DOE/SF/76024--730

PLBR File No. PRJ E 2.2

Rockwell International Atomics International Division	SUPPORTING DOCUMENT		NUMBER N254TI410004	REV LTR/CHG NO. SEE SUMMARY OF CHG
			DOCUMENT TYPE Technical Information	
PROGRAM TITLE Large Systems Improvement Studies			KEY NOUNS Decay Heat, Cost	
DOCUMENT TITLE Decay-Heat-Removal Systems, Arrangements and Costs			ORIGINAL ISSUE DATE	
PREPARED BY/DATE R. H. Riedel <i>Structure for model</i>			DEPT 731	MAIL ADDR JB10
IR&D PROGRAM? YES ☐ NO ☒ IF YES, ENTER TPA NO.			GO NO. 09282	S/A NO. 40005
APPROVALS <i>Ch. Sayles</i>			PAGE 1 OF TOTAL PAGES 78 REL. DATE 9-12-78 SW	
DATE 8/31/78 9-14-78			SECURITY CLASSIFICATION (CHECK ONE BOX ONLY)	
			DOE DOD UNCL ☒ ☐ CONF. ☐ ☐ SECRET ☐ ☐	
			(CHECK ONE BOX ONLY) RESTRICTED DATA ☐ DEFENSE INFO. ☐	
			AUTHORIZED CLASSIFIER DATE	
DISTRIBUTION			ABSTRACT	
*	NAME	MAIL ADDR		
*	J. Auleta (5)	JB10	<p>A set of five backup decay heat removal candidate schemes has been studied in sufficient depth to create conceptual arrangements, P&I diagrams, and equipment lists for each.</p> <p>A summary of the attributes of each system arrangement is developed.</p> <p>System costs were also developed but do not show significant differences.</p> <p><i>ATD3-76SF76026</i></p> <p>DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED</p>	
*	J. Brunings	LB02		
*	D. Burgess	LB11		
*	E. Baumeister	JB10		
*	G. Drucker	JB05		
*	J. Hartung	LB02		
*	R. Lancet	LB02		
*	J. McDonald	JB11		
*	E. Moody	LB02		
*	P. Murphy (2)	LA38		
*	P. Novacek	JB05		
*	R. Ohlenkamp	JB05		
*	R. Riedel	JB10		
*	C. Sayles (12)	LB02		
*	H. Sletten	LB02		
*	L. Stabiński	JB05		
*	S. Stachura	JB10		
*	F. Williams	LB02		
*	L. Pidcoke	LB35		
*	ASU-PLBR	LB11		

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

RESERVED FOR PROPRIETARY/LEGAL NOTICES

THIS REPORT MAY NOT BE PUBLISHED WITHOUT THE APPROVAL OF THE PATENT BRANCH, ERDA

This report was prepared as an account of work sponsored by the United States Government. Neither the U. S. Government, nor any of its employees nor any of its contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

731-Y-6/rak/abg

* COMPLETE DOCUMENT
NO ASTERISK, TITLE PAGE/SUMMARY
OF CHANGE PAGE ONLY

03-824/26 8-3 LTR. DATED 9/29/78

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

CONTENTS

	<u>Page</u>
1.0 INTRODUCTION.....	3
2.0 CONCLUSIONS AND RECOMMENDATIONS.....	5
3.0 SYSTEMS DESCRIPTIONS.....	7
3.1 SGACS-1.....	7
3.2 SGACS-2.....	11
3.3 SGACS-3.....	15
3.4 SGACS-4.....	18
3.5 IRACS-1.....	21
4.0 TECHNICAL UNCERTAINTIES AND RISKS.....	24
5.0 STARTUP, TESTING, AND MAINTENANCE.....	31
6.0 COSTS.....	36
7.0 REFERENCES.....	40
APPENDIX A.....	A-1
APPENDIX B.....	B-1
APPENDIX C.....	C-1

1.0 INTRODUCTION

The study presented herein is a continuation of selected portions of the Trade Study of Alternate Backup Decay Heat Removal System Concepts for the Large Systems Improvement Studies reported in N254TI410001 and N254TI400001. Reliability aspects are documented in N254TI410003. Safety and licensing aspects are documented in N254TI410005.

As a result of previous studies on the subject of decay heat removal for a 2600 Mwt (thermal) loop-type LMFBR plant, a small group of candidate concepts for the backup system was identified for further evaluation. The backup system is the second of three levels of decay heat removal paths which are now envisioned for the plant: 1) the normal system using the main plant condenser and which bypasses the turbine through desuperheating valves, 2) the backup decay heat removal system (subject of this study), and 3) a diverse system which extracts heat directly from the reactor cavity.

Four of the alternates studied herein are termed Steam Generator Auxiliary Cooling Systems (SGACS) in that they rely on using the steam generators to extract heat from the sodium. One system is termed Intermediate Reactor Auxiliary Cooling System (IRACS) because it is piped from the intermediate sodium system.

