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TITLE

SPECIAL HAZARDS REPORT - I & E FUEL LOADS

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The report was prepared in accordance with the request from the AEC concerning the design of a reactor for the production of plutonium. The report was prepared by A. E. Greenberg, (1) and is a preliminary report. It contains a description of the reactor and the results of the calculations. The report is intended to provide a basis for the design of the reactor and the results of the calculations. The report is intended to provide a basis for the design of the reactor and the results of the calculations.

Summary

A description of the proposed utilization of I & E stage in C reactor together with the associated power increase schedule is presented. The reasons for changing to the I & E element are presented together with a comparison of solid and I & E stage in the C reactor. The changes being made in C reactor under CG 600 are described. The operational characteristics of the C reactor using solid and I & E elements are compared and finally the nuclear safety, as well as all of the Hanford reactors assuming I & E loadings is reviewed.

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CONCLUSIONS

The I & E slug holds considerable promise for increased production from the Hanford reactors. From an engineering and operational viewpoint the change from solid to I & E fuel elements is a small one. The effect of the change in fuel on the safety status of the reactors will be to render the control problems already faced more acute but will introduce no new ones.

C and H reactors face no total control problem with either solid or I & E slugs. The remaining reactors will be forced further to restrict operation in one respect to achieve the power levels proposed using I & E slugs and simultaneously meet the total control criterion as presently stated. This restriction in milder form is presently in force with solid slugs and hence will represent nothing new except degree. Revision of the total control philosophy would eliminate these restrictions which are expensive in terms of lost production.

From a speed of control standpoint, all reactors are capable of preventing a "puff discharge" of fission products due to a power excursion. Calculations indicate that the control systems meet even the strictest interpretation of the speed of control criterion although operation at projected power level with I & E slugs will be close to the limit set by such a strict interpretation.

DISCUSSION

I. Production Increase Schedule

A. C-Reactor

By mid-November 1957, the central zone of C reactor will be completely filled with I & E slugs and the production increases associated with better slug performance will begin. Figure 1 shows the probable increases in power level for C-Reactor, with I & E fuel elements, for the next year. Stepwise power level increases are shown as increases in maximum tube power. It should be noted that the current rupture control limiting tube power is shown by the area A. Operation above the region A results in excessive rupture rates in solid slugs and hence is prohibited on economic grounds. No reactor hazards implications are contained in this limit.

Also included in Figure 1 are curves representing power level limits based upon a 95°C reactor bulk effluent temperature. This limit represents the next above the solid fuel element performance limits and I & E fuel is expected to permit eventual reactor operation up to this limit. Reactor flow rates shown are those expected through the period, and are the result of Project CG-600 which provides higher capacity pumps for the reactor. The initial 82,000 gpm figure is somewhat lower than the normal flow rate and results from removing pumps from the process for purposes of substituting the newer pumps. After 2 or 3 of the newer pumps are installed, the flow rate will return to the normal value (84,000 gpm) until the project is completed. About the time of the completion of the project, central tubes of the reactor will be loaded with low flow resistance I & E fuel elements and the combined effect of the new pumps and the reduced flow resistance of the reactor should increase the flow rate to about 94,500 gpm.

Power Schedules - C Reactor
Figure 1

DISCUSSION (CONT'D)I. Production Increase Schedule (Cont'd)A. C-Reactor (Cont'd)

Shaded areas under B and C, and to some extent the area of D, reflect some uncertainty regarding the precise path of power level increases. From November 15 to January 15, the lower reactor flow rate will cause coolant temperatures at the top of the annulus, as a result of the eccentricity of the larger diameter fuel element, to near the saturation temperature in some tubes. This can be compensated for by the use of mixing devices which tend to average the coolant temperatures around the annulus, by shortening charge length, or by simply waiting until decreasing inlet water temperature during midwinter months permits the raise to be made without exceeding the saturation temperature in any tube. Actually, some combination of these compensating factors will be used. The next raise (step C) is somewhat dependent upon how rapidly newer I & E fuel elements having a reduced outer diameter (uranium dimensions remaining the same) can be substituted in the central tubes; or at least in certain tubes where the fuel element eccentricity will have the strongest effect. These fuel elements are scheduled for use beginning in January, 1958. The final raise, shown as area D, is shaded because it is with this raise that the 95° C bulk effluent limit is reached.

Because there is no estimate of actual failure rate for I & E fuel elements, (as yet no failures have occurred in I & E fuel elements being routinely processed to exposures of about 800 MWD/T,) the manner in which power increases following October, 1958, will be made is difficult to predict. As can be seen from Figure 1, if the bulk effluent limit is followed rather rapid increases of power will result after September, 1958. The actual power raises achieved will depend to a large extent upon the operating experience gained during the preceding months - especially in the area of slug performance. As shown in Figure 1, the reactor will be operated on each power step for about three months. Although some variation will probably occur, this interval is sufficiently long to permit assessing the fuel performance at each step to determine that operation on the next step will be possible without an economically intolerable number of slug failures. This will require irradiating approximately one reactor loading (in tons) at each step.

