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EXPERIMENTAL 5 Mw THERMAL CONVECTION MOLTEN SALT REACTOR

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Abstract

A preliminary study has been made of an experimental 5 Mw thermal convection molten salt reactor. This reactor can be converted, after a period of low power operation, to a 50 Mw pilot power plant by adding a fuel pump, a larger sodium pump, and a turbo generator with associated equipment.

Introduction

Based on the history of other reactor types, the development and demonstration of the molten salt power reactor concept will require the operation of a small experimental reactor and a medium sized pilot plant. The simplest and most reliable experimental reactor system appears to be a thermal convection reactor. The chief disadvantages of the natural convection system - increased fuel volume and larger heat exchangers are not major factors in a five Mw reactor.

By adding a fuel pump to the 5 Mw reactor, it is possible to increase the capacity of the fuel system from 5 to 50 Mw. This, of course, must be accompanied by a corresponding increase in the capacity of the heat dump. It is thus possible to build one reactor that will serve successively as a small experimental reactor and a pilot plant.

Description of Reactor

Fig. 1 shows an elevation of the reactor plant; Fig. 2 is a plan view. The dimensions and operating conditions for 5 and 50 Mw operation are given in Table I. The reactor is five feet in diameter with a 6 inch thick blanket surrounding the core (see Appendix A). Provisions are made to connect the blanket and fuel regions so that the reactor can be operated as a one region reactor.

The 5 Mw reactor is inherently simple and reliable and requires no development of components. No fuel or blanket pumps are required. The sodium pump is a standard PK pump.

In order to provide for future 50 Mw operation of the system, it is necessary that the fuel expansion tank be so designed that a sump type fuel pump can be installed in it and the sodium lines leading to the heat exchanger be sized to handle the flow required for 50 Mw operation.

The 5 Mw reactor would serve the following purposes:

1. Demonstrate the continuing operation of a molten salt reactor.
2. Provide in-pile corrosion data. (This could be done by inserting removable samples in both the hot and cold legs.)
3. Develop and demonstrate remote maintenance procedures.
4. By replacing the air heat dump with a steam heat dump it could be used to demonstrate sodium to steam heat transfer.

Conversion to 50 Mw operation

When the above has been accomplished, the system can be converted to 50 Mw operation and operated as a pilot power plant. Although this plant would not be identical to the reference design plant, there would be enough points of similarity, especially in control, corrosion, and maintenance problems so that successful operation would lead directly to the design and construction of a large power plant.

Conversion to 50 Mw Operation (continued)

The only modification required to the fuel circuit is the installation of a sump type fuel pump in the fuel expansion tank. The fuel to sodium heat exchanger designed for the 5 Mw operation would be satisfactory for 50 Mw operation, because of the reduction in the fuel film resistance in going from laminar flow at the lower power to turbulent flow at the higher power.

A complete analysis of the blanket circuit has not been made, however, rough calculations show the possibility of designing a thermal convection blanket circuit that could be used at both power levels. If this turns out to be impractical, a blanket pump can be installed for 50 Mw operation.

The sodium system is cut at the points shown in Figs. 1 and 2 and a new system consisting of a 10,000 gpm pump and sodium to steam heat exchanger is installed.

A turbo-generator and associated equipment is also installed to complete the pilot plant.

Cost Estimate

Table II shows a rough cost estimate, of approximately $10,000,000 for the construction of the 5 Mw plant. For approximately $10,000,000 additional, this plant could be converted to the 50 Mw size, as shown in Table III.

No attempt was made in this limited study to optimize either the 5 or 50 Mw plants.

Further study would undoubtedly be profitable. The 5 and 50 Mw power levels were chosen arbitrarily and it is quite possible that a different choice is preferable. A number of problems remain which were not investigated but which appear to be capable of solution. Among these are: 1) the design of the blanket circuit, 2) the method of removing fission gas, 3) the design of the 5 Mw heat dump, and 4) the design of the steam system.

