HANFORD SITE PRODUCTION REACTOR DATA PERTINENT TO ACTINIDE BURNING

H. Toffer and S. P. Roblyer
Westinghouse Hanford Company
Richland, Washington 99352
509/376-2894 509/376-0436

INTRODUCTION

During the 44 years of operation, irradiation of special actinides occurred in the Hanford Site production reactors. The data derived from such irradiations could be of value to advanced actinide burners having a thermal neutron spectrum. Recently, such information has become unclassified and, therefore, available for public release.

BACKGROUND ON HANFORD SITE PRODUCTION REACTORS

The Hanford Site production reactors were graphite-moderated, light-water cooled reactors. During 1943 through 1963, nine production reactors were built. There were some basic, common features between the reactors such as the use of graphite as a moderator, low-enriched uranium metal fuel clad in aluminum or zircalloy, horizontal process tubes, light-water cooling, horizontal control rods, and vertical backup safety systems. Nevertheless, evolution in the reactor concepts occurred with time. The nine reactors can be grouped into three categories: the six small single-pass reactors, B, D, DR, F, H, and C; the large single-pass reactors, KE and KW; and the dual-purpose N Reactor with a pressurized recirculating primary loop. A front face view of a K Reactor is shown in Figure 1. As experience was gained in operating the reactors, the power level increased from nameplate values. In the late 1950's, major plant modifications to permit increased cooling resulted in substantial increases in power level. Figure 2 illustrates the operating history, the original design power levels, and the maximum achieved power levels at which the reactors operated. During the mid 1960's, the total operating power level was nearly 26 GW thermal power or the equivalent to the thermal power output of seven large-size commercial nuclear power plants. Figures 3a and 3b show the annual and cumulative thermal power production by the Hanford Site production reactors. N Reactor, in its dual production mode, was for a number of years the largest power reactor in operation and, as such, the leader in electrical power generation in the world.

Some reactor core characteristics for the Hanford Site production reactors are listed in Figure 4. Because the early reactors used natural uranium exclusively, the design of these reactors had a high carbon-to-uranium (C/U) ratio resulting in a very thermal neutron spectrum. As slightly enriched uranium fuel became available, the C/U ratio was lowered to operate the reactors with a hardened neutron spectrum that was more suitable for plutonium production. A listing of typical fuel designs used in the reactors is shown in Figure 5. Original fuel in the small reactors were clad uranium metal solid slugs. As the power levels were raised, the fuel design was altered to a tubular geometry with internal and external cooling. The added cooling surfaces permitted more effective heat transfer and, therefore, higher power levels. The N Reactor fuel consisted of two concentric fuel tubes. Targets for the irradiation of special nuclear materials were solid cylinders either concentric with a fuel tube or located separately in adjacent process tubes.

HANFORD SITE IRRADIATION MISSIONS

Although the main mission for the reactors was plutonium production from natural and low-enriched uranium, other materials were irradiated in all reactors were used to produce significant quantities of tritium, ^{233}U, ^{237}Np, lesser amounts of ^{238}Pu, small quantities of americium and curium isotopes, and other special isotopes. A partial test load in the KE Reactor demonstrated plutonium burning.

A number of the irradiations are of interest to actinide burning. Kilogram quantities of neptunium in different target matrices were irradiated to produce ^{238}Pu. A

