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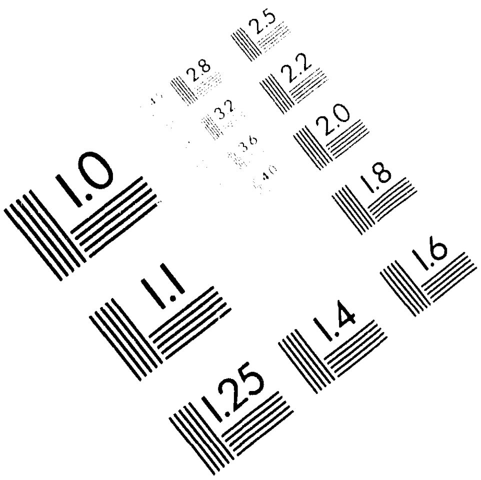

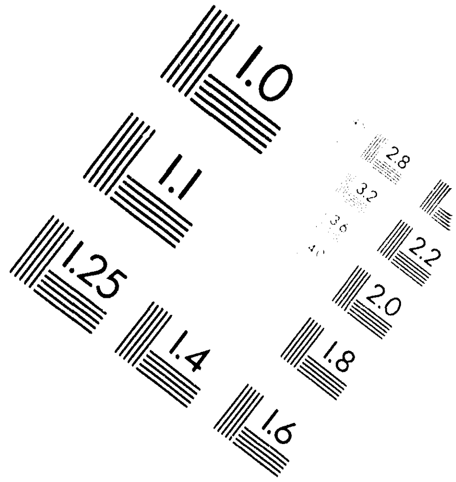

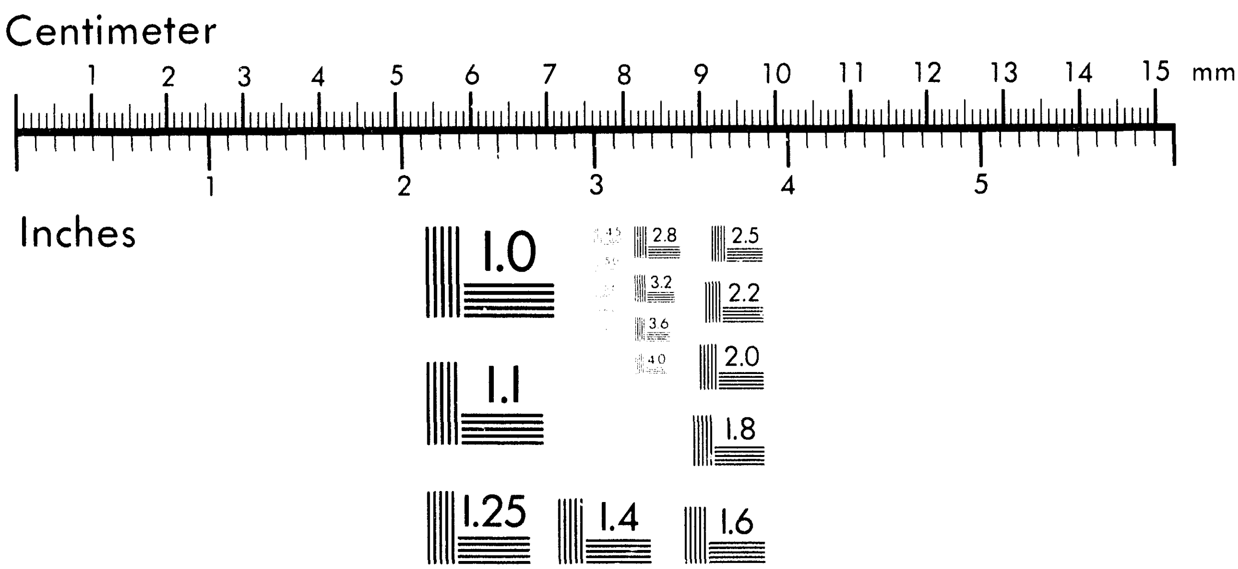

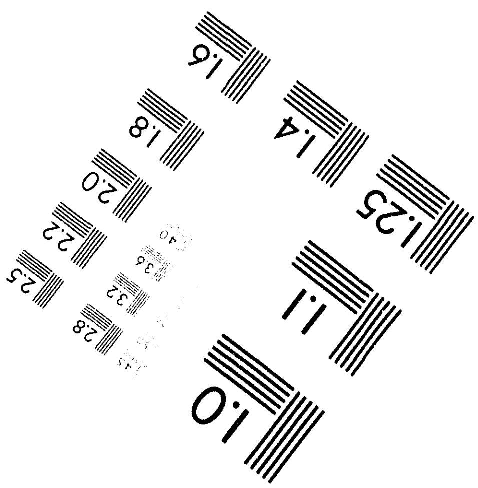

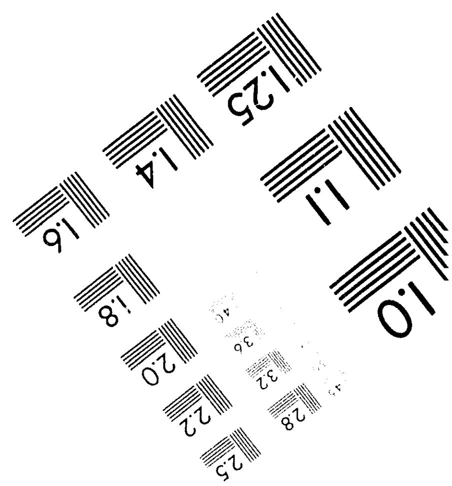

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GENERAL ELECTRIC

HANFORD ATOMIC PRODUCTS OPERATION - RICHLAND, WASHINGTON

DOCUMENT NO.

HW-70317

SERIES AND C[redacted]Y NO.

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DATE

July 11, 1961

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PRODUCTION TEST IP-376-D, SUPPLEMENT B
IRRADIATION OF MGCR-HDR-3 TEST ELEMENT

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PRODUCTION TEST IP-376-D, SUPPLEMENT B
IRRADIATION OF MGCR-HDR-3 TEST ELEMENT

July 11, 1961

HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

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PRODUCTION TEST IP-376-D, SUPPLEMENT B
IRRADIATION OF MGCR-HDR-3 TEST ELEMENT

OBJECTIVE

The objective of this supplement to PT-IP-376-D, Irradiation of MGCR-HDR-3 Test Element[1] is to authorize 1000 hours of operation at a maximum test specimen surface temperature of 1700 F. The original production test authorized a test duration of four months at a maximum specimen surface temperature of 1500 F; supplement A[2] authorized extension of the test duration to ten months.

BASIS

The desired increase in surface temperature is requested to demonstrate the general feasibility of operation of the fuel element at 1700 F, and to obtain specific information on the performance of Hastelloy-X cladding and fuel bodies. The increased temperature has been approved by the Atomic Energy Commission.

SCHEDULE