A brief description of the various systems is as follows: (see Figures 1 through 5)

- 1) SGACS-1, an airblast steam condenser and auxiliary feed-water system is piped across the steam generators of each loop.
- 2) SGACS-2, steam is vented to a cooling tower pond. Hardened condensate storage tanks provide feedwater.
- 3) SGACS-3, a spray condenser takes the place of the air-cooled condensers in SGACS-1 and a heat exchanger transfers decay heat to the emergency cooling water system.

- 4) SGACS-4, this concept is similar to SGACS-3 except that emergency cooling water operates directly on a surface condenser.
- 5) IRACS-1, an airblast heat exchanger is piped across the intermediate sodium system of each loop.

A major thrust of this study was to provide sufficient detail for these systems so that pipe, valve, and component sizes could be developed with sufficient accuracy so that rough layouts could be envisioned. This permitted the generation of equipment and materials lists for reliability (see N2541TI000003) and cost studies. The conceptual P&I diagrams (Figures 1 through 5) are also useful for the study of startup and operation procedures and can form the basis for further dynamic analysis.

2.0 CONCLUSIONS AND RECOMMENDATIONS

2.1 CONCLUSIONS

An overall estimate of the systems costs and a summary of characteristics is presented in Table 1.

2.1.1 Costs

Based on the level of effort available from this task to study five different concepts, only a ranging type cost estimate could be made. These costs are estimated to be accurate within about 20%. Thus, it is concluded that there is no significant cost difference among the systems.

2.2 RECOMMENDATIONS

The selected system should be dynamically modeled to verify the adequacy of its heat rejection capability, the size of its components, and acceptable limitation of plant component temperature transients.

An evaluation of the interrelationship of seismic design of the plant and auxiliary buildings, tornado hardening requirements, and any associated NRC criteria which may be imposed along these lines should be undertaken. The object of such a study is to establish minimum building reinforcing requirements independent of any superimposed requirements of the decay heat removal system so that a more accurate cost penalty can be charged against the decay heat removal system.

TABLE 1
DECAY HEAT REMOVAL SYSTEMS CHARACTERISTICS

	SGACS-1 Air-Cooled Condenser 3 per Plant	SGACS-2 Steam Vent 3 per Plant	SGACS-3 Jet Condenser 1 per Plant	SGACS-4 Surface Condenser 1 per Plant	IRACS-1 Sodium Cooler 3 per Plant
Total Installed Capacity - % of Full Power	1.2	1.2	0.8	0.8	1.2
Cost - Dollars	14×10^6	12×10^6	13×10^6	12.5×10^6	14×10^6
Snubbed Pipe Length - ft	2,490	3,260	4,485	4,185	990
Number of Valves	69	34	52	38	18
Number of Pumps/Blowers	9	5	6	2	0
Start-up Actions	30	25	29	17	18
Active Control Loops	12	12	6	6	3

3.0 SYSTEMS DESCRIPTIONS

Based on bulk sodium upset temperature limits in Table III-1 of Reference 9 (1100°F maximum), a decay heat removal capacity of 0.4% per loop was chosen. For the SGACS-3 and SGACS-4 concepts, one condenser serves all three heat transport loops and is sized for 0.8% of full power. When the terms full capacity or half capacity are used in the text to follow, reference is made to 0.8% and 0.4% of 2600 MWt.

3.1 STEAM GENERATOR AUXILIARY COOLING SYSTEM CONCEPT SGACS-1 AIR-COOLED CONDENSER (FIGURE 1)

This concept provides the first alternate heat sink for decay heat removal in the event that the normal feedwater supply becomes unavailable or the steam desuperheating and condensing train becomes inoperative. In that event, the steam generator module isolation valves are closed, and the SGACS-1 is automatically activated by the plant protection system through the valve actuation sequence described below. This is initiated by a sodium-to-feedwater flow ratio mismatch or by a loss of condenser vacuum.

The system incorporates a forced draft air-cooled condenser, hot water storage tank, steam conditioning valve, feedwater pump, and associated valves and controls (see Figure 1). The SGACS-1 is tornado missile hardened and designated Seismic Category I to survive a safe shutdown earthquake. It is designed to meet the requirements of ASME Code Section III, Class 3. A half capacity system is supplied for each of the three loops. (The plant operates at 50% power with two loops.)

As an engineered safety function, it must have access to ancillary safety grade systems in order to function in the event the corresponding nonsafety grade plant systems fail, i.e., the emergency compressed air supply for valve actuation, the emergency chilled water system for pump and pump driver oil cooling, the emergency diesel generators for motor

SGACS-1

FIG. 1

power, and a Class 1E power supply for the controllers. Each of the three SGACS loops is serviced by a separate one of the three emergency diesel generators.

Steam is processed in the same way that it is in the normal decay heat removal system except that a high pressure air-cooled condenser is substituted for the subatmospheric water-cooled turbine generator main condenser, and thus no feedwater heaters are required. Steam pressure and temperature are reduced in the steam conditioning valve to provide saturated steam to the air-cooled condenser. This valve incorporates multifiuted pressure breakdown passages and injects desuperheating water in the lower pressure high velocity flow area. The pressure signal used for modulating the pressure drop is taken upstream of the valve, and thus steam generator pressure is controlled. Desuperheating water is taken from the auxiliary feedwater pump and modulated by a temperature signal taken downstream of the conditioning valve.