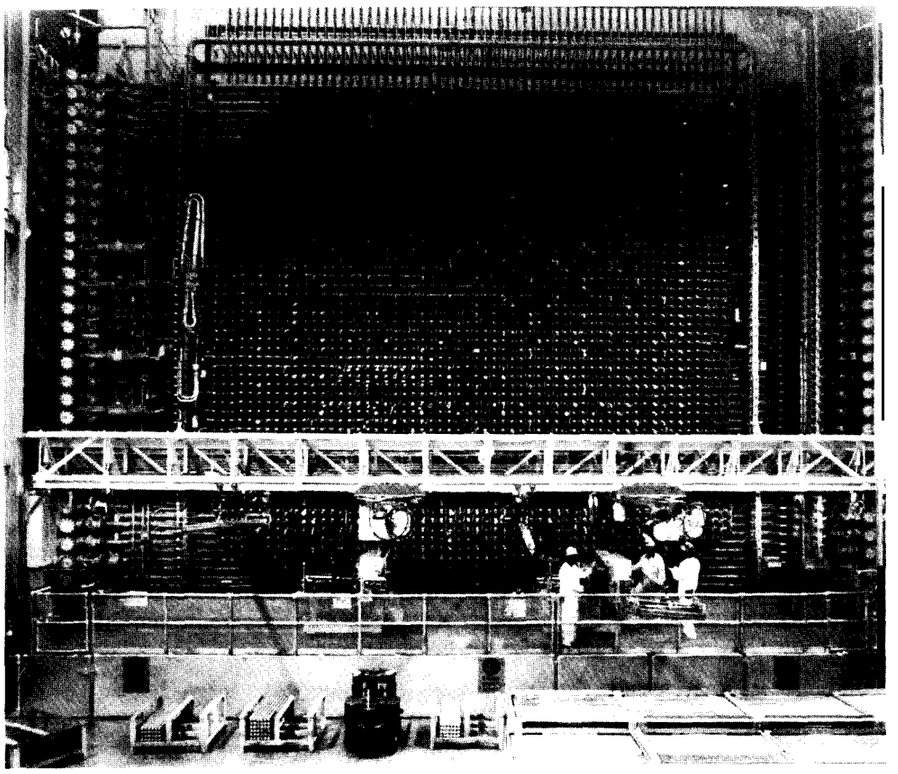


Figure 1. Front Face of a K Reactor.

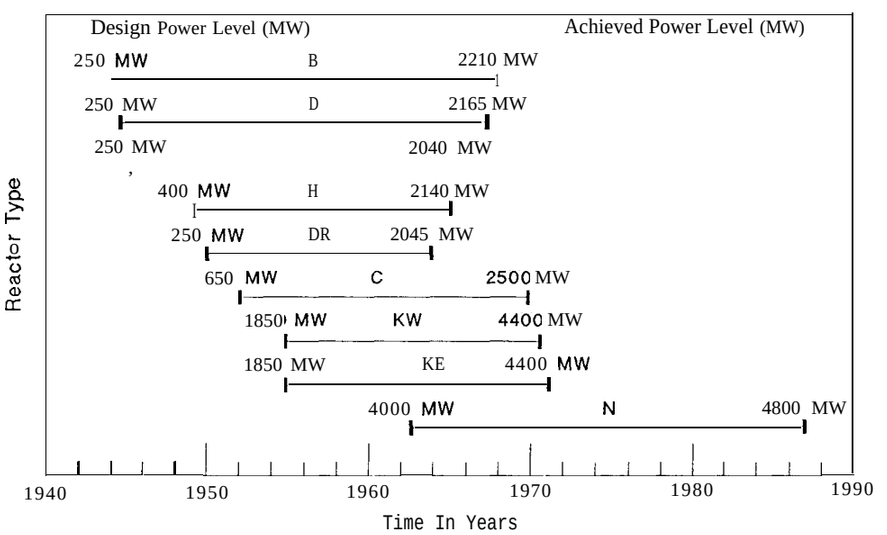


Figure 2. Operating History.

