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OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE CORPORATION
NUCLEAR DIVISION

POST OFFICE BOX X
OAK RIDGE, TENNESSEE 37830

17 August 1977

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E.O. 13526, Sec. 3.
NW51408
By DM&MG, NARA, Date 07-25-2022

Mr. Robert E. Upchurch
International Security Affairs
U.S. Energy Research and
Development Administration
Washington, D.C. 20545

Dear Mr. Upchurch:

We have studied the possibility of plutonium production in the 20 megawatt Safari Reactor (ORR-swimming pool type) located at the National Nuclear Research Center, Pretoria, South Africa. Based on examination of quarterly reports on its operation (from reactor startup on April 28, 1965 through April 12, 1977), other information, and estimates, we report the following:

1.0 Conclusions

1.1 There is no evidence that this research reactor has been used to produce plutonium. We are convinced that it has not been used for plutonium production.

1.2 This reactor has a small annual production potential for plutonium, most probably less than 1.0 kilogram plutonium per year, at 85 per cent on-stream factor.

See para. 1.5, p. 2

Since the Safari is fueled with fully enriched uranium, plutonium production can be achieved only by placing natural uranium (^{238}U) in favorable locations in the 72 position fuel matrix. If such were done, there would be a noticeable increase in the number of fuel elements consumed per unit of energy produced, and this would be different from the similar fuel burnup for the Oak Ridge Research Reactor (ORR). Safari burnup for similar fuel and fuel loadings correspond to ORR experience.

1.3 We are not aware of the existence of a radiochemical reprocessing plant in South Africa in which plutonium could be recovered, even if it had been produced.

But, the capacity requirement is low, of the order of several kilograms natural uranium per day, so that recovery of plutonium at this low rate could be accomplished in specially equipped laboratory-scale hot cells.

1.4 The natural uranium that would be required would preferably be placed in the reactor matrix (as a blanket or dispersed optimally as natural uranium plates in certain fuel elements) as uranium-aluminum alloy plates clad in aluminum. We are unaware of the existence of facilities to fabricate plate-type fuel in South Africa.

1.5 It is most improbable that this research reactor has been, or would be in the future, used for the production of plutonium for weapons use because of its very low production rate. Assuming that the minimum quantity of plutonium required for one nuclear device is of the order of 10 kilograms, then ten to twenty years would be required to produce plutonium for one device in the Safari. Surely absurd.

1.6 The United States has supplied 104.2 kilograms total uranium, or 94.8 kilograms of uranium-235 to fuel this reactor. From our accounting, the reactor has produced about 24,218 megawatt days of heat, which consumed 30,685 grams of uranium-235. If an average of 35 per cent of uranium-235 in each fuel element was consumed, then 87,670 grams have been both burned or committed to spent fuel. This leaves an inventory of perhaps 36 or more fuel elements as a minimum (7 kilograms uranium-235); or assuming 40 per cent burnup, perhaps 90 elements (18 kilograms uranium-235).

This supply of fuel is normal; it is inspected, we think, under a United States bilateral by the IAEA inspectors. We have no concern about the fuel inventory as a potential source of fissile uranium-235 for nuclear device fabrication.

2.0 Supporting Information and Analysis

2.1 The enriched uranium supplied for fueling this reactor was supplied by the United States, and perhaps Great Britain. Fuel elements of the 19 plate MTR-type have been fabricated by various U.S. contractors, most recent of which was U.S. Nuclear, now defunct. Early on, some fuel fabrication using U.S.-supplied uranium may have been done in Great Britain. From records in the Oak Ridge Operations Office, ERDA, we learned that the following quantities of uranium have been provided as fuel for the Safari, through 1975 (no later shipments):

Total uranium:	104.200 kilograms
Containing uranium-235:	94.823 kilograms

2.2 From quarterly reports, the following approximate operating history has been derived:

Calendar Period	Nominal Power Level	Megawatt Hours in Period	
4/26/65 to 9/30/65	Start-up	2,045	
10/1/65 to 3/1/68	5 Mw	8,829	
2/1/69 to 12/31/71	10 Mw	93,196	
1/1/72 to 4/12/77	20 Mw	477,169	
	Total.............	581,239	or 24,220 Mwd

Note:

(1) Early period operation (through 3/1/68) one shift per day, five days per week.