The air-cooled condenser in each of the three decay heat removal loops is made up of two parallel 50% units, each of which has its own variable speed fan drive and motor-driven inlet and outlet flow control louvers. Therefore, a loss of one condenser unit can only degrade the capacity of the loop by a maximum of 50%. Both condenser units are insulated throughout, and special sealing arrangements are provided for the air flow control louvers to minimize heat losses and to help maintain an acceptable standby temperature with the small steam leakage expected through the steam conditioning valve during normal plant operations. When SGACS is active, the fan motors and flow control louvers will be modulated by reference to a condensed water tank pressure to maintain 470°F input to the hot water storage tank. This temperature is consistent with the normal feedwater temperature. Redundant vents are supplied to sweep out noncondensibles by periodic bleed during standby.

Hot water storage is in a 9,000-gal carbon steel tank, insulated and trace heated to maintain a water temperature of 470°F. It is sized to allow refilling the entire system with water at the end of the decay

heat removal cycle when hot water is being recirculated. A level gage and connections to the normal treated water supply are provided so that water level variations due to valve leakage during standby can be accommodated. (The supply is not seismic or tornado hardened.)

The pump has a recirculation valve in the discharge line which bypasses approximately 20% of pump design flow when demand drops below the level which assures maintenance of acceptable temperature. The bypass valve is opened when the pump discharge pressure sensor indicates that pressure is approaching shutoff head. A check valve in the discharge line prevents reverse flow during startup or any operating mode changes. An automatic isolation valve in the discharge line is held closed during normal standby and is opened as required during startup and operation. The flow control valve is modulated to provide a constant ratio of sodium to feedwater flow.

During normal standby conditions, the auxiliary feedwater pump discharge valve, the pressure breakdown pintle of the steam conditioning valve, and the desuperheating water valve are held closed. Both non-condensibles vent valves and the pump recirculating valve are also closed. All air-cooled condenser louvers are shut. Leakage steam keeps the air-cooled condenser bundle hot. The noncondensibles vent valves are periodically activated, and the hot water tank level is maintained at the required level by operator action. This water level will change because of leakage of steam through the steam conditioning valve or water through the auxiliary feedwater isolation valves. Water temperature is maintained by tank insulation and trace heating. System pressure is limited by the tank ullage pressure relief valve.

Upon receipt of a sodium/feedwater flow ratio mismatch or high condenser pressure signal by the plant protection system, the steam generator modules for all operating loops are isolated and the corresponding SGACS activated. The auxiliary feedwater pump is started for each loop and its isolation valve opened, the steam conditioning valve

is enabled and begins to regulate steam generator pressure, and the air-cooled condenser is enabled. When pump pressure is high enough to provide feedwater, its check valve opens and the flow control valve accepts its function.

As the steam generator sodium inlet temperature is reduced, the feedwater flow control algorithm is changed to avoid steam generator flooding, and the pressure breakdown valve control algorithm is modified at about 650°F steam temperature to prevent shutoff. However, the last part of a long-term heat removal cycle will involve recirculating hot water throughout the system.

Layout of the equipment is essentially that shown in Reference 1 with only minor changes as shown in Reference 7. Although explicit piping layouts for this system were not made, it was possible to estimate lengths of piping required by reference to the drawings of Reference 1. The materials list so obtained (Appendix A) was input to Pricing and Estimating for costing.

3.2 STEAM GENERATOR AUXILIARY COOLING CONCEPT SGACS-2 STEAM VENTING (FIGURE 2)

This concept utilizes a large stored volume of conditioned water to allow once-through venting of steam. The existing condensate storage tanks (total volume of approximately 750,000 gallons) can be used for this purpose if they are tornado missile hardened and constructed to the requirements of Seismic Category I and ASME Section III, Class 3. This would provide about 2000 MWh of heat capacity without water replenishment. If the system is activated immediately on reactor trip, water replenishment would be required in 96 hours (assuming steam venting matches reactor decay power). If the system is activated 10 days after reactor trip, water replenishment would be required after 335 hours. With continuous replenishment at about 40 gpm, the system could operate indefinitely even if activated immediately after reactor trip. Therefore,

SGACS-2

FIG. 2

this system requires the feedwater treatment equipment to be sized at 40 gpm minimum, tornado hardened, and constructed to Seismic Category I and ASME Section III, Class 3 requirements.

A nonsafety related system feature is incorporated to prevent generation of a steam plume during venting. This is accomplished by venting below the surface of the plant cooling tower pond. Steam is rapidly condensed and heats up the pond water. Cooling tower operation dissipates the heat to the atmosphere. Inasmuch as the primary function of reactor heat dissipation is not affected by failure of the cooling tower or pond integrity, these will be constructed to commercial standards.

The system consists of the two condensate storage tanks, the water conditioning system, and a redundant pair of condensate water pumps which service all three loops. Each loop has its own desuperheater, hotwell, redundant pair of feedwater pumps, steam nozzle array, and associated valves and controls (see Figure 2). The SGACS-2 is tornado missile hardened and designated Safety Category I to survive a safe shutdown earthquake. It is designed to meet the requirements of ASME Code Section III, Class 3. The system will make use of non-safety grade plant equipment to inhibit a steam plume, i.e., the cooling towers and pond.