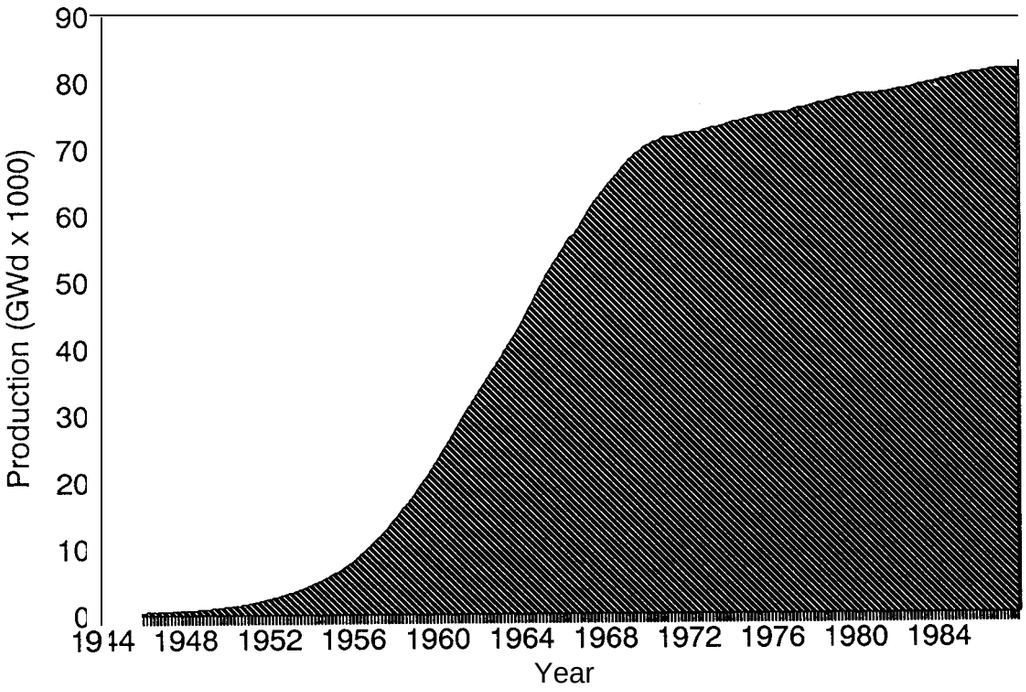


Figure 3a. Cumulative Production. (All reactors)

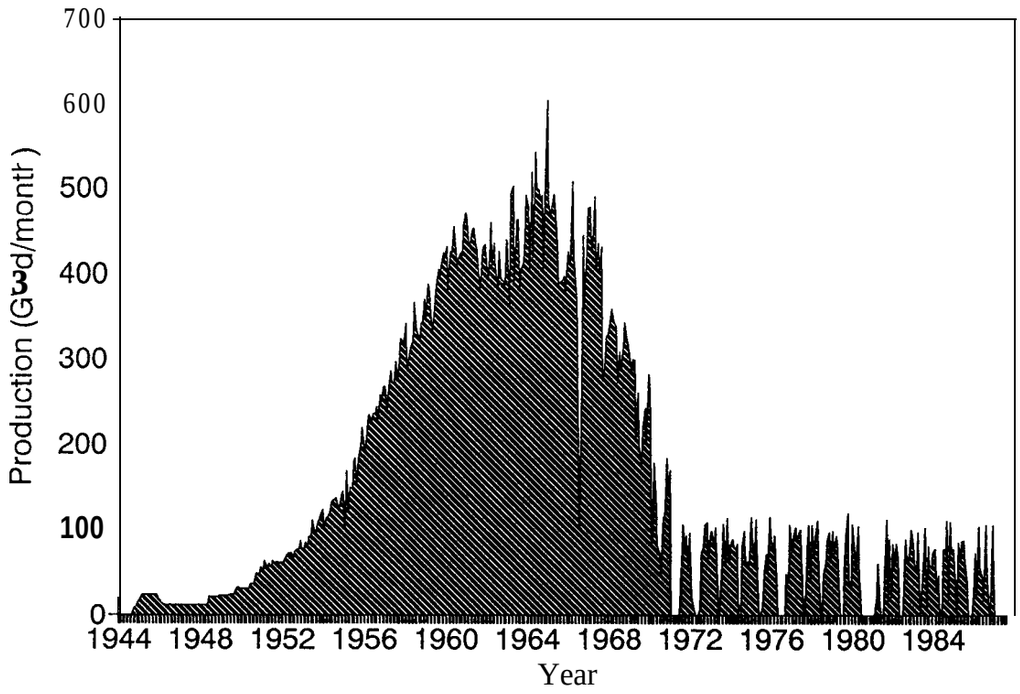
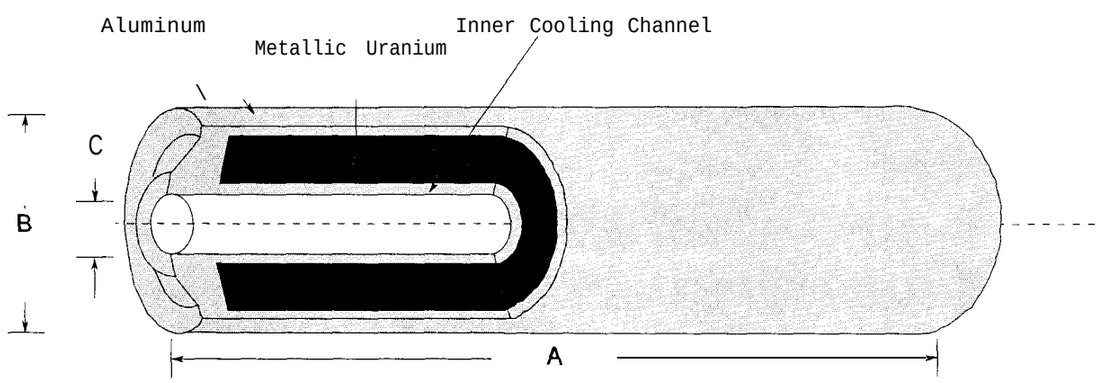