Acknowledgements

Acknowledgement is made to L. G. Alexander for selecting the Uranium concentration and core size and to G. D. Whitman and M. E. Lackey for consultation on the cost estimate and heat transfer, respectively.

Table I

Power Output	Mw (thermal)	5.19		50 Mw
Reactor				
Core Size	ft		5	
Blanket Thickness	ft		1/2	
Power Density	watts/cc	1.5		15
Fuel Pump		none		Sump type
Riser and Downcomer Dia.	in		10"	
Height of Fuel Heat Exchanger (above reactor centerline)	ft		20	
Fuel Velocity in Riser	ft/sec	.64		6.17
Fuel Head	ft	.39		12.66
Fuel Volume	ft^3		120	
Fuel Flow	gal/min	158		1515
Sodium Flow	gal/min	578		9250
Sodium Pump		PK		
Heat Exchanger				
Tube I.D.	in		.6	
Tube Wall Thickness	in		.050	
Tube Length	ft		20	
No. of Tubes			250	
Shell O. Dia.	in		18	
Shell Wall Thickness	in		.375	
Fuel Temp. in	°F	1210		1210
Fuel Temp. out	°F	1010		1010
Na Temp. in	°F	850		850
Na Temp. out	°F	1100		1000

Table II

Cost Estimate - 5 Mw Experimental Reactor

A.	Engineering, Design and Inspection		$ 3,000,000
B.	Construction Costs		
	1. Land and Land Rights		
	2. Improvement and Land		750,000
	3. Buildings		
	Reactor Plant and Auxiliary		
	Reactor Structure		
	(containment and shielding)	$ 800,000	
	Instruments and Control	500,000	
	Reactor System	480,000	
	Fuel	480,000	
	Blanket	60,000	
	Sodium	162,000	
	Maintenance	500,000	
	Auxiliaries	200,000	
	Inventories	416,000	
	Building	2,000,000	
	Sub-Total		5,118,000
	Heat Removal		500,000
C.	Contingency at 10%		1,000,000
D.	Total		$10,368,000

Table III

Additional Cost to Convert to 50 Mw

1.	Fuel Pump	$ 500,000
2.	Blanket Pump	100,000
3.	Na Pump	200,000
4.	Blanket Na Pump	50,000
5.	Additional Instrumentation	500,000
6.	Steam and Electrical System	4,000,000
7.	Spare Parts	500,000
8.	Installation	1,000,000
9.	Engineering	2,000,000
10.	Contingency	1,000,000
	TOTAL	$9,950,000

Appendix A

Selection of Uranium Concentration and Core Size

The design variables in the Reference Design Reactor, described in reference 1, which it is desirable to match in a test reactor are, in order of their importance:

1. power density in fuel,
2. heat flux and delta T in exchanger,
3. uranium concentration,
4. radiation level at pump,
5. power density in core vessel, and
6. thorium concentration.

The design of the test reactor will require a compromise among these variables. It seems desirable to sacrifice thorium concentration first. Using RDR-1 data for a basis, an eight foot core with 1% ThF_4 will go critical at a U-235 concentration of 12.5 x 10^{19} atoms/cc. This concentration will render a five foot core critical when no thorium is present, and the critical mass will be about 85 kg. A concentration of 36 x 10^{19} atoms/cc would make a four foot core critical, with a critical mass of about 130 kg.

A blanket three to six inches thick should suffice to test the reliability of the core vessel. In the case of a six inch blanket on a five foot core, if the core vessel failed and the system were operated as a one region reactor, the critical concentration would fall to about 4 x 10^{19}, and the critical mass would be about 50 kg. Adding about 3/8 mole per cent thorium would raise the critical concentration back to 12 x 10^{19}, and the critical mass to 140 kg.