The following table lists the assumptions and resulting process conditions used in developing Figure 1:

TABLE I

Power Step	A Oct. 15	B Jan. 15	C Mar. 15	D Aug. 15
Reactor Power Level (MW)	1475	1630	1780	1875
Max. Tube Power (KW)	950	1050	1150	1210
Reactor Flow (gpm)	82,200	84,000	84,000	94,500
Central Tube Flow (gpm)				
& E	43.8	46.0	46.0	52.5
Solid	45.5	- -	- -	
Bulk Outlet Temperature (°C)	84.8	79.5	86.8	95.0
Max. Tube Outlet Temp. (°C)				
I & E	95.8	92.6	101.1	107.2
Solid	98.8	- -	- -	- -
Specific Power in Maximum Tube (KW/ft)				
Average	42.8	47.3	51.8	54.2
Maximum	60.0	66.3	72.6	75.8
Maximum Graphite Temperature °C	600	620	640	650
Average I & E Discharge Concentration (MWD/T)	800	650	650	650

Assumptions:

Effective Flow Tubes, with solid fuel elements	1870 tubes
with 1540 central I & E tubes	1830 tubes
with 1540 central tubes of reduced OD I & E	1800 tubes
Effective central power tubes	1550 tubes

DISCUSSION (CONT'D)I. Production Increase Schedule (Cont'd)B. Other Reactors Schedule for I & E Loads

The schedules by which other reactors are connected to processing I & E fuel elements are given below. The dates given are for initial loadings leading to full pile conversions. Prior to the dates given, pilot loading of 10-15 tons/month will be loaded into KW reactor and into D reactor. Pilot charging into KW will begin in October of 1957 while pilot charging at D reactor will begin in January, 1958.

<u>Pile</u>	<u>Start Full Loading - I & E</u>
C	Already underway
KW	December, 1957
KE	February, 1958
D	March April, 1958
H	July, 1958
DR	September, 1958
F	November, 1958
B	January, 1959

II. The Slug ProblemA. Rupture Rates and "Optimum" Operation

The practice of optimizing power level, even though it may result in incurring fuel element failures, has been shown to be economically justified for any reactor in which fuel performance is a controlling factor. Power levels are increased until production losses resulting from increased fuel element failures just equal the production increase involved in the next incremental power increase. The power level at this point is optimized and the number of ruptures suffered at this point is "optimum." This practice can be exercised only when fuel performance is controlling reactor power, and if some other limit is controlling, i.e., bulk effluent temperature, then the "optimum" number of ruptures is not definable in terms of power level changes.

Similarly, the discharge concentration, or exposure, is another process variable which may be optimized. At a given power level the exposure fixes fuel costs by establishing throughput rates, burnout charges, and total fabrication and separation costs. High fabrication and separation costs tend to drive exposures to high values to reduce throughput rates, and the outage

DISCUSSION (CONT'D)

II. The Slug Problem (Cont'd)

A. Rupture Rates and "Optimum" Operation (Cont'd)

time lost for charge-discharge. Product burnout tends to drive exposures to lower values. The combined effects establish an optimum exposure. Both power and exposure affect operating efficiency not only by fixing outage time losses for charge-discharge, but also because they are prime variables in determining the rate at which failures occur. Their effects must be factored into consideration when determining optimum discharge concentration.

During the pilot phase, where I & E fuel elements are loaded in the central tubes of C, K, and one of the older reactors, power increases will be made at an exposure below the economic optimum defined by failure free operation to avoid operational difficulties should the "piloting" proceed into a highly rupture-prone condition. After achieving successful operation at the bulk effluent limit, exposure will become a variable and will be progressively increased to the economic optimum value. In the failure free (or at least not limiting) case this exposure is thought to be about 850 MWD/T in all but the K-Reactors where the optimum is about 950 MWD/T. Safety considerations as outlined later may require operation at exposure below the "optimum" levels. An economic penalty will thus be imposed by the requirements of the present safety criteria.

B. Comparison of I & E and Solid Slugs

Slug rupture experience indicates that the present solid natural uranium fuel element will experience intolerably high failure rates at power levels potentially attainable with increased flow rates resulting from water plant expansion projects and operation of the reactors on a 95-98° C bulk effluent temperature limit. The failure experience is divided into two major categories, 1) the core or split failures, and 2) failures associated with corrosion penetration of the aluminum jacket.

The thermal gradient within a fuel element, under irradiation, induces high stresses in the uranium core. Initially, these stresses are not sufficient to split the core. However, as irradiation damage alters and weakens the uranium, a situation can result wherein the thermal stress is greater than the uranium strength. Such a condition leads to a splitting of the uranium core and, on occasion, the fuel element jacket - resulting in the "failure" of the slug. The magnitude of these stresses can be considerably reduced by removing a central core from the solid uranium slug. The thermal gradient is greatly reduced if the coolant is allowed to flow through the axial void in the dual channel cooling arrangement.

The operation of a solid uranium slug at specific powers slightly greater than 70 KW/ft will cause the central metal temperature to exceed that required for α - β phase transformation (662°C). At this temperature, the crystalline structure of the uranium changes from an orthorhombic to a tetragonal system - which results in a greater than one percent volume increase. It has not been definitely established that beta phase operation

DISCUSSION (CONT'D)

II. The Slug Problem (Cont'd)

B. (Cont'd)

(in the solid slug) constitutes a real limit but steps are being taken to avoid the limit, should it exist. In the I & E slug the transformation temperature is not reached at any specific power attainable under conditions of 95-98°C bulk effluent limits. Figure 3 shows approximate maximum uranium temperatures calculated for both solid and I & E fuel elements for various specific powers.

I & E experience to date indicates that the new fuel element will be a major improvement over the old solid elements. Approximately 600 natural uranium I & E tube charges have been irradiated to target exposures of about 800 MWD/T and no slug failures have as yet occurred. This number includes those charges still in pile which are nearly ready for discharge.

A summary of some of the pertinent characteristics of solid and I & E elements appears in the following table. The numbers given apply to C-Reactor although somewhat similar variations are expected for the K pile and the old pile lattices.

III. History of C Pile I & E Testing

A. Development Tests

PT-105-587-A (2)

Production Test 105-587-A authorized the irradiation of seven tubes of I & E slugs, canned by the hot press process, to test the irradiation performance of a fuel element having this geometry. Individual coolant channel temperatures, recorded during the irradiation of the first tube charged under this test were not in agreement with those predicted by flow laboratory test or by heat transfer calculations. The reason for this inconsistency could not be determined. To resolve the inconsistency, another test was conducted in which slugs having three different hole diameters were irradiated. (3) For the second test, experimental and theoretical results were in good agreement. (4) The irradiation was completed in September, 1955.