Immediately upon approval of this supplement the maximum surface temperature will be increased to 1700 F in steps of 50 F and the specimen will be operated at 1700 F for 1000 hours. At that time, the temperature will be reduced to the previous level of 1500 F until the completion of the test. The test assembly will be removed from the reactor during the first reactor outage in November 1961.[2]

COSTS

Cost Code: **XXX** - 5R51 - **XXX**.76
Elevator time: none required.
Shutdown time: none required.

DESCRIPTION OF SPECIMEN

The following gives a brief description of the test specimen. For a more detailed treatment see References (1) and (4). The test element consists of nineteen rods with one rod in the center and the balance arranged in two concentric rings of 6 and 12 rods each. The center rod contains non-fueled hollow cylinders of BeO; the other rods contain 0.355-inch OD $BeO-UO_2$ fuel pellets. The fuel pellets are 70 volume per cent BeO, 30 volume per cent UO_2. The UO_2 is present as a dispersion of 250μ mean diameter particles. The fueled length of the specimen is 15 inches. The pellets are contained in 0.375-inch OD by 0.010-inch thick Hastelloy-X tubing with welded enclosures. The rod bundle is encased in a round 2.106-inch OD by 0.010-inch thick shroud, also Hastelloy-X. Spiral spacers spot-welded to the cladding maintain a spacing of 0.044 inch between rods and 0.022 inch between rods and shroud.

Temperatures of the specimen inlet and outlet gas and of the center rod BeO sleeve are measured by thermocouples. Six thermocouples in all are provided, two for each gas temperature and two for the BeO sleeve. A stainless steel tube carries the thermocouple leads out of the reactor and positions the specimen.