Figure 3b. Monthly Production. (All reactors)

		Reactors								
		B	D	F	DR	H	C	KE	KW	N
Graphite Stack Dimensions (Core + Reflector)	Axial (m)	8.53	8.53	8.53	8.53	8.53	8.53	10.21	10.21	11.88
	Vertical (m)	10.97,	10.97,	10.97,	10.97,	10.97,	10.97,	12.50,	12.50	10.06
	Width (m)	10.97	10.97	10.97	10.97	10.97	10.97	12.50	12.50	10.06
Mass of Graphite	Moderator (MT)	1089	1089	1089	1089	1089	1089:	1542	1542	726
	Reflector	544	544	544	544	544	544	907,	9071	907
Lattice Pitch (cm)		21.27	21.27	21.27	21.27	21.27	21.27	19.05	19.05	20.32x 22.86
C/U Atomic Ratio (Typical Loads)		101	99	100	106	109	100	78	77	34
Number of Process Tubes		2004	2004:	2004	2004	2004	2004	3220	3220	1003
Material of Process Tubes		Al	Al	Al	Al	Al	Al	Al/Zr	Al/Zr	Zr-2
Horizontal Control Rods		9	9	9	9	15	15	20	20	84
Vertical Control Rods		29	29	29	29	45	44	41	41	0
Ball Channels		29	29	29	29	45	45	51	51	107

Figure 4. Reactor Core Characteristics For Hanford Production Reactors.



Fuel Type	^{235}U Content (Wt %)	External Dimensions A (in.)	B (in.)	c (in.)	Uranium Core Dimensions Length (in.)	OD (in.)	ID (in.)
OIIIN	0.711	8.965	1.444	0.310	8.378	1.356	0.423
CIIN	0.711	8.965	1.466	0.375	8.378	1.370	0.481
KVN	0.711	8.865	1.520	0.420	8.325	1.431	0.533
OIIIE	0.947	6.640	1.443	0.310	6.053	1.356	0.423
CIIIE	0.947	6.640	1.460	0.375	6.053	1.370	0.488
KVE	0.947	6.540	1.509	0.432	6.007	1.419	0.545

Figure 5. Typical Production Reactor Fuel Elements.

total of 150 g of americium was burned to produce ^{238}Pu and curium.. A test block in the KE Reactor explored the use of plutonium as a reactor fuel. These irradiations took place under controlled test conditions. In some cases, the results were chemically and isotonically analyzed.

