. Tube Outlet	113 C	113 C
2.8.1.3 Bulk Outlet	95 C	95 C
2.8.2 Pressures		
2.8.1.1 ΔP, Active Zone	217 psi	247 psi
2.8.2.2 ΔP, Header-Header ^d	362 psi	328 psi
2.8.3 Max. In-Core Velocity		
2.8.3.1 Inner Coolant Passage	47 ft/sec	50 ft/sec
2.8.3.2 Outer Coolant Passage	28 ft/sec	26 ft/sec
2.8.4 Circulation	No	
2.8.5 Decontamination System	None	
2.8.6 Design Activity Level	Does not apply	
2.8.7 Secondary Loops	None	
2.8.8 Process Tube	28 Aluminum	Zr-2
2.8.8.1 O.D.	1.633"	2.147"
2.8.8.2 I.D.	1.764"	2.250"

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	<u>Present</u>	<u>Overbore</u>
2.8.9 Flow Rate ^e	100,700 gpm	107,000 gpm
2.9 Fuel		
2.9.1 Geometry	Hollow cylinder (I&E) ^f	
2.9.2 Uranium I.D.	0.481"	0.452"
2.9.3 Uranium O.D.	1.370"	1.883"
2.9.4 Clad I.D.	0.375"	0.339"
2.9.5 Clad O.D.	1.460"	1.991"
2.9.6 Fuel Weight	9.97 lb/ft	20.25 lb/ft
2.9.7 No. Fuel Channels	2004	2004
2.9.8 Clad	X-8001 Aluminum Alloy	
2.9.9 Supports	Ribs in Tube	Self-Support
2.9.10 Fuel Design Lifetime ^g	81 days	163 days
2.9.11 Average Specific Power ^b	10.7 kw/kg	5.42 kw/kg
2.9.12 Total Energy Extracted ^g	0.0167 MWD/cm ³	0.0167 MWD/cm ³
2.9.13 Average Enrichment	0.75 w/o U ²³⁵	0.81 w/o U ²³⁵
2.9.14 Maximum Tube Power ^b	1360 kw	1446 kw
2.9.15 Maximum Specific Power ^b	77.6 kw/ft	82.5 kw/ft
2.9.16 Fuel Temperatures		
2.9.16.1 Maximum Uranium Core	315 C	365 C
2.9.16.2 Maximum Inner Surface (Clad)	123 C	119 C
2.9.16.3 Maximum Outer Surface (Clad)	145 C	130 C
2.9.17 Heat Fluxes (Btu/hr-ft ²)		
2.9.17.1 Maximum Inner Surface	867,200	867,700
2.9.17.2 Maximum Outer Surface	475,000	403,400

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-6-

HW-72374 SUP1

	<u>Present</u>	<u>Overbore</u>
2.9.18 Burn-Out Safety Factors		
2.9.18.1 Inner Surface	3.9	4.9
2.9.18.2 Outer Surface	4.6	5.9
2.9.19 Maximum-to-Average Factors		
2.9.19.1 Front-to-rear Peaking	1.15	1.15
2.9.19.2 End Cap Peaking	1.12	1.12
2.9.19.3 Fuel Support Peaking	1.10	1.10
2.9.20 Fuel Prototype Experience	1957	6 Months
2.9.21 Reactivity Worth of Single Fuel Column	0.02%	>0.02%
2.9.22 Refueling	Manual-Offstream	
2.10 Physics		
2.10.1 Maximum Excess Reactivity		
2.10.1.1 Cold	2.4%	2.94%
2.10.1.2 Operating ^h	3.8%	3.5%
2.10.2 Effect of Fuel Slumping (Est.) ⁱ	-0.3% $\Delta k/k$	+0.1% $\Delta k/k$
2.10.3 Reactivity Balance		
2.10.3.1 Rods and Flattening	-1.0%	-1.0%
2.10.3.2 Doppler Coefficient	-0.5%	-1.0%
2.10.3.3 Xenon (Hot, Equilibrium)	-2.6%	-2.2%
2.10.3.4 Samarium (Cold, Equil. Conc.)	-0.45%	-0.46%
2.10.3.5 Graphite Temperature Coeff. ^j	+1.7%	+1.3%
2.10.3.6 Long Term Gains (Cold)	+0.45%	+0.42%
2.10.4 Temperature Coefficients		
2.10.4.1 Doppler	$-1.9 \times 10^{-5}/^{\circ}\text{C}$	$-3.5 \times 10^{-5}/^{\circ}\text{C}$