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TEST HISTORY TO DATE

The specimen was installed in the loop on January 5, 1961. It had operated 2632 hours at a 1500 F maximum cladding surface temperature and had experienced 17 thermal cycles as of July 7, 1961.

The specimen has usually operated at 35 KW with maximum and minimum powers of 38 and 32 KW, respectively. The predicted power was 40 KW. The flow has been maintained constant at 410 lbs/hr with specimen temperature control accomplished entirely by preheat adjustment. Inlet gas temperatures to the in-reactor assembly have ranged from 450 F to 900 F.

Gas sampling for fission products has continued throughout the course of the test. No fission products have been detected in the samples. Gamma activity rates, as measured by the two loop monitors, have been no higher than those experienced during periods when no test was installed.

HEAT TRANSFER ASPECTS

Loop performance has been calculated for the higher surface temperature over the range of specimen powers observed thus far. The calculations show that at lower powers the flow rate must be reduced from 410 to 370 lbs/hr to avoid exceeding loop component temperature limits. (SEE TABLE 1). In all cases, the preheater outlet temperature limit was the most restrictive. At 32 KW specimen power, 370 lbs/hr flow and 1700 F specimen surface temperature, other loop temperatures were calculated as follows:

1.	Preheat outlet temperature,	987 F.
2.	Maximum outer tube wall temperature,	1140 F.
3.	Maximum inner tube wall temperature,	1247 F.
4.	Reactor outlet gas temperature,	1137 F.
5.	Specimen inlet gas temperature,	1121 F.
6.	Specimen outlet gas temperature,	1363 F.

These calculations are based on the analyses and machine programs described in References (5) and (6). In this, the limiting case, the Reynold's number for the specimen outlet is 5160. While close, it is still higher than the 4000 normally quoted for the upper limit of the transition between turbulent and laminar flow.

For operational control purposes, the specimen surface temperature will be calculated in the same manner as at the 1500 F level. The peak and mean fuel temperatures corresponding to a surface temperature of 1700 F are calculated to be 1862 F and 1820 F, respectively.

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HAZARDS OF THE PROPOSED CHANGE

Loss-of-coolant transient temperatures have been recalculated for the specimen and the portion of the loop assembly in its vicinity, assuming the emergency cooling system does not operate. Two cases were calculated for the 1700 F surface temperature. One corresponds to a specimen power of 32 KW and the other to a power of 38 KW. The same method of calculation was used as is described in Reference (4).

Peak fuel temperatures determined for the two cases were 2290 F (32 KW) and 2390 F (38 KW). For comparison, the peak fuel temperature quoted in Reference (4) for a power of 48 KW and a surface temperature of 1500 F was 2415 F.

The maximum fuel temperatures four seconds after loss of coolant were about 1930 F for both cases at the higher initial surface temperature. For the 1500 F initial temperature case, Reference (4), the corresponding fuel temperature was 1770 F. These temperatures are representative of a loss-of-coolant accident for which the emergency system is actuated. Comparison of other temperatures (shroud, inner tube, and outer tube) among the three cases yields results similar to the peak fuel temperatures, except for the outer tube. The outer tube temperature for all three cases exhibits two peaks, one shortly after coolant is lost, and one after the fuel temperature peaks. For the two cases at the 1700 F surface temperature, the first peak is the higher of the two; for the other case, the second peak is the higher. None of the three outer tube peaks exceeded 1200 F.

The peak fuel temperatures, essentially the same as the peak cladding temperatures for no-emergency system operation, do not differ significantly among the three cases. The four-second temperatures (more realistic for an actual occurrence) show that at the 1700 F initial cladding temperature peak cladding temperatures some 160 F higher than for the lower initial temperature would be experienced. At 1900 F (corresponding to peak cladding temperature for the 1700 F initial temperature), the 2 per cent off-set tensile yield strength for Hastelloy-X is 11,200 psi. For 10 per cent release of stable and long-lived volatile fission products, the calculated internal pressure is 116 psia.(7) This includes 60 psia for helium atmosphere sealed in the enclosure at the time of the end closure weld. Thus, at normal loop pressure (215 psia), the net load on the cladding will be external. At the above strength (11,200 psi), a net internal pressure (over loop pressure) of 620 psi could be supported; this would require an increase of about 720 psi above the calculated internal pressure. Burst tests on Hastelloy-X tubing conducted by General Atomic (7) showed that net internal pressures of 360 and 1150 psi are required to burst the cladding at pressurization rates of 0.2 and 50 psi per second, respectively. The latter result agrees well with calculations based on the ultimate tensile strength (1600 psi) at 1900 F.