The ancillary safety grade systems which are required are: the emergency compressed air supply for valve actuation, the emergency chilled water system for pump and pump driver oil cooling, the emergency diesel generators for motor power, and a Class 1E power supply for the controllers. The motor driven feedwater pump for each system is serviced by a separate one of the three emergency diesel generators. The motor driven condensate pump can be switched to any one of the emergency diesels.

In this system, the steam produced by the steam generators is simply discarded. Required feedwater is taken from a large stored volume which accommodates the early high flow requirements plus a

continuous makeup stream from the water treatment system which accommodates the long-term requirements. Steam generator pressure is maintained by a steam conditioning valve which also incorporates a desuperheating spray just downstream of the pressure breakdown pintle. The flash tank size (3,000 gal) is judged to allow adequate deintrainment time (>30 min) at the maximum required feedwater rate and also provides a local reservoir to permit short-term independence from the condensate storage tanks. This tank is constructed of carbon steel, is insulated, and maintains the feedwater at 470°F during standby and in operation through modulation of the steam vent valve to maintain 520 psia tank pressure. The tank water level is maintained during operation by injecting excess desuperheating water in the steam conditioning valve. During standby, leakage or condensing water can either be drained or vented to the cooling tower pond. The steam lines are maintained hot either by leakage or bypass steam.

Upon receipt of a sodium feedwater flow ratio mismatch or high condenser pressure signal by the plant protection system, the steam generator modules for all operating loops are isolated and the corresponding SGACS are activated. All water pumps are started and the feedwater isolation valves are opened. When the feedwater pump develops enough pressure to provide feedwater, its check valve opens and the flow control valve accepts its function.

The condensate storage tanks shown on Figure 11.1-1 of Reference 1 were moved closer to Steam Generator Building 1 and hardened. The auxiliary condensate pumps are located in the same cell of SGB 1 as the recirculating pump for that loop, and this bay may have to be slightly larger. However, the "pill box" on top of all the steam generator buildings which held the air-cooled condensers is no longer necessary. The desuperheating valve and mixing tank are in the cell that held the hot water storage tanks, and this cell can be made smaller. It is probable that the layout of equipment may permit a slight reduction for this concept because of the smaller size of the decay heat removal components.

Feedwater is piped from the redundant auxiliary condensate pumps in SGB-1 to the other two SG buildings through protected lines routed as directly as possible. A commercial grade steam vent line (1,000 ft) was allowed for routing decay heat steam from each SGB to one of the cooling tower ponds. An auxiliary makeup water treatment system is also housed in SGB 1 to provide 40 gpm makeup to the storage tanks.

3.3 STEAM GENERATOR AUXILIARY COOLING SYSTEM CONCEPT SGACS-3 SPRAY CONDENSER (FIGURE 3)

This concept incorporates a direct contact water spray steam condenser and a water-to-water heat exchanger which transfers decay heat ultimately to the atmosphere by means of the emergency cooling towers (Figure 3). Feedwater pumps take suction from the spray condenser hotwell which is operated at a pressure of approximately 550 psia to provide a mixed mean temperature of 470°F water to the steam generators. Most of the water from the condenser hotwell is cooled in the water-to-water heat exchanger before being routed back to the condenser spray nozzles. The remainder is recirculated through the steam generators. The existing emergency cooling towers are sized to include the additional duty of providing cooling water for the water-to-water heat exchanger. The hotwell is sized for a 10 min residence time at maximum flow (3,000 gal). An additional volume of water is available in a 20,000 gal storage tank which provides sufficient water to refill all three loops with water at the end of the decay heat removal cycle when hot water is being recirculated.

The spray condenser and hotwell, water-to-water heat exchanger, feedwater and recirculation pumps, storage tanks, and associated valves and piping are constructed to Seismic Category I and ASME Section III, Class 3 requirements. The condensate storage tanks are not necessary to system operation and are therefore not safety grade. The required

FIG. 3

ancillary safety grade systems are: the emergency compressed air supply for valve actuation, the emergency chilled water system for pump and driver cooling, the emergency diesel generators for motor power, the emergency cooling water system including the emergency cooling towers, and a Class 1E power supply for the controllers.

A steam conditioning valve ahead of the spray condenser reduces the steam pressure and can desuperheat the steam when necessary by injecting water in the highly turbulent area below the pressure breakdown pintle. Redundant valves and pumps are provided to allow system operation with a single active failure .

The spray condenser is similar to units which are callet jet condensers or barometric condensers in the process industries, except that it operates well above atomospheric pressure instead of a vacuum as in the commercial units. The steam conditioning valve takes its signal upstream and thereby controls steam generator pressure. The recirculating pump control valves are modulated to yield the required feedwater temperature. Cooling water flow is regulated to cool the spray water to approximately 110°F.

All three steam generator loops are serviced by one spray condenser and water-to-water heat exchanger. The redundant feedwater and recirculation pumps also service all three loops. The motor-driven pumps can be operated by any one of the three emergency diesels.