(2) From 1973, average on-stream time was about 55%. Currently, reactor is on two shifts per day, five days per week schedule.

2.3 The Safari core contains from 26 to 30 fuel elements, six control rods, 21 beryllium reflector pieces, and aluminum filler pieces to fill 72 lattice positions. The fuel elements (currently) contain 200 grams uranium-235 initially and are burned down to about 120 grams at discharge (40 per cent burnup).

At 20 Mw power level, the average thermal flux in the fuel is between 8×10^{13} and 9×10^{13} n/cm^2-sec, slightly higher in the moderator positions (about 10^{14} n/cm^2-sec).

The rate of production of plutonium depends on the neutron flux and the amount of target uranium-238 that can be exposed: at first approximation, the rate of production is given by the following:(1)

$$\text{gram } {}^{239}\text{Pu/kg } {}^{238}\text{U per week} = 5.1 \times 10^{-15}\,\phi \qquad \text{(a)}$$

where ϕ = flux in n/cm^2 sec

Thus, for uranium-238 exposed in reflector position where the flux might be about 10^{14} n/cm^2 sec, the plutonium production would be about 0.5 gram/kilogram uranium-238 per full power week (or 0.0036 gram/kilogram uranium-238 uranium per megawatt day).

2.4 In reference(1) F. T. Binford suggests three possibilities for exposing natural uranium in the ORR-type lattice. His calculations are approximate and not optimized but are accurate enough for this exercise.

The three loading possibilities are:

(1) Uranium-238 could be introduced into the reactor in the form of fuel plates interspersed among the highly enriched plates. As much as 350 grams per plate could be introduced in this way. The exact number of such plates which could be used cannot be easily determined since the introduction of the uranium-238, which is a mild neutron poison, will have an effect on the core loading and result in a lowering of the flux. However, if it is assumed that 15 per cent of the plates could carry uranium-238, then the total target loading becomes 28 kilograms and the production rate would be about 14 grams per week.

(2) Flux traps which effectively increase the local neutron flux could be used. If dedicated to this purpose the Safari core could probably support four such traps in which the thermal neutron flux could be as high as 5×10^{14} n/cm^{2}sec. The traps could utilize light water or perhaps heavy water and contain as much as four kilograms uranium-238. The production rate by this method would be about 40 grams per week.

(3) By using lower enrichment uranium-235, say 20 per cent, a fuel loading of 5.5 kilograms would contain 27.5 kilograms of uranium-238 and the production rate would be about 12 grams per week.

Of these methods, the first would be the simplest but would require the capability to fabricate fuel plates having virtually 100 per cent natural uranium in the cores. In any case, the technology exists to fabricate fuel cores containing up to 50 per cent uranium for this purpose.

The second method would require dedication of the reactor or a larg portion of it to plutonium production. Of course, more refined calculations would be required to support the accuracy of our estimate.

The third method has the distinct disadvantage that the separations process would involve handling very large quantities of fission products. In the other two cases, the associated fission product inventories in the target are considerably smaller.

2.5 Based on the foregoing, we estimate that as a practical matter it is not unreasonable to suppose that something of the order of ten grams to twenty grams per week of plutonium could be produced in a research reactor such as the Safari.

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(1) Memorandum of August 17, 1977, F. T. Binford to F. L. Culler, subject: Pu Production in Safari.

3.0 Hypothetical Estimates of Past and Possible Future Production in Safari

The following table sums up the hypothetically possible past production, and similarly future potential, for several loadings and two power levels. These are hypothetical only. We emphatically do not believe that plutonium has been or will be produced in the Safari.

	Hypothetical Plutonium Production for:	
	Pu Loading (1) Easiest	Pu Loading (2) Difficult
Since startup (1966-1977) Actual burnup: 24,220 Mwd	2.44 kg	6.9 kg
Maximum Yearly Production Potential 20 Mw, 85% on-stream	0.6 kg/year	1.7 kg/year

4.0 References

Attached is a description of the Safari reactor (Attachment A). If you need details of the operation of this reactor, we have quarterly reports on file at the Oak Ridge National Laboratory. Questions should be directed to Frank T. Binford, Operations Division, who prepared information contained in this letter.