PT-105-615-A-63 MT (5)

Irradiation of four tubes of I & E elements and four tubes of regular solid control fuel elements to exposures of 50-500 MWD/T in C-Reactor was completed in June, 1956. This represented the first phase of the production test, designed to provide preliminary dimensional stability data. Under the second phase four tubes of each of I & E and regular solid control fuel elements were charged to compare rupture resistance in a run-to-rupture test. Irradiation of the solid fuel elements was discontinued after two

COMPARISON OF SOLID SLUGS VS I & E SLUGS AT C-REACTOR

		Solid Slugs	I & E Slugs
a	Full Pile Reactivity (cold, clean) (1h)	~ 800	~ 550
b	Initial Conversion Ratio (atom per atom)	0.820	0.837
c	Conversion Ratio at 500 MWD/T (atom per atom)	0.798	0.803
d	Maximum U Temperature - (100° C bulk temperature limit). See Figure 1.	740	280
e	Maximum Slug Jacket Temp. (°C)	118	115
f	Total Slug Rupture Rate 1) Tubes discharged/tube reaching 500 MWD/T) 2) Cumulative ruptures/slug reaching 500 MWD/T)	0.01 3 x 10 ⁻⁴	~ 0 ~ 0
g	Reactivity Jump upon Loss of Water - Cold Graphite (1h)	about 880	about 1010
h	Reactivity Jump Upon Loss of Water - Hot Graphite (1h)	about 250	about 530
i	Xenon Transient	- 946 1h (present power)	- 1010 1h (35% power increase)
j	Temperature Effect - Metal	- 221 1h (present power)	- 225 1h (35% power increase)
k	Temperature Effect - Graphite	/ 669 1h (present power)	/ 693 1h (35% power increase)

Notes:

- a) Varies with loading pattern, average exposure, etc. About 250 inhours of additional enrichment will be required when I & E slugs are used.
- b) Conversion Ratio: Atoms of Pu Produced per Atom of U-235 consumed.
- d) At 1115 KW/Tube
- e) The maximum jacket temperature varies with tube power, water inlet temperature, and flow rate, but is expected always to be slightly less, for a given set of conditions, with I & E slugs.
- f) The slug rupture rate is for Normal Operation at 950 KW/Tube maximum tube power. Tube jacket corrosion is believed to account for about 75% of the failures. An 80 MWD/Ton increase in exposure, or an 80 KW/Tube increase in power would double the total rupture rate. These rates are within a factor of two at the 90% confidence level.
- g-h) The increase in reactivity jump varies from about 130 in for cold graphite to about 280 in for hot graphite.

DISCUSSION (CONT'D)III. History of C Pile I & E Testing (Cont'd)A. Development Tests (Cont'd)PT-105-515-A-63 MT (5) (Cont'd)

ruptures were incurred at exposures of 842 and 1200 MWD/T, respectively. The I & E elements were discharged in February, 1957, after having reached exposures in the range of 1900 MWD/T without incident. This performance established that I & E rupture resistance was superior to that of solid elements within 98 percent confidence limits.

Conclusions based on the analysis of the data from this test are as follows:

- 1) Warp does not appear to be a function of exposure for I & E fuel elements. Although the differences between solid and I & E fuel elements are insignificant at exposures below 600 MWD/T, less warp is noted for I & E elements at higher exposures.
- 2) I & E fuel elements are not expected to create a stuck charge problem. Less than two tubes per 10,000 may be expected to contain one or more elements with warp greater than 60 mils.
- 3) The extent of difference in diameter growth between I & E and solid fuel elements is possibly a result of power and exposure. At exposures above 450 MWD/T, this difference averages about 5 mils.

No unusual surface conditions were observed during post-irradiation examination of the test material, except for darker film patterns being noted on surface of I & E elements as a result of abnormal top annulus temperatures. In-reactor weight losses for the I & E elements indicated uniform surface corrosion did not exceed 3.5 mils at 500 MWD/T. Subsequent Radiometallurgical examination of two I & E elements irradiated to maximum exposures (1900 MWD/T) has indicated jacket corrosion was generally uniform. One of these elements, which was slightly elliptical (major axis plus 8 mils, minor axis minus 7 mils) exhibited radial micro-cracks in the uranium when sectioned transversely.

PT-IP-1-A-73-MT (6)

Three tubes of enriched (1.44% U-235) I & E, and two tubes of enriched solid control fuel elements, were charged in C Reactor on a "run-to-rupture" test to compare performance at specific tube powers (ave. 75 KW/ft., max. 90 KW/ft.) in excess of those which would be obtained at 98°C bulk operating temperature limits. The two tubes of solid control elements were discharged in July because of ruptures at exposures of about 1,000 and 1,225 MWD/T, respectively. Examination and classification of these failures are incomplete. Gas was being emitted from the one that failed at the highest exposure, necessitating immediate canning to avoid potential radiation hazards.

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DISCUSSION (CONT'D)III. History of C Pile I & E Testing (Cont'd)A. Development Tests (Cont'd)PT-IP-1-A-73-MT (6)

A failure of one charge of the enriched I & E elements occurred at about 2100 MWD/T. The remaining two charges were removed at that time. The rupture has not yet been examined because of difficulty in removing it from the tube in which it is bound. It was necessary to remove the tube at the time of failure. Tentative conclusions from the test are that the I & E elements were superior to the solid elements, by perhaps a factor of three to five, within 95% confidence limits.