Upon receipt of a sodium feedwater flow ratio mismatch or high condenser pressure signal by the plant protection system, the steam generator modules for all operating loops are isolated and the SGACS-3 is actuated. Feedwater and cooling water isolation valves are opened and all pumps are started. When either of the redundant feedwater pumps develops enough pressure to provide feedwater, its check valve opens and

the flow control valve accepts its function. The alternate pump is placed on half speed standby and its recirculation valve is opened. A similar sequence of events applies to the recirculating spray water pumps.

During standby the water in the condenser hotwell and storage tank is kept at 470°F by leakage or bypass steam through the steam conditioning valve. Steam lines to the turbines are similarly kept warm. Water level in the storage tank may change due to valve leakage and steam condensation. The level can be brought back within limits by operator action by the use of valved connections to the condensate storage tanks.

The spray condenser, hotwell, storage tank, and desuperheating valves are all housed in SGB-2 in the cell that was slated for water storage tanks in SGACS-1. This building is closest to the emergency cooling towers and such a location should minimize pipe connection lengths. The auxiliary feedwater pumps are housed in the recirculating pumps room. On this account, SGB-1 and 3 will no longer require the cells used for hot water tanks and recirculation pumps.

3.4 STEAM GENERATOR AUXILIARY COOLING SYSTEM CONCEPT SGACS-4 WATER-COOLED CONDENSER (FIGURE 4)

This concept is similar to the jet condenser SGACS-3 system except that a water-cooled condenser is substituted for the jet condenser water/ water heat exchanger combination (see Figure 4). Decay heat is ultimately rejected to the atmosphere via the emergency cooling water system. Steam is simply condensed at about 520 psia to yield a source of 470°F feedwater. The existing emergency cooling water system is oversized to accommodate the required decay heat removal duty.

This system is designated Seismic Category I and Tornado Missile Hardened. It meets the requirements of ASME Section III, Class 3. It

SGACS-4

FIG. 4

requires the following ancillary safety grade systems to be available: emergency compressed air supply for valve actuation, the emergency chilled water system for pump and pump driver oil cooling, the emergency cooling water system as the ultimate heat sink for the condenser, the emergency diesel generators for motor power, and a Class 1E power supply for the controllers. The motor-driven pumps can be powered by any one of the three emergency diesel generators.

All three loops are serviced by one condenser and the redundant pair of feedwater pumps. Steam from the three loops is manifolded to a common header to the steam conditioning valve. This valve drops the pressure through a multifluted pintle. The pressure breakdown pintle receives a signal from upstream of the valve and so controls the steam generator pressure. Desuperheating water from the active feedwater pump is injected in the highly turbulent area just downstream of the pintle and thus controls the desuperheat temperature. Condenser hotwell pressure is controlled by regulating cooling water flow to the water to water heat exchanger.

During standby, the condenser, pump turbines, and all steam lines are kept warm by valve leakage or bypass steam. All isolation and steam control valves are held shut.

Upon receipt of a sodium feedwater flow ratio mismatch or high plant condenser pressure signal by the plant protection system, the steam generator isolation valves for all loops are closed and the SGACS isolation valves are opened. All water pumps are started. When either pump reaches a high enough speed to deliver feedwater, its check valve opens, and the flow control accepts its function. The other pump is put on half speed standby and its recirculation valve is opened. The cooling water valve is opened at a slow enough rate to minimize thermal transients in the condenser and begins to regulate condensing pressure and temperature.

The surface condenser, hotwell, storage tank, and desuperheating valves are all housed in SGB-2 in the bay that was used for water storage tanks in SGACS-1. This building is closest to the emergency cooling towers and such a location should minimize cooling water piping. The auxiliary feedwater pumps are housed in the recirculating pumps room. On this account, SGB 1 and 3 will no longer require the cells used for hot water storage and recirculating pumps. Steam from SGB 1 and 3 is routed to SGB 2 as directly as possible in protected lines.

3.5 STEAM GENERATOR AUXILIARY COOLING SYSTEM CONCEPT IRACS-1 SODIUM-TO-AIR HEAT EXCHANGER (FIGURE 5)

This concept involves heat removal directly from the intermediate sodium loops through sodium-to-air heat exchangers. The steam generators are entirely eliminated by isolation valves in the sodium hot and cold legs (see Figure 5). Sodium flow is obtained by pony motor operation of the intermediate pumps. Air flow is obtained through a natural draft stack (see Appendix C) above the cooler coil banks. One cooler is provided for each of the three loops.

The system is designated Seismic Category I and is tornado missile hardened. It is designed to meet the requirements of ASME Section III, Class 3. Only five valves are activated in each IRACS-1 loop: the two IHTS sodium valves which isolate the steam generators, a sodium flow control valve, a natural draft damper, and inlet louvers. Although these would ordinarily be actuated by the plant protection system through the emergency air supply and Class 1E motor power supply (the air flow damper and louvers are motor driven), all valves are supplied with manual overrides. The system is put into operation by simply closing the isolation valves and opening the sodium and air flow valves.

