SP-100 PROGRAM

SPACE REACTOR SYSTEM AND SUBSYSTEM INVESTIGATIONS

**COST AND SCHEDULE ESTIMATES
FOR
REACTOR AND SHIELD SUBSYSTEMS
TECHNOLOGY DEVELOPMENT**

*Prepared for
the United States Department of Energy
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Rockwell International
Energy Systems Group

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1.0 INTRODUCTION

This report presents cost and schedule estimates of the technology development for reactor and shielding subsystems of a 100-kWe class space reactor electric system. The technology development for the reactor and shielding subsystems can be organized as shown in Figure 1. The subsystems technology development (which includes reactor and shield subsystems ground testing) is supported by materials and processes development and component development.

The cost and schedule estimates were based on refinements of the information presented in Ref. 1. For the purpose of this estimate, seven generic types of reactor subsystems were used:

- 1) Uranium-zirconium hydride, NaK-cooled thermal reactor
- 2) Lithium-cooled, refractory-clad fast reactor
- 3) Na- or K-cooled fast reactor
- 4) In-core thermionic reactor
- 5) Inert gas-cooled particle fuel reactor
- 6) Inert gas-cooled metal-clad fast reactor
- 7) Heat pipe-cooled fast reactor

Also, three levels of technology were included for each of the generic types of reactor subsystem: current, improved, and advanced (see Ref. 1). The data in this report encompass all these technology levels.

The shielding subsystem uses both gamma (heavy-metal) and neutron (hydrogenous material) shields. The shields considered in this report would be used in conjunction with unmanned payloads. The shielding subsystem design varies with the type of reactor used and with the separation distance between the reactor and the payload. For the purposes of this report, ranges on costs and schedule for the shielding subsystem encompass the ranges on the various shield design parameters which occur.

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1. ESG-DOE-13398, "Space Reactor Electric Systems, Subsystem Technology Assessment," Rockwell International, Energy Systems Group, 29 March 1983.

Figure 1. Hierarchy of the Reactor and Shielding Subsystems
Technology Development

The cost and schedule estimates presented in this report are for the reactor and shielding subsystems technology development. The estimates include subsystem development and subsystem ground demonstration tests. They encompass the supporting technology development as well, primarily that for the materials and processes development and for component development.

Technology development costs grouped by reactor type (for various technology levels) are summarized in Figure 2. Also shown are the estimated development times required through completion of the reactor and shield subsystems ground demonstration testing and estimates of the reactor lifetime. The reactor lifetimes are estimates of what could be reasonably achieved within the development times shown. Additional development costs and a lengthened schedule would be required to extend reactor lifetimes. The ranges shown for both cost and schedule are based on uncertainties that could occur in any projected technology development effort.

*THROUGH SUBSYSTEM GROUND DEMONSTRATION TEST ONLY

Figure 2. Summary of Reactor and Shield Technology Development Cost and Schedule

2.0 METHOD OF APPROACH

The cost and schedule estimates for each reactor type and technology level were determined in a method similar to that of Ref. 1. The data base was used in a slightly different manner to break down the pertinent costs in this report. The costs and associated schedules presented are for the reactor and shielding subsystems technology development phase of a total development program. Figure 3 shows such a total program and depicts what portion of the program is included in subsystem technology development. The costs and schedules in this report do not include qualification or acceptance phase activities. This is the basic difference between the data presented in this report and the data in Ref. 1. The technology development phase includes concept development, critical technology development, and subsystem ground demonstration test. The qualification phase includes ground testing of a complete integrated system. The acceptance phase includes all activities associated with the flight system including both ground and orbital tests.

Cost estimates were also segregated by fiscal year. The expenditure rate was derived from actual expenditures experienced during development of the SNAP-8 and SNAP-2/10A reactor and shielding subsystems. The expenditure rate that was found to apply to both of these programs is shown in Figure 4. This curve was then used to estimate the development cost as a function of fiscal year for each type of reactor and shield subsystem combination.

Figure 3. Typical Total Development Program for Space Reactor Electric Systems

Figure 4. Normalized Development Cost versus Schedule for Reactor and Shielding Subsystem Technology Development

3.0 RESULTS

The technology development cost and schedule for the reactor and shield subsystems were estimated for each of the concepts and the various technology levels. A typical detailed result is shown in Figure 5. Both the cumulative cost and cost for each fiscal year are presented in this figure. The uncertainty ranges represent the band that might be expected for development typical in high technology programs.

The cost data are presented in Table 1 for each of the reactor and shielding subsystems and for the various technology levels. The cost information is in mid-FY 1983 dollars. These cost estimates do not include costs for test facilities or major manufacturing facilities, aerospace safety programs, or any system level activities.