An additional tube of enriched I & E fuel elements was exposed to 1000 MWD/T, and discharged because of inability to obtain thermocouple probes early enough to charge a companion tube of enriched solid elements for control purposes. Post-irradiation examination of this material is in progress.

B. Pilot Charging - In Pile Inventory Below 400 I & E TubesPT-IP-19-A-83 MT (7)

This test was designed to confirm the results of preliminary I & E irradiation tests in C-Reactor on a semi-production scale. Lot charging of I & E elements at a nominal rate of 50 tubes (approximately 6 tons) per month, including a maximum of five pre-measured charges, was initiated in November, 1956, and has continued without incident. Because of favorable performance, exposures were increased from a variable goal of 500 to 800 MWD/T in April, 1957. Specific tube powers have averaged about 41 KW/ft., with maximums in the range of 57 KW/ft. To date approximately 1140 tubes have been charged with I & E elements, and 56 tubes have been discharged at an average of 500 MWD/T and 300 tubes at 800 MWD/T. Fifteen pre-measured tubes are undergoing post-irradiation examination. Preliminary dimensional stability data conforms very closely with that obtained under PT 105-615-A-63 MT.

C. Full Loading I & E Charges - C-Reactor

The pilot charging demonstrated the feasibility of charging I & E slugs into the central zone (~1540 tubes) of C-Reactor. This "full pile" loading began in September, 1957, and at current charging rates will be completed in mid-November. Power level increases to take advantage of superior slug performance will begin at that time.

IV. C-Reactor Water Plant and Modifications (8)

The layout of the B-C Reactor area is shown in Figure 4. (9) The main pattern of coolant water flow is indicated by arrows. It is seen that the river pump-house is common to both reactors, but that thereafter the water plants for the two reactors are essentially independent. There are, however, two exceptions. The C-Reactor water plant is not provided with a raw-water reservoir, and may therefore draw raw water from the B-Reactor reservoir which

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SCHEMATIC PROFILE OF C-REACTOR COOLING SYSTEM

181 C	183 C	190 C	105 C
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SIMPLIFIED PROCESS WATER FLOW DIAGRAM - C REACTOR

PROCESS WATER FLOW PATTERN CLEAR-WATER STORAGE TO 105 C

105 C SIDE

190 C SIDE

LEGEND

- 1 MOTOR OPERATED GATE VALVE
- 2 CHECK VALVE
- 3 PRESSURE OPERATED VALVE (FLEX FLOW)
- 4 STRAINER
- 5 ORIFICE
- 6 NEW PUMP, 10,750 GPM AT 1045 T.D.H.
- 7 ELECTRIC MOTOR
- 8 STEAM TURBINE
- 9 ON SAME SHAFT

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IV. C-Reactor Water Plant and Modifications (8)

is part of the raw water export-import system which connects the B, C, D, DR, F and H reactors and the 200 Areas. Also, the B and C Reactor buildings are each supplied with raw water for emergency cooling, from the import-export system by way of the B-Reactor reservoir.

A schematic profile of the C-Reactor water plant is shown in Figure 5. (9) No storage capacity is indicated for the settling basin since water flows from the top of the basin into the filters. Only a negligible quantity of water is available, without continuous raw water input, for replenishment of the clear wells.

A simplified water flow diagram for the C-Reactor is shown in Figure 6. (9) A more detailed water flow diagram for the critical region from the storage tanks to the reactor is shown in Figure 7. (9) The three 24-inch headers which serve the risers at one side of the reactor lie in one pipe-tunnel, while the three headers which serve the other side of the reactor are located in another pipe tunnel. Thus between the 190-C Building and the reactor the two groups of headers are isolated from each other by distance and by physical barriers.

From the riser, the coolant water flows through check-valves into the cross-headers; from the cross-headers into the process tubes via "pig-tail" connectors and flow controlling and monitoring devices (venturi throats, or disc-type orifices); and along the annular spaces between solid fuel elements and the process tubes. With I & E fuel elements an additional flow channel is provided along the axis of the fuel column. The geometry of a fueled process tube at C-Reactor is shown in Figure 8. (9) Upon leaving the process tube, the water registers its temperature with a thermocouple and leaves the reactor area via "pig-tail", cross-header and riser. The effluent water is discharged from the top of the rear-face risers by way of cascade type downcomers, held in retention basins and finally discharged into the Columbia River.

The 14 foot CG-600 water plant modifications at C reactor will consist primarily of:

- (1) Adding one new 10,000 GPM - 150 Ft. T. D. H. electric drive pump at the river pump house.
- (2) Adding one new 21,000 GPM - 155 Ft. T. D. H. electric drive pump to move filtered water from the filter plant (183-C Building) to clear water storage, and
- (3) Replacing ten existing high pressure pumps in the 190-C Building with ten new 10,750 GPM - 1245 Ft T. D. H. pumps.

The existing electric main drive motors and the existing steam turbines are used to drive the new pumps. The electric motor and steam turbine, for a given pump, are on the same shaft.

IV. C-Reactor Water Plant and Modifications (8) (Cont'd)

The immediate effect of these modifications is to increase the maximum coolant water flow rate from 83,000 gpm with ten units, to 88,000 gpm with nine units, thus permitting one pump assembly to remain on standby status. When improved process tube nozzle assemblies (now under development), and low flow resistance I & E elements are provided for C-reactor the coolant flow rate will be increased to about 94,500 gpm.

When the C-reactor is shutdown from equilibrium operation the flow of coolant water required to prevent an increase in the effluent water temperature is shown in Figure 9. (2). The water flow available from various sources is shown on the same diagram. If loss of electric power to the area is the signal which shuts the reactor down, about 1.8 seconds will elapse before the vertical safety rods penetrate far enough into the reactor for the flux to measurably decrease. The flux decreases very rapidly thereafter.