FIG. 5

The natural draft heat exchangers are housed in the same cells on top of the steam generator buildings as were slated for the air-cooled condensers in SGACS-1. To keep the intermediate pump and expansion tank in the decay heat circuit and to assure the required protection of these items, the outer wall of the intermediate building was "moved" to "absorb" some of the steam generator building. This accounts for the building hardening costs shown on Table 4 in Section 6. A smaller expansion tank was added downstream of the sodium isolation valves to accommodate that small part of the system which would be unprotected by the main intermediate system expansion tank when the isolation valves close.

4.0 TECHNICAL UNCERTAINTIES AND RISKS

4.1 SYSTEM SIZE

Although it does not affect the conclusions of this report, additional effort would be required to select the optimum heat removal capacity of these systems.

Figure 6 shows the temperatures throughout the system (reactor upper plenum, steam generator Na inlet, steam out) for a shutdown system sized for a 1% heat rejection capacity. Such a system limits these temperatures to 1000°F. The effect of rejection capacity on this temperature limit is shown in Figure 7. The transient propagates throughout the hot legs of the systems all the way out to the steam lines. This means that any temperature limits imposed on any of the hot side components must be faced by them all. Inasmuch as the steam generator and its discharge lines are constructed of Cr-Mo steel (with much lower high temperature allowables than the austenitic stainless steels of which the sodium systems are fabricated), it is not improbable that upset temperature will be limited by these (or other) components before it is reached in the reactor vessel. Investigation of this aspect of the problem involves computer modeling of the dynamic system, thermodynamic modeling of the components exposed to the temperatures, and stress analysis of the components under these conditions. Due regard must be given both two-loop and three-loop operation.

Figure 8 shows the behavior of the liquid water level in the steam generator during this transient. Feedwater flow was held at the constant 1 percent rate as it would be for a 1 percent capacity system, but the rapid drop in water level in the steam generator indicates steaming at a rate greater than 1 percent for the first half hour or so. Thus, decay heat removal systems component sizes must be large enough to handle this flow and also to replace this water in the system at the end of the cycle when pressurized water is recirculated.

FIGURE 6

DHRS HEAT REMOVAL CAPACITY SELECTED:

21 MW = .8% OF FULL POWER (N-1 LOOPS)

10.5 MW = .4% OF FULL POWER (PER LOOP)

FIGURE 7

RUN 1-05 REACTOR TRIP WITH 40 PONY MOTOR AND 10 POWER REJECTION
XP - LENGTH(FRAC), STEAM GEN PREHEAT
XS - LENGTH(FRAC), STEAM GEN SUPERHEAT

*0717532-33
121677 0013

FIGURE 8

There is also an economic aspect of system size which has not yet been fully addressed. Certainly, it is a fundamental objective to minimize the cost of the heat transfer systems as a whole, but this is not a guaranteed result of minimizing the cost of each system individually. Specifically, the size of the decay heat removal system determines the maximum temperatures to which the reactor and main heat transport system components are exposed. If it is found necessary to utilize expensive materials or construction because of high temperatures induced by a smaller decay heat removal system, the differential cost of these more expensive materials may more than offset the savings obtained with a smaller heat transfer system.

4.2 SPECIFIC TO SYSTEMS

4.2.1 SGACS-1

The size of the water storage tank is a function of the water requirements to fill the entire system at the end of the decay heat removal cycle when only hot water is being recirculated. To this must be added any losses from the system. The tanks in this study are sized at 9,000 gallons on the premise that minimum steam would be vented. This means that most of the initial reactor decay heat is allowed to heat up all the hot leg components throughout the systems to 1100°F. The impact of this on hot leg component designs may be considerable as discussed above.

4.2.2 SGACS-2

As presently designed, the makeup water treatment unit which allows this system to operate takes its water from a protected source for the first 96 hours, if the system is activated immediately on reactor trip and then from an unprotected source. It is not clear that this system can be considered to be operable indefinitely under these circumstances.

It is not clear that the unprotected steam vent line can be considered nonplugging after a seismic event and a burst disc may have to be provided which allows venting to a hardened atmospheric exhaust.

The design of the hardened water storage tanks was not optimized for this trade study. For this conceptual design, they were considered to be constructed of 3-ft thick reinforced concrete.

4.2.3 SGACS-3

The heat exchanger operates with a relatively large temperature difference between hot water and cooling water (370°F) which would require a study in greater depth to verify the capability of the tubes to sustain the thermal stresses. This is associated with the maximum allowable water temperature to the emergency cooling tower which was assumed to be 130°F. This latter temperature would also be given a more thorough verification. This is not considered to be a severe problem as there are relatively simple methods whereby these temperature differences can be reduced if necessary.

4.2.4 SGACS-4

The comments above for the SGACS-3 Heat Exchanger apply equally well to the surface condenser of SGACS-4. In addition, an investigation in greater depth is required to set the operating pressure level of the condenser because of the inevitable subcooling which will be encountered with such a great condensing-cooling water temperature difference.

4.2.5 IRACS-1

It will be necessary to obtain some credible leakage rates for the isolation valves to verify the adequacy of the expansion tank. A study in greater depth is also in order to verify that the benefits of these valves (ease of maintenance) are about equal to the penalties (loss of plant availability) as was done in this study.