NEPTUNIUM IRRADIATIONS

The objective of the neptunium irradiations that took place in the K Reactors and the N Reactor was to produce medical grade ^{238}Pu with *very* small contamination by ^{236}Pu. Different target material matrices were tested to minimize ^{236}Pu buildup and to demonstrate operation under elevated temperatures and pressures.

In all, 30 neptunium targets were irradiated in the KW Reactor. Twelve targets used an aluminum-neptunium matrix. They were irradiated in the central core region. Twelve targets had a neptunium-graphite core and were also irradiated in the central core region. Six neptunium-graphite targets were irradiated in the low power fringe of the reactor to demonstrate a softer neutron spectrum and lower production of ^{236}Pu by the (n,2n) reaction. These samples were sent for post-irradiation examination. Results of the irradiations are discussed in Meichle and Nosier.[2] Neptunium in graphite matrices produced lower ^{236}Pu levels than neptunium/aluminum (Np/Al) matrices. However, some neptunium graphite targets experienced failures because of graphite swelling.

Additional thin annulus neptunium targets were charged into KE Reactor on May 10, 1970. Part of these targets had a water core and part had a graphite core. This test was terminated by the KE Reactor shutdown in January 1971. The results of post-irradiation testing provided data for Table 1.

Table 1. Test Results from KE Reactor Neptunium Tests.

	Target Type	
	Water Core	Graphite Core
g ^{238}Pu/ g ^{237}Np	0.125	0.112
Quality (% ^{238}Pu/total Pu)	87.7	89.4
^{236}Pu in ^{238}Pu	0.39, 0.52	0.51

A successful ^{238}Pu production demonstration test was carried out in 1967 in N Reactor. Three target columns with various neptunium loadings supported by MKIA driver fuels were irradiated. A total of 3,981.6 g of neptunium was charged in the Np/Al alloy targets. The total ^{238}Pu production was 501.4 g. The average quality of the plutonium was 90% ^{238}PU. The irradiation occurred in a supercell arrangement and lasted from 74 days to 147 days for these three target charges. Approximately four to five MKIA charges were required to support one target column. The target was doubly clad with zircalloy and aluminum. The Np/Al alloy region was covered with aluminum on both surfaces; the center of the target was occupied by graphite slugs. The target dimensions in terms of outside diameters of the various regions were zircalloy clad, 6.11 cm; aluminum clad, 5.92 cm; Np/Al matrix, 5.57cm; aluminum clad, 4.44 cm; and graphite slug, 4.28 cm. The target column had a concentration of 70 g neptunium/ft. The Hanford Site experience demonstrates that ^{237}Np can be very effectively transmuted into a useful isotope such as ^{238}Pu with minimal contamination by ^{236}Pu in a thermal reactor.

PLUTONIUM BURN TEST

The plutonium-aluminum (Pu/Al) elements were charged as a special irradiation test in the KE Reactor in February 1969, and discharged in February 1971. The objective of the test was to support thoria irradiation to produce ^{233}U and to demonstrate plutonium burnup. Thoria targets were located in separate process tubes surrounded by the process tubes containing Pu/Al fuel elements and process tubes containing regular driver fuel (KVE and KVN). The test block contained 225 process tubes, 13 loaded with Pu/Al, and the remainder with thoria targets and various driver fuels. A total of 10 kg of plutonium with an isotopic composition of 75 Wt% ^{239}Pu, 20 Wt% ^{240}Pu, 4 Wt% ^{241}Pu, and 1 Wt% ^{242}Pu was used. The plutonium was in an aluminum matrix with an effective density for the alloy of 2.88 g/cm^3. There were 322 Pu/Al elements irradiated in 13 separate process tubes. Eleven charges contained 28 elements, 1 contained 6 elements, and the other contained 8 elements. The Pu/Al elements were cylindrical in shape with an aluminum cladding and a Pu/Al core. The outside diameter of the clad was 3.78 cm and of the fuel region 3.29 cm. The core composition was 6 wt% plutonium in aluminum.[3] The power level on the Pu/Al charges was maintained between 1,000 to 1,100 kW during the 24-month irradiation.