The immediate source of water flow after loss of electric power is the energy stored in the flywheels which are an integral part of each high pressure pumping unit. This energy starts to be dissipated immediately. Consequently there is a period of about two seconds during which the effluent temperature will rise approximately 5° C. For the next hundred seconds the water flow due to flywheel energy will be in excess of that required. If steam power is available, the turbines will pick up the load within about forty seconds and carry it indefinitely. The normal supply of stored, filtered water for C reactor will supply the reactor cooling for 14 days after shutdown. This may be extended to 21 days by using 9 million gallons of water from the B-reactor raw water storage. Under the same conditions and using the remaining water in the raw water reservoir the B-reactor total reserve would supply cooling water to the B-reactor for 21 days also. The minimum supply of stored, filtered water permitted by the process standards will supply the C-reactor for 6.0 days after shutdown. This may be extended to 13 days by using 9 million gallons of raw water from the B reservoir.

However, steam pumps at the river pump house are capable of replenishing the raw water reservoir at the rate of approximately 18,000 gpm, which is equal to the designed export rate from the B-C Area. By diverting 1000 gpm to the C-reactor filter plant the shutdown coolant flow may be continued indefinitely from within the area. In the event of complete power failure at the B-C reactor area, untreated river water from the export-import system may be used to cool the reactor.

If the C-reactor shutdown from equilibrium operation is initiated by loss of both steam and electric power in the area, only that fraction of the normal supply of stored and filtered water which can be supplied by the energy stored in the flywheels will be available to cool the reactor. Before the coolant flow from this source becomes inadequate to cool the reactor, an emergency supply of filtered water will automatically become available from the high tanks. Before the high tank supply is depleted the decrease in the rate of heat generation in the reactor will have been large enough that the available flow of untreated water from the export-import system will be adequate to cool the reactor. The available flow is compared with the required flow in Figure 9.

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STANDARD COLUMN CHARGE - C PILE

OVERALL TUBE LENGTH VANSTONE TO VANSTONE - 499"
 "8 INCH" SOLID SLUG = 8.95", "8 INCH" IEE = 9.004 - .064 MALE TRU-LINE

WATER FLOW AFTER LOSS OF ELECTRIC POWER - C REACTOR

(10) (11)

V. Operational Physics Aspects - I & E Slugs for C Pile.A) Loading Patterns1) Standard Column Charge

Natural uranium slugs are loaded in standard charge lengths in parallel tubes in a Hanford reactor. The slugs are centered radially by ribs which were formed on the inside of the tube during its extrusion. They are centered longitudinally by aluminum spacers in the downstream portion of the tube; water fills the upstream space ahead of the charge. Figure 8 shows a standard charge in a C pile column which consists of 32 natural uranium slugs centered within the graphite stack by approximately ten feet of dummies. The I and E charge is equivalent to that of solid slugs in numbers of slugs and composition of the downstream dummy pattern. The water which flows down the center hole of the I and E slug can flow out into the main stream again through the holes in the hollow perforated aluminum dummies.

Charging and discharging is carried out during shutdown under reduced flow conditions. Rear discharge results from displacement as the new charge is inserted by a hydraulic piston charging machine from the front.

2) Flow Zones

Flux distribution is manipulated by loading patterns and control techniques so that the majority of the tubes operate within a narrow heat generation range; this flux distribution modification is called flattening, and the bulk of the tubes in the pile are in or adjacent to the "flattened" region. Therefore, the majority of the tubes in the pile may efficiently have equivalent flow characteristics. Because of the sharp flux gradient near the pile fringes, the flow may be graduated downward in outer tubes. The flow pattern is determined by the size of the venturi or orifice installed in the inlet nozzle fitting.

Except for a region of approximately 110 tubes, all tubes out to about three lattice units from the reflector have a flow of 43 gallons per minute; this central flow region includes approximately three-fourths of the tubes in the pile. Flow is reduced stepwise in each of the three outer lattice units; the outermost tubes have a flow of 28 to 29 gallons per minute. The central block of about 110 tubes mentioned previously has been outfitted with a proto-type system for permitting charge-discharge during operation. In order to accommodate special pilot fuel tests in these charge-discharge tubes, the flow has been raised in this region to approximately 46 gpm.

3) Enrichment Patterns

Enrichment has been used from the time of C pile start-up for increasing pile reactivity and improving pile flux distribution. This enrichment has been loaded in a ring of columns four lattice units from the reflector as U-235 to 0.34%; Approximately 200 "E" columns are required in the pile fringe region under existing operating conditions.

V. Operational Physics Aspects - I & E Slugs for C Pile.

A) Loading Patterns (Cont'd)

3) Enrichment Patterns (Cont'd)

Because the natural uranium I and E slugs are less reactive than the solid slugs, from 100 to 150 more "E" columns will be required, partly as "spike" columns within the flattened zone. Essentially the problem of flux distribution is that of making the reactivity properties of the central region (including control rods and either flattening or spike columns) barely chain-reacting, whereas the fringe, or "buckled" region must be reactive enough to make up for exterior leakage losses.

E) Reactivity Variables - Background Discussion

1) Metal Coefficient

Hanford operating practices are tied to a considerable extent to the peculiarities of reactivity transients. We experience the customary negative metal coefficient associated with Doppler broadening of U-238 resonances; this is a rapid acting and straight-forward effect with a total magnitude over our operating range of about one half percent δk .