Very truly yours,

Floyd Culler

Floyd L. Culler, Jr.
Deputy Director

FLC:vmw

Attachment A

cc: F. T. Binford
J. A. Cox
J. A. Lenhard
H. Postma
Official Files - RC

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Attachment A not reproduced.
@ 8/23/77

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SOUTH AFRICA

To: F. L. Culler 8/17/77
From: W. K. Bensen, ERDA/ISA

SAFARI-I RESEARCH REACTOR

REACTOR TYPE: ORR tank, fully enriched (90%) uranium, light water moderated and cooled, beryllium reflected.

POWER: 20 MW thermal: Initially 6.67 MW cooling capacity.

LOCATION: National Nuclear Research Center, Pelindaba, near Pretoria, South Africa.

OWNER: South African Atomic Energy Board

DESIGNER/BUILDER: Reactor: Allis-Chalmers Manufacturing Co.

Building, process equipment, etc: Atomic Energy Board and South African Firms

CONSTRUCTION:
Start of Construction: 1961
Reactor Critical: 1965

Typical operating core consists of:
22 fuel elements
5 control rod elements
22 Beryllium reflector elements
23 Al filler pieces

*With the present schedule of operation at 20 megawatts thermal operating 5 days a week SAFARI-I requires a reload every 3 weeks, when 4 new elements of 200 gm U-235 each are loaded. Every 6 weeks 1 new control rod containing 135 gm of U-235 is loaded. Over a period of 1 year taking in account a total of 10 weeks shutdown time, the reactor requires an average of 14 reloads of fuel elements and 7 reloads of control rods. The annual requirement is therefore 56 times 200 gm elements and 7 times 135 gm control rods giving a total of 12.145 kg of U-235 contained in 13.494 Kg uranium at 90% enriched.

Data from: Directory of Nuclear Reactors
Volume V
Research, Test and Experimental Reactors
Page 95.
*Published by: IAEA

*Attachment A to August 17, 1977 letter from F. L. Culler to R. E. Upchurch

*Supplied by South Africa

ATTACHMENT A to August 17, 1977 letter from

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SAFARI-1 RESEARCH REACTOR

PURPOSE: Research and Test

DATE OF INFORMATION: January 1963

GENERAL

1. Reactor type	Tank type, fully enriched (90%) uranium, light water moderated and cooled, beryllium reflected
2. Nominal reactor power	Design 20 MW thermal Initially 6.67 MW cooling capacity
3. Purpose	Basic research, engineering tests, isotope production, fuel element development
4. Location	National Nuclear Research Center, Pelindaba, near Pretoria, South Africa
5. Owner and operator	South African Atomic Energy Board
6. Designer and builder	Reactor: Allis-Chalmers Manufacturing Co. Buildings, process equipment, etc.: Atomic Energy Board and South African firms
7. Present status & construction schedule	Under construction Start of construction 1961 Reactor critical 1964

REACTOR PHYSICS

8. Neutron energy and lifetime	Thermal Lifetime, initial 6.9×10^{-5} sec mean approx. 10^{-4} sec
9. Core parameters	Calculated: $\eta = 2.07$ $\varepsilon = 1.0$ $f = 0.77$ $p = 1.0$ $k_{\infty} = 1.59$ $k_{eff} = 1.13$ (cold, clean) $L^2 = 3.86$ cm² $\tau = 61.0$ cm² $B^2 = 54.4$ m⁻² Thermal leakage factor 0.978 Fast leakage factor 0.718 $k_{eff} = 1.04$ at end of core life

10. Neutron flux	Calculated, in n/cm² sec: 6.67 MW	20 MW
	Thermal av. 5.0×10^{13}	1.8×10^{14}
	Thermal max. 1.3×10^{14}	4.0×10^{14}