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-7-

HW-72374 SUP1

	<u>Present</u>	<u>Overbore</u>
2.10.4.2 Graphite		
2.10.4.2.1 Green	$+3.0 \times 10^{-5}/C$	$+2.4 \times 10^{-5}/C$
2.10.4.2.2 Ripe (600 MWD/T)	$+5.2 \times 10^{-5}/C$	$+4.1 \times 10^{-5}/C$
2.10.5 Void Coefficient		
2.10.5.1 Cold	$+3.5\% \Delta k/k$	$-0.9\% \Delta k/k$
2.10.5.2 Operating ^k	$+1.6\% \Delta k/k$	$-1.9\% \Delta k/k$
2.10.6 Flooding Coefficient		
2.10.6.1 Cold	$-2.0\% \Delta k/k$	$+0.2\% \Delta k/k$
2.10.6.2 Operating	- -	$+0.6\% \Delta k/k$
2.10.7 Maximum Reactivity By Increasing Temperature		
2.10.7.1 Coolant Loss	$+3.5\%$	-0.9%
2.10.7.2 Doppler to Fuel Melting	-1.4%	-2.8%
2.10.7.3 Graphite Coeff. to Fuel Melting	$+2.3\%$	$+2.2\%$
2.10.7.4 UAl ₃ Formation ¹	-2.4%	-1.0%
2.10.7.5 Fuel Slumping ¹	-0.3%	$+0.1\%$
2.10.7.6 Fuel Redistribution in lattice ¹	-7.0%	-7.0%
2.11 Control Systems		
2.11.1 Operating Control System		
2.11.1.1 Number of Rods	15	15
2.11.1.2 Total Reactivity of Rods		
2.11.1.2.1 Cold	2.5%	1.9%
2.11.1.2.2 Hot	2.7%	2.1%
2.11.1.3 Max. Single Rod Reactivity Worth	0.3%	0.2%

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	<u>Present</u>	<u>Overbore</u>
2.11.1.4 Rod Dimensions	2.84" O.D.	2.84" O.D./
2.11.1.5 Composition ^m	Boron Cyl.	Boron Cyl.
2.11.1.6 Design Basis	No Change	
2.11.1.7 Mounting	Horizontal	
2.11.1.8 Prototype Experience	1953	
2.11.1.9 Max. Rate System Inserts Reactivity		
2.11.1.9.1 Automatic	0	0
2.11.1.9.2 Manual ⁿ	0.025%/sec	0.02%/sec
2.11.1.10 Max. Reactivity Under One Actuator	0.3%	0.2%
2.11.1.11 Removability of Rods and Actuators	Requires Removal of Electrical Drive	
2.11.1.12 No. Rods to keep Cold Reactor Shutdown ^o	12	>15
2.11.2 Supplementary Control		
2.11.2.1 No. Splines Required (max) ^p	90	170
2.11.2.2 Individual Worth	~0.02% Δk/k	~0.012% Δk/k
2.11.2.3 Dimensions	0.5" x 0.05" x Variable Length	
2.11.2.4 Composition	12% Boron Sintered Into Alum. Ribbon	
2.11.2.5 Max. Rate of Reactivity Variation	+0.0007%/sec	+0.0004%/sec
2.11.3 Vertical Safety Rods		
2.11.3.1 Number of Rods	45	45
2.11.3.2 Total Reactivity Worth		
2.11.3.2.1 Cold	4.1%	3.4%
2.11.3.2.1 Hot	4.5%	3.6%

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2.11.3.3	Max. Single Rod Reactivity Worth	~ 0.3%	~ 0.22%
2.11.3.4	Rod Dimensions	2.98" OD	2.98" OD
2.11.3.5	Poison	Boron	Boron
2.11.3.6	Reactivity Rates (Positive)		
	Procedural	0.03%/sec	0.022%/sec
	Maximum Possible	0.225%/sec	0.18%/sec
2.11.3.7	Reactivity Rate (Negative)	2.5%/sec	2.0%/sec
2.11.3.8	Maximum Reactivity Under One Actuator	4.5%	3.6%
2.11.3.9	Shutdown Margins ^q		
	2.11.3.9.1 Cold	+1.6% $\Delta k/k$	+0.5% $\Delta k/k$
	2.11.3.9.2 Hot	+3.5% $\Delta k/k$	+2.6% $\Delta k/k$
	2.11.3.9.3 Minimum (Accident) ^r	-1.5% $\Delta k/k^s$	-0.6% $\Delta k/k^s$
2.11.4	Ball-3X System		
2.11.4.1	No. of Channels	45	45
2.11.4.2	Total Reactivity Worth		
	2.11.4.2.1 Cold	4.6%	3.8%
	2.11.4.2.2 Hot	5.1%	4.0%
2.11.4.3	Max. Single Channel Reactivity Worth	~ 0.4%	~ 0.3%
2.11.4.4	Channel Size	4-3/16" $\square$	4-3/16" $\square$
2.11.4.5	Ball Dimensions	3/8" Diam.	3/8" Diam.
2.11.4.6	Poison	Boron-Steel	
2.11.4.7	Max. Reactivity Rates (Positive)	0.05%/sec	0.04%/sec
2.11.4.8	Reactivity Rate (Negative)	0.28%/sec	0.23%/sec
2.11.4.9	Max. Reactivity Under One Actuator	5.1%	4.0%