5.0 STARTUP, TESTING, AND MAINTENANCE

5.1 STARTUP

All of the candidate systems lend themselves to automatic startup or transfer to and from the normal shutdown system, but the procedures will not be of equal complexity. If complexity and risk are associated, it would be of value to rank these systems on the basis of complexity of procedure.

SGACS-1

- 1) Auxiliary feedwater pump is started and auxiliary feedwater flow control valve enabled (stop valve opens when pump delivers flow), steam conditioning valve enabled.
- 2) Main steam isolation valves close--normal decay heat removal system depressurization valves automatically close.
- 3) Noncondensibles vent actuated for several minutes, water storage tank pressure control loop (condenser fan motor and louvers) enabled.

10 Actions Per Loop

SGACS-2

- 1) Auxiliary feedwater pump is started and auxiliary feedwater flow control valve enabled (flow stop valve also opens when pump pressure rises), auxiliary condenser pump starts, steam conditioning valve enabled, tank vent valve enabled.
- 2) Main steam isolation valves close and normal decay heat removal system depressurization valves automatically close.

8 Actions Per Loop Plus 1 Per Plant

SGACS-3

- 1) Auxiliary feedwater pump is started and auxiliary feedwater flow control valve enabled (flow stop valve also opens when pump pressure rises), spray condenser recirculating pumps started and flow control valve enabled, emergency cooling water system enabled and heat exchanger flow control valves enabled, steam conditioning valve enabled.
- 2) Main steam isolation valves close and normal decay heat removal system depressurization valves automatically close.

4 Actions Per Loop Plus 7 Per Plant

SGACS-4

- 1) Auxiliary feedwater pump is started and auxiliary feedwater flow control valve enabled (flow stop valve also opens when pump pressure rises), emergency cooling water system enabled and condenser cooling flow control enabled, steam conditioning valve enabled.
- 2) Main steam isolation valves close and normal decay heat removal system depressurization valves automatically close.

4 Actions Per Loop Plus 5 Per Plant

IRACS-1

- 1) IRACS temperature control loop activated (three louvers opened), activation valve opened, and loop sodium isolation valves closed.

6 Actions Per Loop

Summary of decay heat removal systems startup actions:

	<u>SGACS-1</u>	<u>SGACS-2</u>	<u>SGACS-3</u>	<u>SGACS-4</u>	<u>IRACS-1</u>
Loop Actions	10	8	4	4	6
Plant Actions	<u>-</u>	<u>1</u>	<u>7</u>	<u>5</u>	<u>-</u>
Total (3 Loops)	30	25	29	17	18

This suggests that the air-cooled condenser concept involves the greatest number of component manipulations during startup.

5.2 TESTING

Four types of tests have been identified for possible application to these systems:

- 1) Performance test
- 2) Relief valve testing
- 3) Seismic snubber testing
- 4) Inservice inspection of hardware.

Performance Testing

None of the systems allow testing the main line isolation valves during plant operation and are equally deficient in this respect. Testing these isolation valves would require loop shutdown.

All of the systems appear to lend themselves to on-line performance testing because the heat rejection capacity is so small (per loop) compared to the plant output. Required instrumentation to verify performance does not appear in the flow diagrams (Figures 1-5) and must be added.

For the IRACS system, which depends on the intermediate pump for circulation, an orificed bypass across its activation valve may be required to yield the proper flow. However, for the SGACS systems which include auxiliary feedwater pumping systems, some complication would have to be dealt with to inhibit interaction with the plant feedwater control for testing during plant operation. For the steam lines, some type of isolation valve orificed bypass may suffice to limit the steam flow.

Thus, there does not appear to be any insurmountable obstacles to on-line performance testing for any of the concepts although such tests for an IRACS system may be simpler to implement.

Relief Valve Testing

The IRACS system has no relief valves. The steam side systems have either relief valves or pressure control valves which could be tested after the system is disabled. That is, the plant protection system feature which automatically activates the loop being tested would first have to be defeated. An alternative to this would be to provide redundant pressure relief valves with interlocked isolation valves so that no two isolation valves can be shut at the same time.

Seismic Snubber Testing

Some idea of the relative magnitude of this operation can be discerned by comparing seismically snubbed line lengths:

TABLE 2

SGACS-1	2,490 ft
SGACS-2	3,260 ft
SGACS-3	4,485 ft
SGACS-4	4,185 ft
IRACS-1	990 ft

Inservice Inspection of Hardware

None of the equipment or piping for any of the systems will be in inaccessible areas so the complications for this procedure are about equal.

5.3 MAINTENANCE

A tabulation of the number of isolation, on-off, and modulating valves or dampers and pumps gives some indication of the relative magnitude of these operations: (numbers are plant totals)

TABLE 3

	<u>SGACS-1</u>	<u>SGACS-2</u>	<u>SGACS-3</u>	<u>SGACS-4</u>	<u>IRACS-1</u>
ISO valves					
Locked open	27	17	29	20	3
Locked closed	9	0	--	--	--
On-Off	12	5	10	8	3
Modulating					
Steam	3	6	4	3	--
Water	6	6	9	7	--
Air	12	0	--	--	6
Pumps					
Active	9	4	3	1	--
Standby	0	1	3	1	--
Valves per plant	69	34	52	38	12
Pumps/blowers per plant*	9	5	6	2	0

Note that isolation valves do not include the two main plant isolation valves per loop, i.e., steam isolation for SGACS or sodium isolation for IRACS.