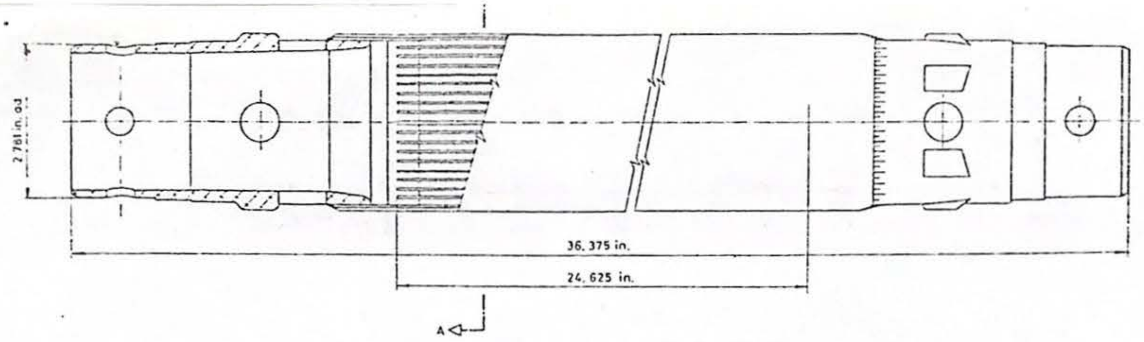
11. Reactivity balance		6.67 MW	20 MW
	Max. built in (cold, clean):	13.3%	14.5%
	To compensate for		
	temperature	0.76%	0.76%
	Xe and Sm	4.93%	5.32%
	burnup	2.82%	2.77%
	experiments	3.98%	4.85%
	operation.	0.81%	0.81%

CORE

12. Shape and dimensions	Parallelepiped, max. 27.5 × 25.5 in., 24 in. high; typical operating core T-shaped, 16 × 21 in., 24 in. high
13. No. of channels & subassemblies	Grid plate with 9 × 8 positions; typical operating core consists of 22 fuel elements 5 control rod elements 22 beryllium reflector elements 23 aluminium filler pieces (or experiments)
14. Lattice	Rectangular Pitch 3.035 × 3.189 in.
15. Critical mass	Calculated 1.521 kg U^{235}
16. Core loading at rated power	Calculated, 6.67 MW: 3.604 kg U^{235} 20 MW: 3.357 kg U^{235} (fully Be reflected)
17. Average specific power in fuel	6.67 MW: 1850 kW/kg U^{235} 20 MW: 5950 kW/kg U^{235}
18. Average power density in core	6.67 MW: 68 kW/litre 20 MW: 204 kW/litre
19. Burnup	Min. 20% of fissionable material
20. Fuel loading and unloading	After reactor shut-down, central hatch on tank can be removed, and fuel elements will be changed manually under water by means of long handling tools
21. Irradiated fuel storage	Storage room for irradiated fuel elements in critically safe racks in the pools
22. Moderator	Light water, temperature 120—131° F
23. Blanket gas	None

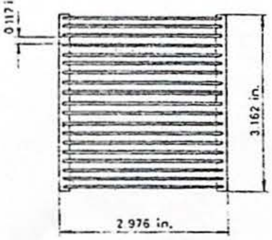
FUEL ELEMENT

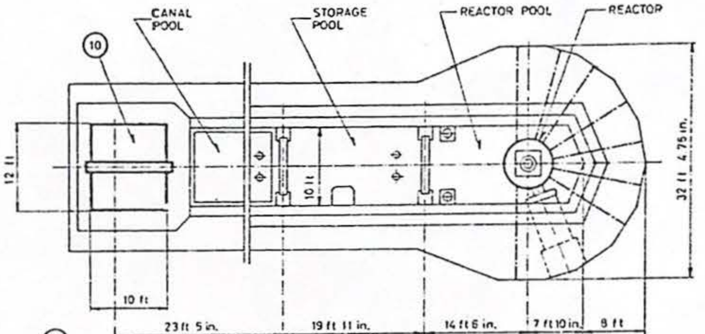
24. Form and composition	MTR-type, flat plates Meat dimensions 0.020 × 2.492 in., 23.625 in. long Plate overall 0.050 × 2.867 in., 24.625 in. long Enrichment 90%, alloyed with aluminium
25. Cladding	0.015 in. type 1100 aluminium alloy
26. Subassemblies	19 parallel plates forming fuel element, 15 plates in control rod elements Overall dimension of fuel element 3.186 × 3.032 in., 36.375 in. long