2) Graphite Coefficient

Largely because the process water channel back-scatters neutrons, a positive moderator coefficient is observed at Hanford in the operating pile. The moderator coefficient effect is time-sensitive to the heating and cooling rate of the graphite itself. The total magnitude of this effect is on the order of 2 to 2 1/2% δk ; this effect comes to equilibrium (following a power change) after several hours. Simple time dependence is shown in Figure 10. (2)

3) Xenon

The third major short term transient effect is fission product xenon poisoning. The total equilibrium effect of xenon is nearly equal (though opposite in sign) to the equilibrium graphite effect. Thus the net effect of these three short term transients under equilibrium conditions is a net loss of about 1/2 to 1% δk relative to cold, xenon-free conditions. In other words, the pile must be reactive enough basically to require about 1% δk of extra rod inserted (in addition to the excess held in rods during equilibrium operation) to keep it sub-critical during an extended outage.

The complicating feature about reactivity transients is the dependence of the xenon on previous events. Xenon formation lags by several hours the pile operation which produces its mother, iodine, and xenon decay lags the xenon formation rate even more. On the other hand, the xenon burnout rate has an immediate dependence on power level. These effects, qualitatively are quite pronounced as shown in Figure 10. The transient

V. Operational Physics Aspects - I & E Slugs for C Pile (Cont'd)

B) Reactivity Variables - Background Discussion (Cont'd)

3) Xenon (Cont'd)

is shown for the case of a pile operated for 96 hours, then shut down. The xenon transient which would take place if the pile were again started 46 hours later is shown as a dashed line. This chart demonstrates the severe xenon buildup - by a factor of 2 or greater - immediately following a shutdown, and the partial xenon burnout immediately following a start-up. The buildup phenomenon is a large factor in "scram time" and "minimum down time" effects, whereas the burnout phenomenon is involved in the "turnaround" effect several hours after start-up.

4) Control of Reactivity Transients

The pile must be operated in such a way that the net amount of thermal, graphite, and xenon effects at any given time can be handled within the capacity of the horizontal control rod system. This system, which has a capacity slightly greater than 2% δk at the C pile, can be supplemented by other less flexible control methods such as temporary poison columns, splines, or certain columns fitted with a rear ball-valve and a special front nozzle to permit charge and discharge of poison slugs during operation. Operating levels and timing are then selected on the basis of reactivity calculations so that the transient will not exceed the capacity of the shim control available. Some control advantage may be gained during start-ups, using proper timing and power level progressions, by playing the negative xenon effect against the positive graphite effect.

Charts showing the total operating transients, such as Figures 11, 12, and 13 give reactivity values from the standpoint of the pile itself. For example, the positive graphite effect would be shown as positive reactivity, but buildup of xenon poison would show up as a reactivity loss or negative reactivity effect.

C) Magnitude of Reactivity Transients

1) Cases Considered

Four cases were calculated for comparison of transients. Two cases compare loadings operation in C pile at current levels with solid slugs and I & E slugs respectively, and the other two cases make the same comparison at a 35% increase in power level. Because the graphite and metal coefficient effects are slightly lower in the I & E case, the two bracketing transients are the I & E case at low level and the solid slug case at high level. These two transients are compared in Figures 11 and 13. All four are shown in Figure 12 for the scram transient case.

2) Comparison of Equilibrium Reactivity Effects

The following table demonstrates the conclusion that the net effect of these transients will change a relatively small amount as power level is increased and even less with change-over to I & E slugs.

FORM OF XENON & GRAPHITE TRANSIENTS

STANDARD OUTAGE TRANSIENTS-C PILE

PILE CONDITION

COMPARISON OF SCRAM TRANSIENTS - C PILE

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COMPOUND OUTAGE TRANSIENTS - C PILE

PILE CONDITION

V. Operational Physics Aspects - I & E Slugs for C Pile (Cont'd)

C) Magnitude of Reactivity Transients (Cont'd)

2) Comparison of Equilibrium Reactivity Effects (Cont'd)

Table III

C Pile Equilibrium Reactivities Effects Vs Operating Conditions

Power Level	1.50 (Existing)	1.00	1.35	1.35 *
Slug Type	Solid	I&E	I&E	Solid
Xenon, inhours	-946	-945	-1010	-1005
Graphite Effect	+669	+632	+693	+781
Metal Effect	-221	-167	-225	-300
Net, cold to hot	-498	-481	-542	-524 in

* A lower goal exposure was used in calculating the solid slug cases because of their reduced rupture resistance. The graphite effect increases with exposure, so the solid slug transient extremes under comparable exposure conditions would be greater than would the I & E transient extremes.

3) Comparison of Reactivity Transients

Figures 11 and 13 show the reactivity range over which non-equilibrium transients take place and the extremes which would be encountered during outages and start-ups. The main result of the higher level is that the increased iodine backlog causes a larger xenon buildup during outages. The larger xenon buildup extends the minimum outage downtime and drives the reactor further subcritical while it is down, but it has a relatively small effect on operating transients; however, the extra excess held in control rod at equilibrium to maintain scram time does require that more control be available for turnaround. The use of supplementary control or of special startup progressing techniques can compensate the small increases in turnaround transients which cause them to go over the 880 inhour capacity of the horizontal rod system. Such techniques have been a necessity for several years at the older piles with their smaller rod systems. The operating transient effects of I & E loads at increased power levels are therefore not expected to have a significant bearing on Hanford practices.

D) Safety Aspects of Reactivity Transients

1) Excursion Possibilities

Reactivity transients during pile operation are really hypothetical - control rod is inserted or withdrawn to maintain constant reactivity and thus constant power level. The question then is, "To what extent do reactivity transients and their magnitudes contribute to the possibility of lapses of control, or excursions?" This question

V. Operational Physics Aspects - I & E Slugs for C Pile (Cont'd)D) Safety Aspects of Reactivity Transients (Cont'd)1) Excursion Possibilities (Cont'd)

might be divided into three parts: (1) Results of insufficient turn-around control, (2) the possibility of lapses of control because of using supplementary techniques, and (3) the effect of modified outage transients on start-up procedures.