References

1. "Molten Salt Reactor Program"; Status Report, ORNL 58-5-3

2. F. E. Romie and B. W. Kinyon, "A Molten Salt Natural Convection Reactor System", ORNL 58-2-46

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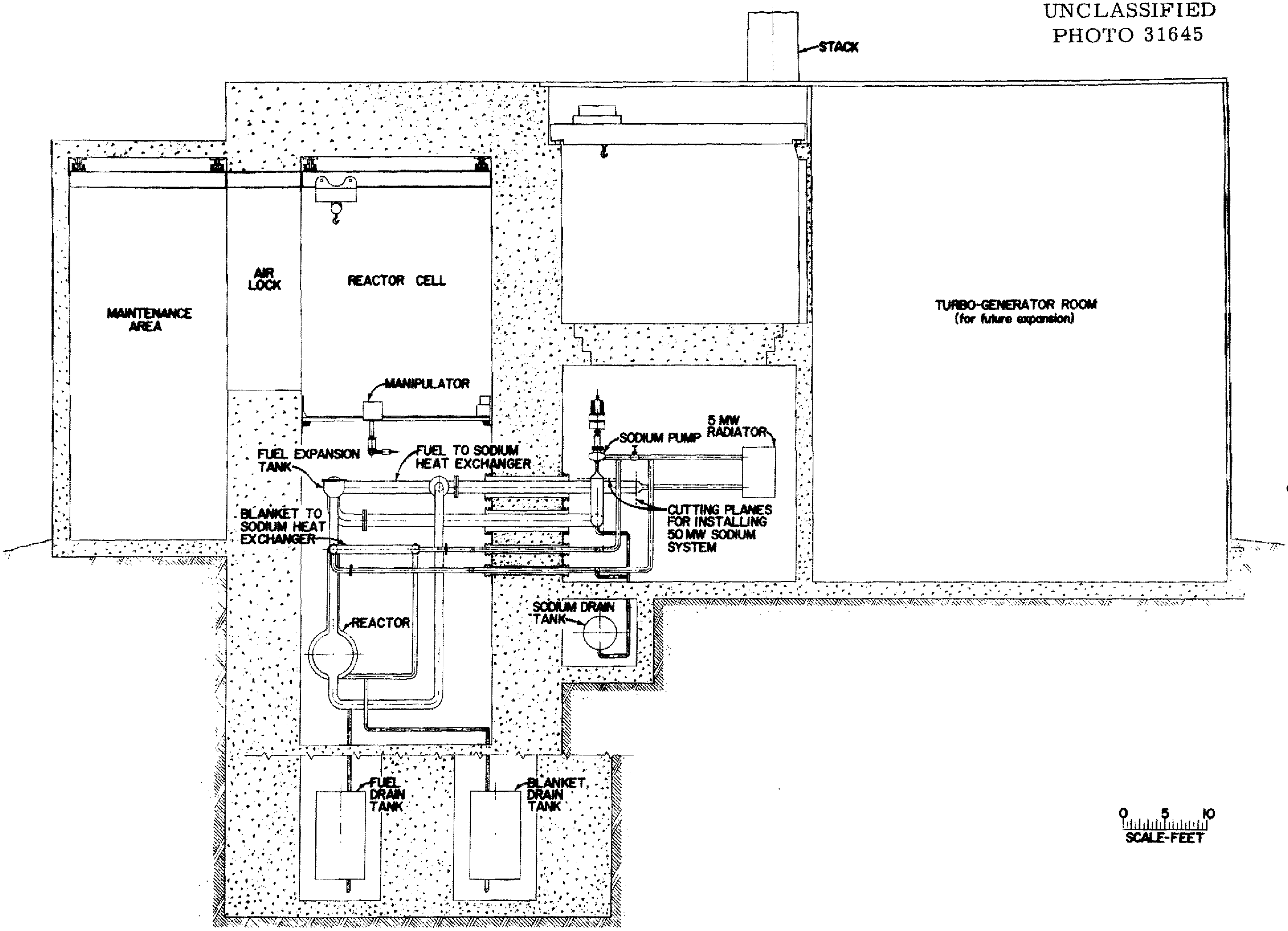