	<u>Present</u>	<u>Overbore</u>
2.11.4.10 Shutdown Margins ^a		
2.11.4.9.1 Cold	+2.1% $\Delta k/k$	+0.9% $\Delta k/k$
2.11.4.9.2 Hot	+4.1% $\Delta k/k$	+3.0% $\Delta k/k$
2.11.4.9.3 Minimum (Accident)	-1.0% $\Delta k/k^b$	-0.2% $\Delta k/k^b$
2.12 Instrumentation	No Change	
3. Containment	No Change	
4. Pressure Vessel	None	
5. Pressure Tube	None	
6. General Plant	No Change	
7. Emergency Systems	No Change	
8. Planned Development Programs	See Text	
9. Maximum Credible Accident	No Change	

^a2175 MW is maximum level attained to date. Present AEC-authorized level is 2310 MW.

^bAssumes levels in 2.4.

^cAs defined by Uniform Code of the Pacific Coast Building Officials Conference, 1950.

^dNominal rear header pressure is only a few psi.

^eFlow rate with 86 per cent orificing efficiency and ten pump operation in each case.

^fInternally-and-externally cooled.

^gAssumes power levels in 2.4 and 800 MWD/T fuel exposure.

^hTurnaround maxima.

ⁱEffect of melting of fuel and slumping into bottom of coolant channel. In overbore case Zr-2 tube constrains.

^jAt 250 MWD/T.

^kAt 400 MWD/T; hot pile.

^lThese three effects not necessarily additive.

^mThere are seven cadmium rods in C Reactor which will be replaced with boron rods by January 1963.

ⁿAssuming two operators each using both hands to operate the four available control rod handles.

^oFor green, xenon and samarium-free condition. Question is somewhat academic since Process Standards require reactor to be at least 0.15% $\Delta k/k$ subcritical with control rods inserted during an outage. Supplemental poison is added to meet the requirement.

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^PAt turnaround for 600 MWD/T average exposure.

^QAssuming no other control in reactor.

^RCold, xenon-free, dry reactor for present reactor; optimum flooding at turnaround for overbore (600 MWD/T).

^SA negative shutdown margin means the reactor would be supercritical with the specific case listed.

PLANNED DEVELOPMENT PROGRAMS

Although the overbore proposal is a modification of an existing Hanford reactor, certain development problems do exist. The critical areas are fuel performance, control adequacy and hydraulic considerations. The following development program is planned and some work is already underway.

Fuel Performance

Sixty-two channels in C Reactor have been overbored and are serving as test columns to irradiate prototypical overbore size fuel elements under typical overbore power generation and hydraulic conditions. Overbore fuel elements have already been under irradiation for as long as six months. Information to be obtained will be resistance to fuel rupture, fuel-failure mechanisms, dimensional instability, corrosion rates and potential for cleavage failures.

Hydraulics

Steady-state and transient flow studies have been completed to determine the hydraulic and heat transfer characteristics of an overbore column. These studies confirmed the computed channel hydraulic characteristics and fuel design, and provided data to be used as a basis for establishing flow monitoring procedures.

Physics

The material buckling of the overbored lattice will be determined for natural uranium and uranium enriched to 0.947 w/o U^{235} to assist in determining the reactor loading. Control rod and Ball 3X strengths will be measured in the overbored lattice and compared to measurements in the present C lattice. The reactivity effect of water loss and core flooding will be determined. The conversion ratio is being determined by irradiating prototypical elements in the C-Reactor overbore test block.