2) Operating Control Inadequacy

Potential "excursions" resulting from either of the first two possibilities present at worst an operating rather than a safety problem. A transient as fast as one inhour per minute after "running out of rod" near turnaround is extremely unlikely. With such a transient, the power level would increase 2% during the following five minutes; under such conditions it would be expected that operating personnel would respond within seconds to activate the safety rod system.

Supplementary control removal is normally covered by procedures requiring prior insertion of control and reduction in level. Should procedure break down and a poison column be flushed rather than displaced by water, the total pile power rise of approximately 6% would occur within about thirty seconds. This rise would there be limited by the metal coefficient effect which had taken place. The slow rate of level rise would give plenty of opportunity for an automatic trip should any tubes in the pile reach instability limits before the operator had taken compensating control action. Here again, operator alertness and reaction time would be expected to be especially keen during supplementary control manipulations. Time transients of these two "excursion" possibilities are shown in Figure 14.

3) Start-Up Procedures

The phase of operation most pertinent to reactor safety is the start-up; unduly fast rod withdrawal rates could be the cause of an excessive rate of rise. During a cold start-up, withdrawal rates are made extremely conservative, and pile transient changes are not greater than one inhour per minute during the withdrawal period. No difference in reactor safety during cold start-ups is foreseen as a result of the proposed changes in slug type and operating level.

During a hot start-up more liberal withdrawal rates are allowed. Pile reactivity is falling away - in the "fail safe" direction - and the falling transient is better known. Frequent scram transient data establish the transient form under equivalent conditions, and there is no chance for significant unknown loading changes to take place. Transient falling rates will be somewhat faster at the higher levels as shown in Figure 12, precluding the possibility of scram recovery in some cases. In any event, rod withdrawal rate standards are deter-

EXCURSION POTENTIALS & OPERATING LEVEL

INSUFFICIENT TURNAROUND
CONTROL

UNCOMPENSATED
"P" COLUMN FLUSH
INITIAL 20 I.H. EXCESS DAMPED
BY METAL COEFFICIENT

V. Operational Physics Aspects - I & E Slugs for C Pile (Cont'd)

D) Safety Aspects of Reactivity Transients (Cont'd)

3) Start-Up Procedures (Cont'd)

mined on the basis of maintaining an adequate degree of safety no matter what the type of loading. Figures 15 and 16 show the maximum rod withdrawal rates permitted during hot and cold start-ups respectively and the pile periods which would be expected when the pile subsequently becomes super-critical. Figure 17 shows the levels at which the power rise would be halted assuming the fast period permitted by operating standards and assuming that the rise were halted by normal operator reaction plus metal coefficient effects. Figure 18 shows the equivalent information assuming an unusually fast period; trip levels shown in this chart show that the pile would likely be scrammed automatically in the hot start-up case.

Nuclear safety standards for rod withdrawal rates are based on the criterion that a start-up can be carried out safely within the complete control of the operator. Because of the adverse economics of slug ruptures, "safely" at Hanford has a considerably more conservative connotation than that of disaster prevention. Instrument sensitivities, operator reaction time, and metal coefficient effects enter into the basis of the specific standard. Automatic trips are then provided in addition to the procedural methods as a second back-up to cover the possibility of procedure breakdown.

The manner of setting process standards thus takes into account the peculiarities of any given loading. The possibility of an excursion induced by lapse of control during a start-up should be no different with one load-type than with another.

VI. Nuclear Safety Considerations

A. Safety Criteria (12) (13) (14) (15)

Operation of the Hanford reactors presently is carried out under two very general restrictions which are applicable to any loading at any power and exposure. The first of these defines the total control strength which must be available while the second specifies the speed of response of the control system to an emergency. These criteria may be stated as:

- 1) The total control strength available must be sufficient to maintain the reactor in a sub critical state under all possible circumstances.
- 2) Operation of the reactor shall be such that in the event of a power excursion from any credible cause, no gross melting of components will occur during the time the reactor is super critical.

HOT START-UP APPROACH TO CRITICAL

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COLD START-UP APPROACH TO CRITICAL

POWER TRANSIENT - NORMAL REACTIVITY

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POWER TRANSIENT - SEVERE REACTIVITY

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VI. Nuclear Safety Considerations (Cont'd)

B. Total Control

The use of I & E slugs means that additional enrichment will be required to compensate for the loss in reactivity associated with the change from solid slugs. This represents an additional load upon the safety controls and calculations indicate that the Ball 3-X system (in the old piles and in the K reactors) alone will no longer be sufficient in a few special cases to hold the pile subcritical throughout the meltdown following loss of cooling water. C reactor and H reactor have a somewhat stronger control system and will be able to meet the criterion throughout the projected range of operation.

In order to meet the total control criterion in the older reactors and in the K piles, it is necessary to provide additional control during certain critical periods. Normal equilibrium operation presents no critical problem because loss of water will be followed by slug melting and permanent poisoning of the reactor before the xenon in the reactor can decay or escape. Long outages likewise provide no difficulty because additional control must be changed either as poison columns or as horizontal rods to allow startup. The only time at which the total control strength afforded by the various materials in place in the reactor is inadequate is during a "minimum startup".

In a minimum startup, all controls are withdrawn from the reactor and the decay of xenon is allowed to bring the pile to critical. Loss of water at this time coupled with an inability to insert any control (except Ball 3X channels which are considered to be in place) could result in a critical state during the subsequent meltdown. The solution to this problem is simple but expensive - minimum startups will be prohibited. Startup is simply delayed until sufficient poison is in place in the reactor to supplement the Ball 3X strength to the desired extent.

It should be noted that this procedure is not unique to I & E loadings. The restriction applies today at today's powers and with solid slug loads. Furthermore, the procedure is quite expensive and will represent a loss in production of from 2% to 5% depending on the precise exposures, power level, and enrichment required for adequate operational swim control.