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Figure 5. Example of Reactor and Shielding Subsystems Technology Development Cost Detail (Through Subsystem Ground Demonstration Testing)

TABLE 1

REACTOR AND SHIELD TECHNOLOGY DEVELOPMENT COST AND SCHEDULE

REACTOR CONCEPT	REACTOR OUTLET TEMPERATURE (K)	TECHNOLOGY DEVELOPMENT TIME (years)	ESTIMATED REACTOR LIFETIME (years)	REACTOR AND SHIELD SUBSYSTEMS DEVELOPMENT COSTS (Millions of 1983 dollars)															
				TOTAL*	FY 84	FY 85	FY 86	FY 87	FY 88	FY 89	FY 90	FY 91	FY 92	FY 93	FY 94	FY 95	FY 96	FY 97	FY 98
1 URANIUM ZIRCONIUM HYDRIDE NaK COOLED THERMAL REACTOR																			
A SNAP 8 TECHNOLOGY	920	4 5	5	55 95	5	15	25-35	10-25	0-10										
B IMPROVED HYDROGEN BARRIER	1000	7-8½	7	190 275	5	15	25-30	45-50	45-65	30-50	15-35	0-25	0 10						
C SEPARATE FUEL AND MODERA TOR COOLING	1100	11 13	7	330-450	5	10	15	25	35-40	50-60	55-70	45-65	35-55	25-45	15-35	0-25	0-15		
2 LI COOLED REFRACTORY CLAD FAST REACTOR																			
A INITIAL VERSION	1350	7 9	2	320-440	5	20	35-50	60-90	75 55	50-85	30-65	0-45	0-30						
B INTERMEDIATE VERSION	1400	9 11	3	350-460	5	15	25-30	40 50	60 75	70-80	50-85	35-65	20-50	0-35	0-20				
C ADDITIVE FUEL	1500	11 13	5	400 525	5	10	20	30	40-50	60-70	70-80	55 75	40-65	30-50	20-40	0-30	0-20		
3 NaK OR K COOLED FAST REACTOR																			
A NaK OR K SS CLAD UO ₂ FUEL	920	5 6	7	85 145	5	15	30-35	25-45	10-30	0-15									
B NaK OR K SUPERALLOY CLAD UO ₂ FUEL	1100	7 8½	7	190 290	5	15	30	50	45-70	30-55	15-40	0-25	0-10						
C BOILING K COOLED SS CLAD UO ₂ FUEL	1100	6 8	2	200 290	5	15	35-50	55-65	45-70	20-55	0-35	0-20							
D BOILING K COOLED REFRACTORY CLAD UO ₂ FUEL	1365	9 11	3	390 510	5	15	25-30	45-55	65-85	75-90	60-85	40-65	25-50	0-40	0-25				
4 IN CORE THERMIONIC REACTOR																			
A CURRENT TECHNOLOGY CON VERTER UO ₂ FUEL	1800	5 7	1	135 205	5	20	30-50	40 55	20-45	0-30	0-20								
B OXYGENATED CONVERTER UO ₂ Mo FOIL FUEL	1800	7 9	2	245 350	5	15	30-40	50-65	60 75	40-70	20-50	0-35	0-20						
C ADVANCED CONVERTER UO ₂ Mo CERMET FUEL Mo COLLECTOR	1800	9 11	5	325-425	5	10	20-25	35-45	55-70	65-75	50-70	35-60	20-45	0-30	0-20				
D Zr C COATED PARTICLE FUEL SUBLIMED Mo COLLECTOR	1800	11 13	7	425 520	5	10	15-20	25-35	40-55	55-75	70-80	60-80	45-70	30-50	20-40	0-30	0-20		
5 INERT GAS COOLED PARTICLE FUEL REACTOR																			
A GRAPHITE BLOCK FUEL	1200	5-6	3	60 95	5	10	20	15-30	10-20	0-10									
B Zr C COATED PARTICLE FUEL IN GRAPHITE BLOCK	1300	6 8	5	200 290	5	20	30-50	55-65	40-70	20-55	0-35	0-20							
C FIXED BED REACTOR (FBR) PARTICLE FUEL INCONEL FRIT	1100	6-8	3	200 300	5	20	35-50	60-65	40-70	20-55	0-35	0-20							
D FBR PARTICLE FUEL HIGH TEMPERATURE FRIT	1300	11 13	5	365 590	5	10	15	25-30	40-50	50-65	60-75	45-70	35-60	30-50	20-40	0-30	0-20		
6 INERT GAS COOLED METAL CLAD FAST REACTOR																			
A BeO/UO ₂ FUEL HOSTALLOY X CLAD	920	5-6	1	70 120	5	10	25-30	20-40	10-25	0-10									
B UO ₂ FUEL REFRACTORY CLAD	1300	7 9	2	325-450	5	20	40-50	65-90	80-95	50-90	30-60	0-45	0-30						
C IMPROVED UC UN OR CERMET FUEL	1500	9 11	3	350-480	5	15	25-30	40-50	60-75	70-85	50-80	35-65	20-50	0-35	0-20				
7 HEAT PIPE COOLED FAST REACTOR																			
A UO ₂ FUEL Na HEAT PIPES	1100	5 7	2	190 290	5	20-35	45-70	55-80	25-70	0-45	0-25								
B UO ₂ FUEL Mo Re CLAD Li HEAT PIPES	1500	8 10	2	325-440	5	15	30-35	50-65	70-85	60-85	40-70	25-55	0-40	0-25					
C IMPROVED UO ₂ FUEL Mo Re CLAD Li HEAT PIPES	1500	11 13	4	350-460	5	10	15	25-30	40-45	50-60	60-70	50-70	35-55	25-45	15-35	0-25	0-15		
D UC ZrC PARTICLE FUEL Mo Re CLAD Li HEAT PIPES	1500	12 14	4	390 510	5	10	15	25	35-40	45-50	60-65	55-75	45-65	35-55	25-45	20-35	0-25	0-15	

*HIGHS AND LOWS MAY NOT ADD TO TOTALS SHOWN DUE TO DETAILS OF MODEL