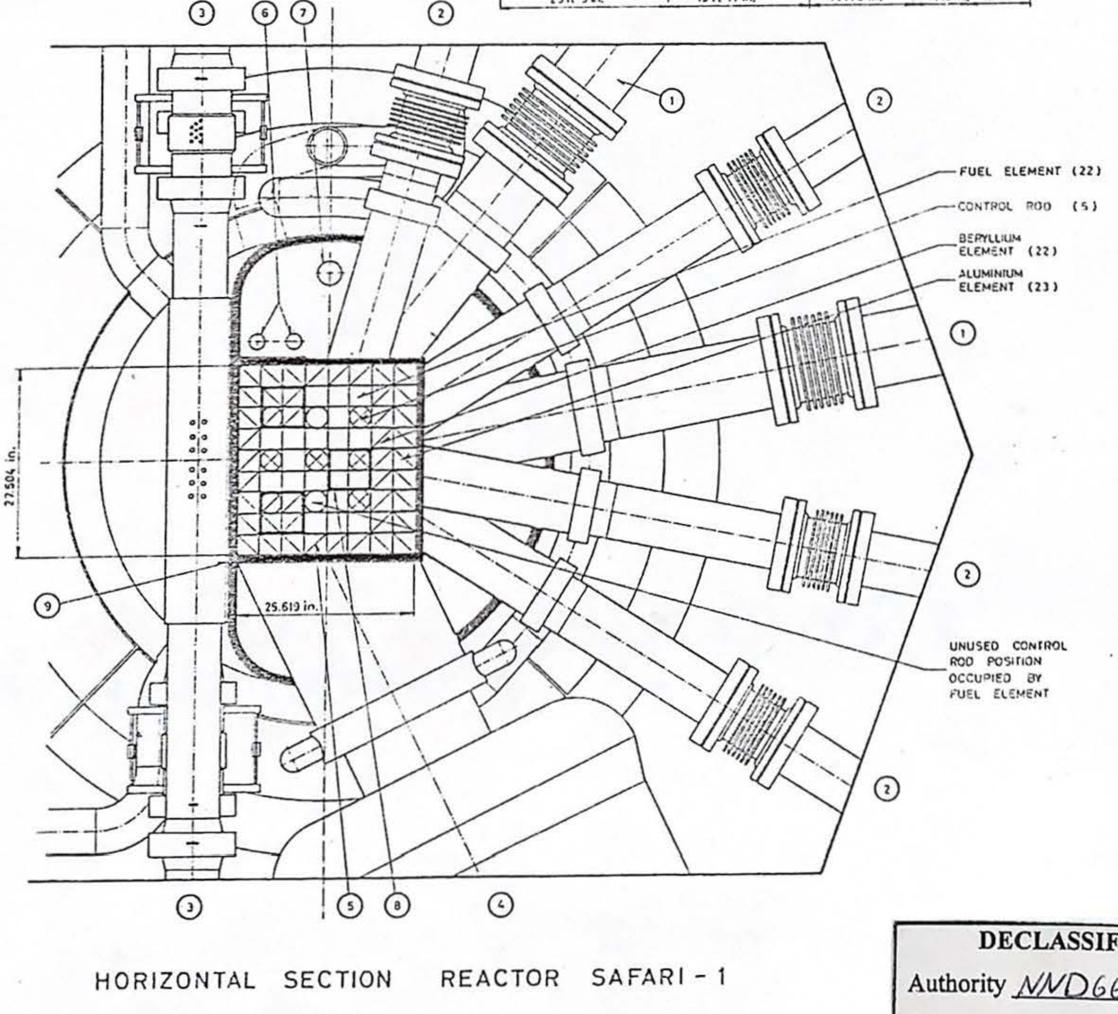


FUEL ELEMENT

SECTION A-A







HORIZONTAL SECTION REACTOR SAFARI - 1

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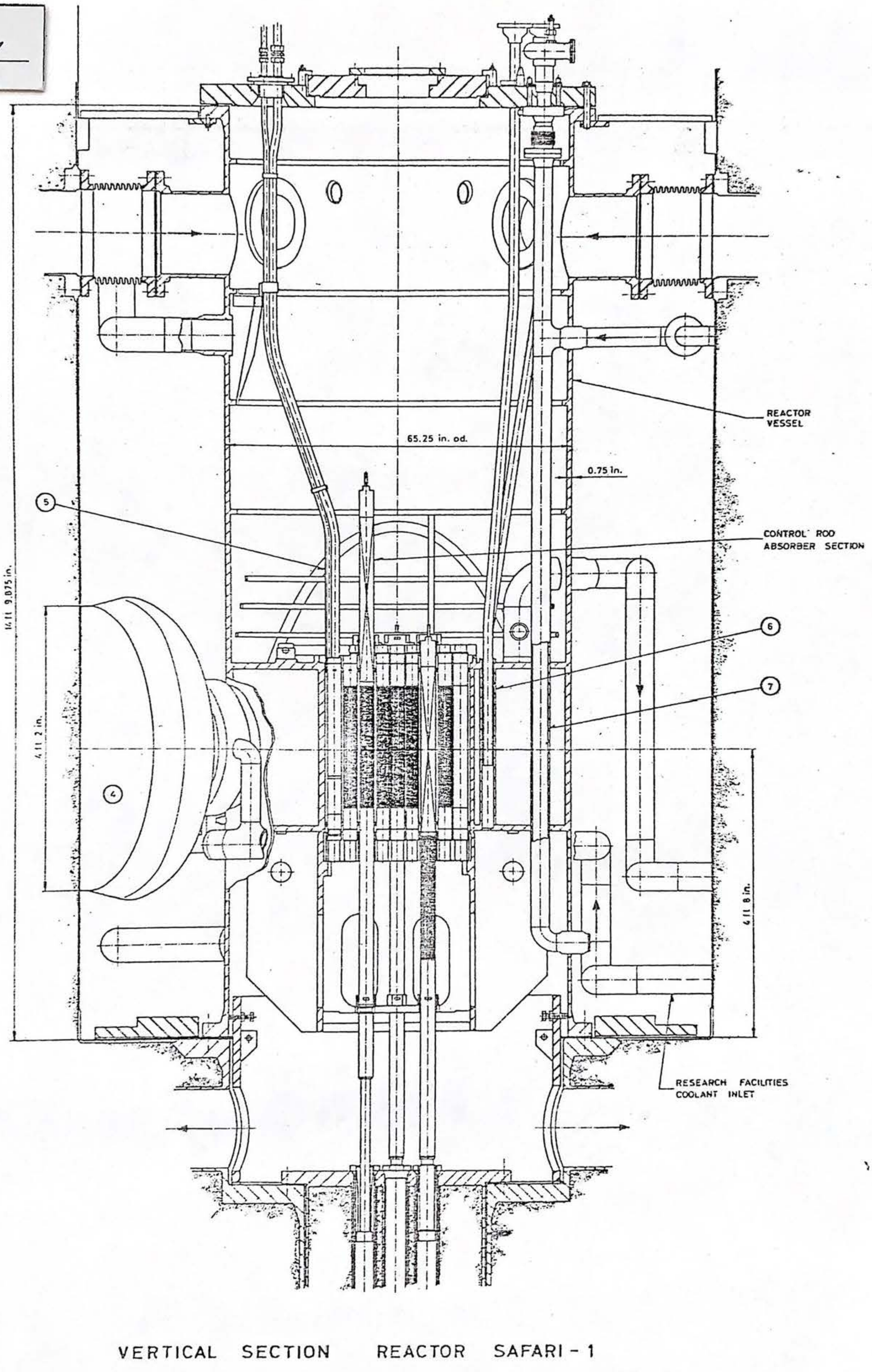


VERTICAL SECTION REACTOR SAFARI - 1

CORE HEAT TRANSFER

27. Heat transfer area	For core of 22 fuel elements and 5 control rod elements half-way out: 370 ft² (34.37 m²)	32. Coolant mass flow rate	At 6.67 MW: 3000 gpm (1.5×10^6 lb/hr) At 20 MW: 12000 gpm (6×10^6 lb/hr)
28. Heat flux	In BTU/ft² hr: 6.67 MW 20 MW Av. 54000 166000 Max. 123000 380000	33. Coolant pressures & temperatures	At 20 MW: Inlet 120° F, 24 psig Outlet 131.5° F, 12 psig
29. Fuel element temperatures	Max. cladding, design: 268° F (at 3000 gpm and 6.67 MW)	34. Hot channel factors	Film drop 1.98 Coolant rise 1.29
30. Heat transfer coefficient	At 6.67 MW: 1830 BTU/ft² hr °F At 20 MW: 5500 BTU/ft² hr °F		
31. Coolant flow area & velocity	6.67 MW 20 MW Total flow area 1.32 ft² 1.28 ft² Av. velocity 5.2 ft/sec 20.7 ft/sec	35. Shut-down heat removal	1000 gpm pump, driven from fail-safe power supply