The basis for the total control criterion has been investigated and a recommendation made that the criterion be revised. If the revision is accepted, this expense will no longer be necessary in any of the Hanford reactors. Finally, it should be repeated that the C reactor is, and will in the foreseeable future be, able to meet the criterion on total control with no operating restrictions.

C. Speed of Control (16) (17)

The second operating criterion concerns the speed of the control system in containing any power excursion. Considerable work has been done on this subject and for a complete discussion the references given should be consulted.

VI. Nuclear Safety Considerations (Cont'd)

C. Speed of Control (Cont'd)

The results of the calculations indicate that the C pile with I & E slugs will satisfy the criterion as stated up to a power level of 2000 MW and an average exposure of 500 MWD/T. These conditions represent approximately the post CG 600 conditions at 95° C bulk outlet temperatures. A minor restriction on operation at the highest power level may be necessary but this will simply restrict the rate at which the pile can be brought from shutdown to full power and will not represent a significant production loss. Similar conclusions apply to the older reactors also. The K reactors have more rapid acting VSR's, will suffer somewhat smaller reactivity jumps following loss of water and are being fitted with accelerated safety rods in six new channels. Thus, the K reactors are expected to meet the speed of control criterion with no difficulty both now and in the foreseeable future.

The potential power excursions which dictate the speed of control requirement would result from a water flow interruption during operation. The analyses have been concerned with cases which may be unrealistically pessimistic. The water loss for example, has been assumed to be total and instantaneous. Also, the criterion itself has been interpreted very strictly in that "no gross melting" is assumed to mean "no melting at all". Since the purpose of the criterion is to prevent a "puff" discharge of fission products as a result of the power excursion, such a strict interpretation is probably unwarranted. A report is in preparation outlining this problem and proposing a more logical interpretation of the criterion.

In summary, it can be stated that the control systems on all of the reactors will surely prevent an appreciable discharge of fission products during a power excursion. Furthermore, calculations indicate that the control systems are fast enough to meet even the strictest interpretation of the speed of control criterion although operation at projected power levels with I & E slugs will be close to the limit set by such a strict interpretation.

VII. Comparison of Hanford Reactors:

A table of significant differences among the various Hanford reactors appears below.

Table 4
Pile

	B,D,DR,F	C	H	KE-KW
No. of Tubes	2004	2004	2004	3220
No. of Shim Rods	9	15	15	20
No. of VSR	29	45	45	41 (76)

VII. Comparison of Hanford Reactors (Cont'd)

Table 4 (Cont'd)
File

	B,D,DR,F	C	H	KE-KW
No. of Ball 3-X	29	45	45	51
Lattice Spacing	8 3/8"	8 3/8"	8 3/8"	7 1/2"
Solid Slugs				
a) Uranium OD	1.336"	1.336"	1.336"	1.336"
b) Canned OD	1.440"	1.440"	1.440"	1.440"
c) Water Annulus	.086"	.103"	.086"	.120"
I & E Slugs				
a) Uranium OD	1.356"	1.370"	1.356"	1.365"
b) Uranium ID	.414"	.479"	.414"	.481"
c) Canned OD	1.460"	1.474"	1.460"	1.474"
d) Canned ID (Halesite)	.310"	.375"	.310"	.375"
e) Outer Water Annulus	.076"	.086"	.076"	.103"
Ultimate Water Flow	74,000 gpm	94,500 gpm	74,000 gpm	173,000 gpm
Bulk Outlet Temp.				
Ultimate (I & E)	98° C	98° C	98° C	98° C
Max. Tube Temp.				
a) Present rupture limit	105	105	105	105
b) No rupture limit	130	130	130	130
Cold clean reactivity	-250	-250	-250	-300
Change due to change to I & E on full pile basis - in				
Change in water loss effect	/130	/130	/130	/100
Change in graphite coefficient	- Expect some loss - for safety studies assume 25% -			
Metal Power Coefficient	- Expect to lose about half -			
Metal Temperature Coefficient	- Essentially unchanged -			

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It will be noted that the differences existing among the various reactors are not tremendously large. One principal difference lies in the various rod strengths. H and C reactors contain 45 VSR's while the older piles have only 29 VSR'S. For this reason, as noted in the previous section, the older piles will be forced to adopt restrictive measures in order to meet the total control criteria (as presently stated) while C and H reactors will experience no difficulty. The K piles are physically larger than the older reactors and in spite of having 51 Ball 3-X columns will also be forced to adopt restrictive measures in order to meet the present total control criterion.

The other principal difference is the variation in the reactivity jump to be expected following water loss. Startup measurements show that the K reactors would suffer a much smaller reactivity jump than the other piles. For cold, clean, zero exposure loads, this jump is about 880 ih at C pile, 536 ih at K pile, and about 750 ih at the remaining reactors. Coupled with the rod speeds which are fastest in the K piles, these figures indicate that K reactor will have no difficulty from the standpoint of the speed of control criterion which the remaining reactors will be forced to adopt some restrictions to operation in order to abide by the present criterion when ultimate power levels are reached.

Aside from these differences, the reactors are quite similar. The operational problems introduced by changing to I & E slugs are substantially the same at all areas. The programs and power level increases are similar in nature though they vary in magnitude and timing at the various reactors. The slug performance is not expected to vary drastically among the reactors. Thus, it is felt that the pilot operation of C reactor will, with proper account for the differences outlined above, provide an adequate basis for proceeding with I & E loadings at all reactors.

Reactor Physics Operation
Research and Engineering

Process and Reactor Development
Research and Engineering

Reactor Physics Operation
Research and Engineering

Operational Physics Operation
Research and Engineering

JH Brown:GC Fuller:RE Trumble:FW Van Wormer:ack

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