FIG.I ELEVATION OF 5 MW EXPERIMENTAL MOLTEN SALT REACTOR PLANT

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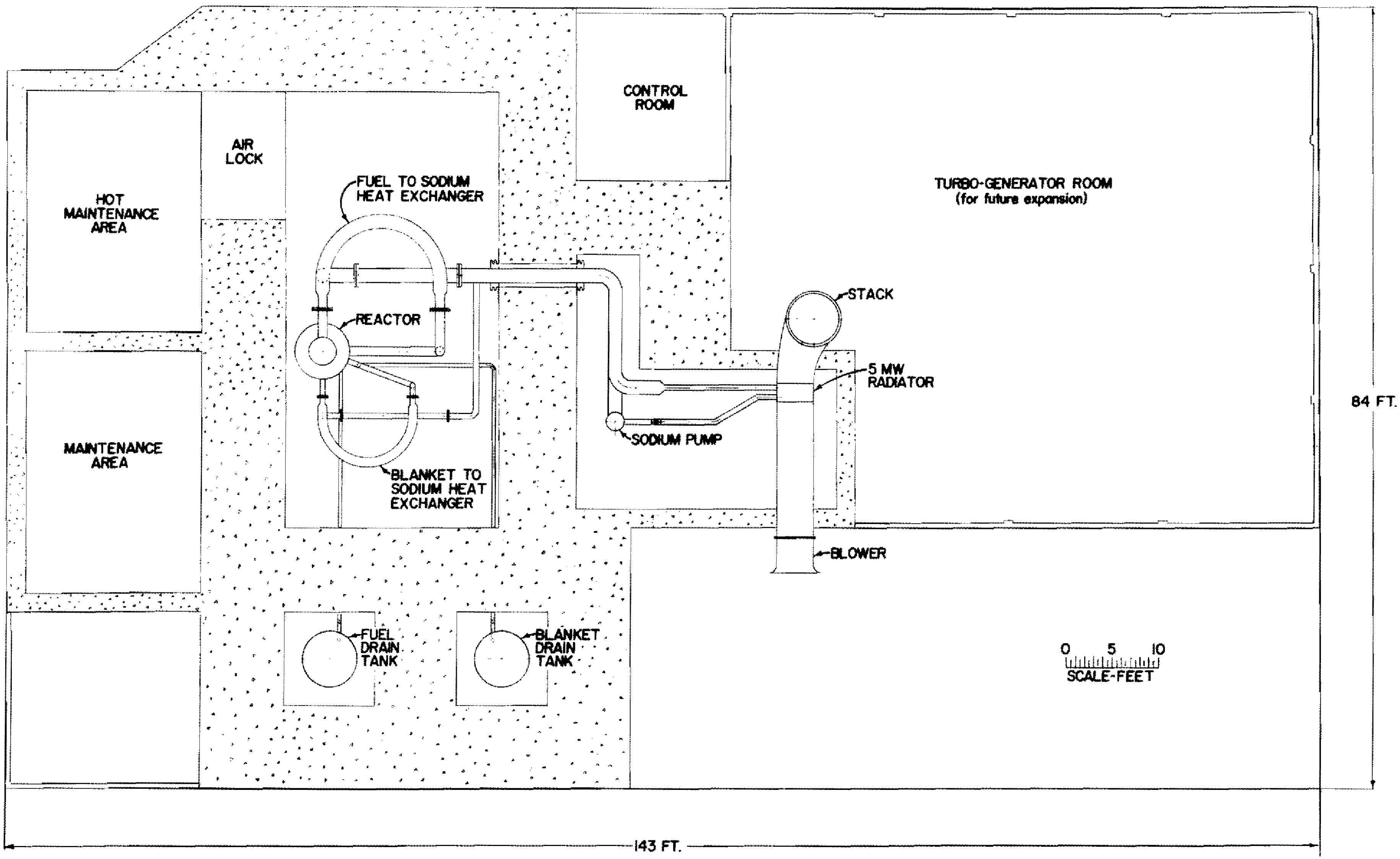

FIG. II PLAN VIEW OF 5 MW EXPERIMENTAL MOLTEN SALT REACTOR PLANT

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