CONTROL

36. Control, regulating and safety rods	5 control rods, one of them used as regulating rod. Rod consists of two sections: upper section of 32 in. cadmium, clad in aluminium, lower section 24 in. long fuel plates (15 plates per rod); total rod length 117 in., approx. 3 × 3 in.; rods are driven from below the reactor Total worth of 5 rods $26\,\%\,\frac{\Delta k}{k}$ for 6.67 MW core Worth of single (regulating) rod $5\%\,\frac{\Delta k}{k}$ Max. rod speed approx. 0.083 in./sec	38. Scram time & mechanism	Magnetic release, gravity fall Release time 0.07 sec, rod drop time 0.3 sec
		39. Sensitivity of auto. control	±0.5% of nominal power Automatic control limited by interlocks to $0.5\%\,\frac{\Delta k}{k}$
		40. Temperature coefficients	Av., calculated $-2.37 \times 10^{-2}\%\,\frac{\Delta k}{k}/{}^\circ\mathrm{C}$
		41. Burnable poison	None
		42. Other control, safety & shut-down provisions	None
37. Reactivity addition rate	Estimated max. $0.1\%\,\frac{\Delta k}{k}$/sec when 5 rods are withdrawn simultaneously		

REACTOR VESSEL & OVERALL DIMENSIONS

43. Form, material and dimensions	Cylinder, 14 ft 9.875 in. high, 5 ft 3.75 in. id., made of type 5052 aluminium, wall thickness 0.75 in., some parts 1.375 in. Reactor tank is located in one of three pools, approx. 28 ft deep; reactor pool 22 ft 4 in. long, storage pool 19 ft 11 in., canal pool approx. 13 ft; internal width 10 ft for all pools	44. Working, design & test pressures	Working pressure 30 psi Design pressure 36 psi Test pressure 54 psi
		45. Reactor with shielding	Overall dimensions of 3 pools approx. 82 × 32 ft, 28 ft high

REFLECTOR AND SHIELDING

46. Reflector	Beryllium metal elements, outer dimensions and shape similar to fuel elements; 22 elements for 6.67 MW core, 37 elements for 20 MW core	48. Shielding	Sides: approx. 4 ft light water, 9 to 11 ft magnetite concrete, density 3.5 Bottom: approx. 6 ft light water, 7 ft magnetite concrete, density 3.5 Top: 23 ft light water
47. Radiation levels	At 20 MW: less than 0.75 mr/hr outside concrete shield, less than 2 mr/hr above pool		

CONTAINMENT

49. Type and material	Semi gas-tight concrete structure, approx. 110 × 90 ft, 100 ft high Working pressure 0.05 in. H_2O below atmospheric Test pressure 0.05 in. H_2O below and above atmospheric	50. Surroundings	The National Nuclear Research Center is situated 17 miles from the nearest large city, in a sparsely populated area. Terrain of open country with low hills and valleys; river approx. 1 mile from the site.