For cases where the emergency system operates, the time spent at elevated temperatures will be very short. Thus, short-time properties should be valid for bursting considerations.

It is thereby concluded that the cladding-failure potential presented by a loss-of-coolant accident is not significantly greater for a steady-state cladding surface temperature of 1700 F than it is for 1500 F.

The mechanical properties of Hastelloy-X at 1700 F are, of course, less than at 1500 F. Furthermore, the thermal cycle is increased by 200 F at the higher temperature. Thus, the possibility of cladding failure during normal operation is greater at the higher temperature.

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Because the diffusion coefficient increases with temperature, the actual rate of release and the actual fractional release of fission products will be higher at the maximum surface temperature of 1700 F than at 1500 F. Therefore, both probability of failure and potential magnitude of fission product release increase with the higher operating temperature.

However, the estimated magnitude of release quoted for the lower temperature is still felt to be conservative for the higher temperature. The estimated release for the simultaneous failure of two rods totals 4.7 curies of all types of fission products, including 0.3 curies of I_{131}. If all rods should fail simultaneously, 42 curies total including 2.5 curies of I_{131}, could be released. The characterization and estimated magnitudes of release are given in Tables 2, 3, and 4 in the Appendix.

The estimates of release magnitude were based on the experience with the second test run, HDR-2 [4], which exhibited 0.2 per cent release of Xe_{133}. While the total power of this specimen was only 10 KW, it had approximately twice the power per unit length of fueled rod. Because of the greater specific power and additional heat barriers between the fuel and the coolant, HDR-2 operated with calculated peak and mean fuel temperatures that were 200 to 250 F higher than those for the current test at the 1700 F surface temperature. For this reason, the estimated magnitude of release has not been changed.

As previously noted, the estimated internal pressure is 116 psia, with the net load on the cladding being external. The stress-to-rupture stress for Hastelloy-X is about 4500 psi for 1000 hours at 1700 F, as compared to 9500 psi at 1500 F. Even at the 1700 F temperature, the cladding could withstand a net increase of about 350 psi in internal pressure; this is approximately six times the estimated component of internal pressure due to volatile, released fission products.

It was pointed out in Reference (4) that the release of available fission products to the gas stream from the first two tests (HDR-1 and HDR-2) was significantly inhibited by the graphite bar which totally enclosed the two fuel rods. This protection is not present in the current test. However, data collected during the first two tests and on post-irradiation examination of the assembly lead tubes showed that, of the fission products which did escape to the coolant, only xenon and krypton remained gas borne. Of the others, only I_{131} was found in significant quantities on ex-reactor loop surfaces, and there, only upstream of the heat exchanger. I_{131} also was deposited on the lead rod and the inner tube. I_{131} never was detected in the gas stream for either test, though a loop burden of as low as 10^{-16} µc of I_{131} can be detected. The deposition results quoted for I_{131} apply only to HDR-2, no release was detected from HDR-1.

It can be concluded, therefore, that even without the graphite protection, released fission products will be largely deposited on in-reactor loop surfaces, and only xenon and krypton will remain gas borne.

An additional consideration is the fact that the current specimen has demonstrated its integrity at 1500 F for an extended period of time, and is definitely free from leaky welds or other fabrication defects. Considering all factors, the increased hazard of fission product release due to the increased operating temperature is concluded to be acceptable. In retrospect, the hazard accepted here is less than that accepted when HDR-1, an unproven concept, was installed.

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OPERATIONAL CHANGES AND PROCEDURES

When this supplement is approved, the increase in temperature will be accomplished as follows:

1. The preheater outlet temperature will be lowered in accordance with the current power to a calculated level consistent with a 1550 F surface temperature at a flow of 370 lbs/hr.

2. The flow will be adjusted to 370 lbs/hr.

3. The preheat outlet temperature will be adjusted as necessary until the calculated surface temperature is 1550 F.

4. After approximately 100 hours (4 days) at 1550 F the preheater outlet temperature will be adjusted to give a specimen surface temperature of 1600 F.

5. Further adjustments in 50 F increments will be made, allowing about 100 hours at each level, until 1700 F has been reached.