As the thoria targets and the driver fuels reached goal exposure, they were discharged. Newly charged fuel helped maintain the tube powers on the Pu/Al fuel. Some of the Pu/Al tubes were discharged at 20,000 MWD/T and chemically analyzed. At discharge, the entire test irradiation had an average exposure of 25,000 MWD/T. During the entire irradiation, no operational difficulties were encountered with the Pu/Al fuel. The calculated discharge composition of the fuel was 12.8 wt% ^{239}Pu,

25.6 wt% ^{240}Pu, 6.7 wt% ^{241}Pu, 3.4 wt% ^{242}Pu, and 46.4 wt% fission products. The test indicated that plutonium can be burned up very effectively in a highly thermal neutron flux environment.

AMERICIUM IRRADIATION

Americium-aluminum targets were irradiated in KE Reactor for the production of heat-producing isotopes such as ^{238}Pu, ^{242}Cm, and ^{244}Cm. This irradiation pathway promised to produce ultra-pure ^{238}Pu compared to the more conventional route using ^{237}Np. The targets remained in the reactor for 15 months. One hundred and fifty grams of americium oxide ($Am0_2$) matrixed with 11OF aluminum powder was contained in twelve n-in. targets. The concentrations of the americium corresponded to linear loadings of 10, 20, and 45 g/ft in the targets. The targets were doubly encapsulated with a total cladding thickness of approximately 200 roil. They included a gas plenum for accommodating helium and fission gas during irradiation and subsequent cooling periods. The targets were operated at a low specific power of approximately 8 kW/ft. The external dimensions of the targets were 1.48 in. in outer diameter and 10.885 in. in length. Each target element contained two 4-in. clad target cylinders and two 0.82-in.-long gas plenums. The gas plenum provided 2.98 cc of void for gas accumulation. The targets were loaded in a single process tube with dummy spacers in between targets so that each target concentration was subjected to different levels of neutron flux. The target charge was supported by two 51-piece K5E drivers.

The americium targets were charged in May 1969, and irradiated successfully with no incident of failure in the target cladding. The irradiation time for the test was planned to be 260 full-power days that would be determined from the power of the adjacent process tubes.

The targets were discharged in August 1971. Upon termination of the test, the target elements were discharged and placed in a burial casket without post-irradiation examination. The irradiation demonstrated that transplutonium actinides can be successfully irradiated in a thermal flux reactor. It is still possible to retrieve the targets for analysis and product recovery.

CONCLUSIONS

The examples of transuranic material irradiations in the Hanford Site production reactors indicate that such materials can be successfully irradiated or burned in thermal reactors. The Hanford Site information could supplement the broader database derived from the light-water reactor industry and its use of mixed oxide fuel for plutonium burning. The information could be of use to reactors such as modular high-temperature gas (cooled) reactor concepts considered as actinide burners, special isotope production or destruction reactors, or to hybrid accelerator subcritical reactor concepts.

REFERENCES

1. H. Toffer, 1989, "Evolution of the Hanford Graphite Reactor Technology," *50 Years with Nuclear Fission,* pp. 237-243, Gaithersburg, Maryland, April 25-28.

2. R. H. Meichle and J. C. Nosier, 1969, "Clean Pu-238 from Np-237 Irradiation," *Proceedings from American Nuclear Society Annual Meeting,* V. 12, Number 1, p. 53-54, Seattle, Washington.

3. R. L. Miller and H. Toffer, 1972, "Criticality Control Parameters for Discharged Fuel," *American Nuclear Society Transactions,* V. 15, Number 2, p. 802.