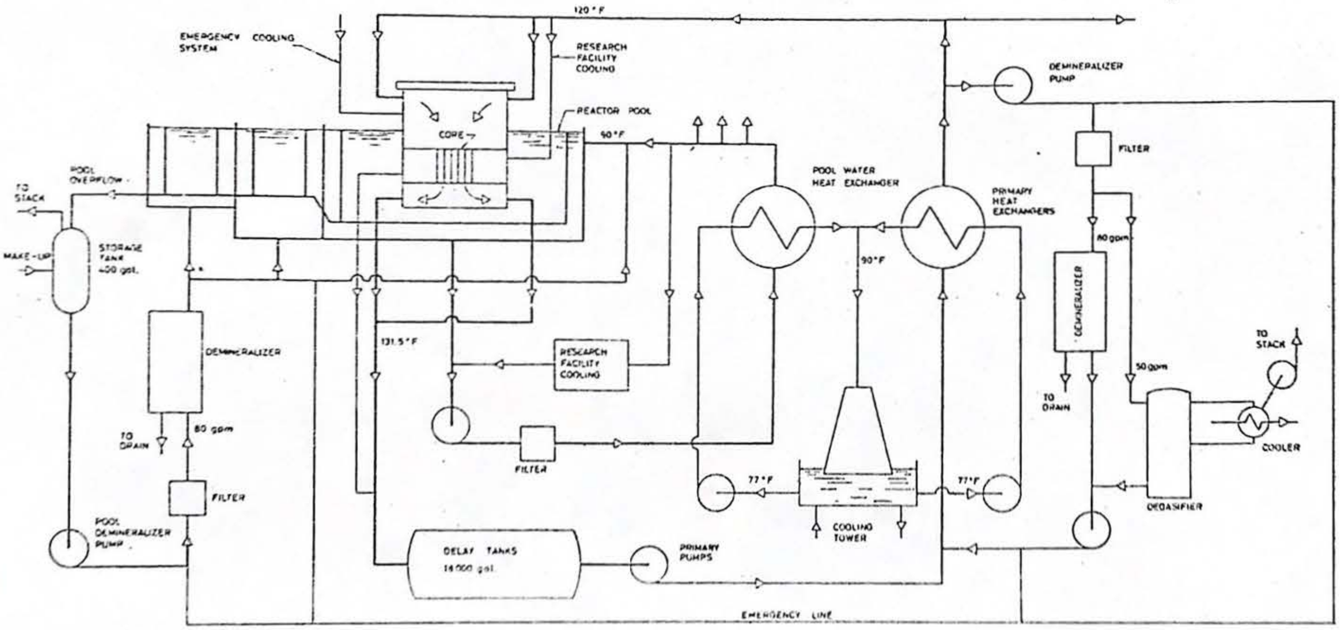
COST ESTIMATE

51. Reactor and building	$4.5 million including associated laboratories and Assembly Hall	53. Operating costs	Not available
2. Support facilities	See under 51	54. Staff requirements	Estimated: 27 operating staff, excluding maintenance and experiment installation

RESEARCH FACILITIES

Designation	No.	Position	Useful dimensions (in.)	Neutron flux (n/cm²sec)	Remarks
				at 20 MW:	
Horizontal beam tubes	2 4	(1) (2)	10 diam. 7 diam.	1.5×10^{14} 1.5×10^{14}	
Horizontal through tubes	2	(3)	7 diam.	1×10^{14}	on flat side of tank
Large facility	1	(4)	60 diam.	5×10^{13}	may be converted to thermal column
Hydraulic tube	1	(5)	1.5 od.	1.6×10^{14}	in core position
Pneumatic tubes	2	(6)	1.5 od.	1×10^{13}	in reflector position
Vertical tube in reflector	1	(7)	3 diam.	1×10^{12}	
In core positions	variable max. 3	(8)	3 × 3 6 × 6	max. 2×10^{14} max. 4×10^{14}	access holes, so that loops may be installed access holes, so that loops may be installed
Channels in Be-elements	10		2 diam.	max. 2×10^{14}	for isotope production
Pool side facility	1	(9)	32 × 48	1×10^{14}	on flat side of tank
Dry gamma facility	1		24 × 24		in storage pool
Hot cell	1	(10)	120 × 144 × 132		2 sub-cells above canal pool

55. Heat exchangers	Horizontal tube and shell type, one installed for 6.67 MW, three required for 20 MW Capacity per exchanger 22.8 × 10⁶ BTU/hr	58. Cooling system safety	Opening tank to pool water for nat. convection cooling; spray system above core supplied from process water; anti-syphon loop in primary circuit
56. Coolant losses & purification	Purification by filters and a 80 gpm demineraliser	59. Fuel failure detection	Monitoring for fission products in primary coolant
57. Decomposition & recombination	50 gpm degasifier, venting of decomposition products to off-gas system		



FLOW DIAGRAM REACTOR SAFARI - 1

REMARKS

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1) Nuclear Power, January 1963