Materials

The results of relatively short-term irradiation tests indicate that no major deleterious effects should occur during the intended twenty-year life of the Zircaloy process tubes at C Reactor conditions. The longest Zircaloy exposure to date has been seven years in D Reactor with the bulk of the data obtained

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during the last two years of exposure.* From radiation damage data obtained to date there is no reason to believe that twenty-year life cannot be obtained. It will be prudent, however, to monitor the performance of the Zircaloy tubes throughout their period of use. To accomplish this, tubes will be periodically removed from the reactor to evaluate long-term mechanical, physical, and chemical changes.

Studies will also be directed towards determining the graphite heat generation rates and temperature distribution in the graphite blocks. The overbore program will require a re-evaluation of the effects of distortion, stored energy and graphite burn-out on safety and operational performance.

DAMAGE APPRAISAL

The worst conceivable accident is assumed to be an earthquake so severe that the reactor building is shaken down, all coolant lines are broken and the reactor is destroyed by burning. Essentially the full inventory of fission products is released.

No quantitative analyses have been made of the sequence of events in such an accident. The earthquake assumed would be severe enough to prevent reactor shutdown by safety rod insertion and also probably by Ball-3X insertion. In the case of the present reactor, the possibility exists for the reactor to be supercritical if coolant is lost and the reactor fails to scram. However, what additional inventory in fission products a post-accident supercritical state would produce has not been analyzed in any quantitative terms. In the overbore lattice, the loss of coolant is expected to render the reactor subcritical even if the scram system fails thus leaving little likelihood of additional fission products being produced following the accident.

For present purposes, in lieu of the quantitative analyses to be included in the Hazards Summary Reports^{2,3} it has been considered sufficient to compare inventories of biologically-significant fission products in the present and overbored reactor under the likely operating conditions and use this as a relative measure of the potential damage from the worst conceivable accident. The figures for a K Reactor are included for comparison. (See Table on next page).

The longer exposure effects do not show up in the results in the table since many of the short-lived fission products (which are primarily a function of power level) are still strong emitters only 24 hours after reactor shutdown. The inventory of the biologically-significant radioisotopes one year after shutdown is also shown. Here the longer exposure of the overbore fuel is significant in its effect; however, the inventory is still about equal to that from a K Reactor. The exposure and power level assumptions are given in the footnote to the first table.

*There has been one Zircaloy tube in D Reactor for seven years. There have been about 70 Zircaloy tubes (above the 62 overbore channels) in C Reactor, the majority of them placed in service in 1960.

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Table
Inventory of Biologically-Significant Fission Products^a (Megacuries)
24-Hour Cooling

	<u>C Present</u>	<u>C Overbore</u>	<u>K</u>
<u>Noble gases</u>			
(Xe ^{133,5})	148	160	272
<u>Halogens</u>			
(I ^{131,2,3,5})	168	188	309
<u>Volatile Solids</u>			
(Ru ^{103,5,6} , Te ^{127,9,132} , Cs ¹³⁷)	122	144	224
<u>Non-Volatile Solids</u>			
(Sr ^{89,90} , Zr ⁹⁵ , Ba ¹⁴⁰ , Ce ¹⁴⁴)	251	334	462

^a 2175 MW for 81 days for C present, 2310 MW for 163 days for C overbore and 4000 MW for 81 days for K.

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Table
Inventory of Long-Lived, Biologically-Significant Radioisotopes (Megacuries)
One Year After Shutdown

<u>Isotope</u>	<u>C Present</u>	<u>C Overbore</u>	<u>K</u>
Sr ⁸⁹	0.42	0.60	0.77
Sr ⁹⁰	0.564	1.2	1.0
Zr ⁹⁵	1.37	2.1	2.5
Ba ¹⁴⁰	3×10^{-7}	3.6×10^{-7}	5.5×10^{-7}
Ce ¹⁴⁴	7.7	15	14
Ru ¹⁰³	7.5×10^{-2}	0.1	0.14
Fu ¹⁰⁶	0.5	0.98	0.92
I ¹³¹ ^a	6.7×10^{-2}	7.1×10^{-2}	0.122
Te ¹²⁷	3×10^{-2}	5×10^{-2}	5.5×10^{-2}
Te ¹²⁹	5×10^{-3}	6.4×10^{-3}	9.2×10^{-3}
Cs ¹³⁷	0.615	1.3	1.1
<hr/> Total	<hr/> 11.4	<hr/> 21.4	<hr/> 20.7

^aI¹³¹ was reported incorrectly in HW-72374.

DATE

FILMED

8/12/94

END