6. Operation at 1700 F will be maintained until 1000 hours have been accumulated at this level.

7. The flow rate will then be readjusted to 410 lbs/hr, after which the preheater outlet temperature will be readjusted as required to maintain a 1500 F surface temperature for the duration of the test.

The purpose of the extended period between each upward temperature adjustment is to permit detection of fission product diffusion through the cladding, if such should occur. Arrangements will be made for use of a 128-channel gamma spectrometer to facilitate gas sample activity analysis.

With the exception of a lower flow rate and higher cladding surface temperature, all other provisions and limits stated in the original authorization and Supplement A remain in force.

R. E. Baars/ecb
Irradiation Testing

R. E. Baars/rch

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REFERENCES

1. Bennett, E.C., Production Test IP-376-D, Irradiation of MGCR-HDR-3 Test Element; HW-67372. November 29, 1960.

2. Marshall, R.K., Production Test IP-376-D, Supplement A, Irradiation of MGCR-HDR-3 Test Element; HW-69490. May 3, 1961.

3. General Atomic, Division of General Dynamics Corporation, Hanford Irradiation Request MGCR-HDR-3; GA-C-184, Addendum No. 1. Undated.

4. Baars, R.E., Technical Aspects of MGCR-HDR-3; HW-67325. November 4, 1960.

5. Baars, R.E., DR-1 Gas Loop Thermal and Fluid Flow Analyses; HW-69882. June 16, 1961.

6. Baars, R.E., DR-1 Gas Loop Thermal and Fluid Flow Analyses Classified Supplement; HW-69899. June 16, 1961.

7. General Atomic, Division of General Dynamics Corporation, Hanford Irradiation Request MGCR-HDR-3; GA-C-184.

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TABLE 1

OPERATING TEMPERATURE LIMITS ON GAS LOOP COMPONENTS

1.	Preheater outlet gas.	1000 F
2.	In-reactor tube assembly, outer tube wall.	1275 F @ 215 psig
3.	Exit gas from in-reactor assembly.	1200 F

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TABLE 2

GROSS RELEASE ACTIVITY CHARACTERIZATION

Case	Beta Radiation: Curies	Gamma Radiation (MEV - Curies): 0.1-0.4 MEV	0.4-0.8 MEV	0.8-1.3 MEV	1.3 and up MEV	Total (0.1 MEV and up
Release from 40 KW (18 rods)	42.2	2.93	5.7	2.89	3.9	14 8
Release from 4.44 KW (2 rods)	4.69	0.32	0.63	0.32	0.43	1.65

TABLE 3

RELATIVE RELEASE ACTIVITY CHARACTERIZATION
(per cent basis)

Category	Beta	Gamma: 0.1-0.4	0.4-0.8	0.8-1.3	1.3 and up	Total
*Xe & Kr Isotopes	16.5	33.0	4.1	0.48	21.0	15.2
*I Isotopes	15.5	20.0	75.3	47.0	39.4	50.6
*Total gas-borne contamination	32.0	53.0	79.4	47.5	60.4	65.8
*Portion of non-gas borne contamination decaying in 9 hours	38.7	13.5	10.4	44.2	37.7	21.7
*Portion of non-gas borne contamination remaining after 9 hours	29.3	33.5	10.2	8.3	1.9	12.5
*Total non-gas borne contamination	68.0	47.0	20.6	52.5	39.6	34.2

*-All percentages are based on respective column total for all categories.

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TABLE 4

RELATIVE IODINE RELEASE

Iodine Isotope	Curies / Curie Xe-133	131 Eq. Curies / Curie Xe-133	MPC ($\mu c/ml$) (3)
131	0.415	0.415	9×10^{-9}
132	0.412	0.0186	2×10^{-7}
133	0.338	0.112	3×10^{-8}
134	0.125	0.0023	5×10^{-7}
135	0.142	0.0128	10^{-7}
TOTAL	1.433	0.561	

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APPROVED BY:

C. G. Lewis
Manager, Testing

R. W. Reid
Manager, Process Technology

for J. H. Brown
Manager, Process and Reactor Development

O. H. Greager
Manager, Research & Engineering

D. S. Lewis
Manager, DR Processing

W. D. Richmond
Manager, D-DR Reactors

for E. R. Astley
Manager, Applied Reactor Engineering

O. C. Schroeder
Manager, Manufacturing

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