* All systems utilize the intermediate and primary pony motors.

6.0 COSTS

Appendix A contains the data lists which were submitted to Pricing and Estimating and which formed the basis for Table 4. The cost data presented in Table 4 was developed to show only differences in cost attributable to variation in selection of decay heat removal system, and no costs are included that were assumed to be the same for all systems. The basic condition was that the intermediate system and building were seismic and tornado hardened in an arrangement shown in Reference 1 as modified by Reference 7. Thus, costs for SGACS-1 include piping and equipment shown on Figure 1 plus steam generator building hardening above 100 ft elevation (see Item 5 below). It was assumed that the intermediate system out to the steam generators and the steam generators themselves would be ASME III, Class 3, Seismic Category 1, for all systems. The steam and water piping in the main plant out from the steam generators was also assumed to be the same for all systems (commercial standard). Costs include materials, any special packaging, installation and inspection, overhead, and profit. Sodium pipes are heat traced and all high-temperature lines are insulated. Costs, therefore, represent only capital expenditure and make no attempt to include life cycle expenses such as maintenance, testing, or repair. Likewise, any possible differences in plant availability which may be distinguishable between these systems, was not investigated. Table 1, which shows valve totals and total line lengths for these systems may be of help in assessing these aspects. Certain major items required special consideration because they fall out of range of readily available information.

- 1) Seismic Snubbers - Following the procedure set in Reference 4, all seismic category I lines were considered to be supported and snubbed every 15 ft. Snubber costs for mechanical snubbers were obtained from Precision Scientific Company.

TABLE 4
DECAY HEAT REMOVAL SYSTEMS COST BREAKDOWN

	<u>SGACS-1</u> <u>Air-Cooled Condenser</u>	<u>SCAGS-2</u> <u>Steam Dump</u>	<u>SCAGS-3</u> <u>Jet Condenser</u>	<u>SCAGS-4</u> <u>Surface Condenser</u>	<u>IRACS-1</u> <u>Sodium Cooler</u>
Cooler/Condenser	2,120,000	0	150,000	450,000	5,580,000
Tanks	1,270,000	3,330,000	1,060,000	1,060,000	300,000
Pumps	744,000	780,000	1,000,000	674,000	-
Valves	885,000	624,000	807,000	697,000	2,861,000
Piping	830,000	1,210,000	2,970,000	2,740,000	1,970,000
I&C	60,000	60,000	60,000	50,000	10,000
Miscellaneous	-	272,000 (40 GPM Water Treatment)	450,000 (Additional Cooling Tower Capacity)	450,000 (Additional Cooling Tower Capacity)	-
Total Equipment	5,909,000	6,276,000	6,497,000	6,121,000	10,720,000
Structural	8,127,000	5,630,000	6,462,000	6,462,000	3,000,000
Total	14,000,000	12,000,000	13,000,000	12,500,000	14,000,000

- 2) Sodium Valves - Cost data for 12-in. and 28-in. SNR valves manufactured by Clow Company (Reference 10) were extrapolated linearly to our size.
- 3) Air Blast Condenser - Cost data for the protected air-cooled condenser being manufactured for the CRBRP (Reference 11) was modified on the basis of the 0.6 power rule. $(\text{Cost A} = (\text{Capacity A}/\text{Capacity B})^{0.6} \text{Cost B})$. Cost obtained from GE for three 15 MWt units was \$1,250,000 without any breakdown between design and fabrication costs. A \$700,000 nonrecurring design cost was assumed to be included in this, and is also included in Table 4.
- 4) Air Cooled Sodium Heat Exchanger - Cost estimates from J. Oat Company for a 5.5 MWt air blast heat exchanger for the CRBRP EVST (Reference 11) was extrapolated to our conditions as follows. First, the "equivalent" size of the J. Oat unit was halved because it was operating in the forced air draft mode whereas we are (presently) planning natural convection on the air side. Cost was then extrapolated according to the 0.6 power rule. A \$700,000 nonrecurring design cost is also included.
- 5) Building Hardening (Seismic and Tornado) - This was one of the most troublesome costs to determine and probably represents the greatest uncertainty. There are several reasons why the steam generator building might require strengthening which are independent on the decay heat removal systems. There appears to be an incentive to utilize a common, massive basemat for all plant buildings to minimize inputs to the complex and inhibit overall and relative building motions. Similarly, the outer walls or all buildings from the basemat up to the reactor

deck level (approximately 100 ft) were considered to be equivalently seismically hardened to provide stiffness for the whole below deck complex. For these reasons, steam generator building hardening costs represent only differences above (100 ft).

There have been discussions which deal with the effect of an earthquake on an unhardened steam generator building. If one postulates massive failures, sodium-water reactions would occur with consequent aerosol formation that could interfere with local air flows, such as those for cooling heat exchangers, ventilation, or operating diesel generators. It has been suggested that NRC may require steam generator building hardening just to limit sodium aerosol concentrations at the site boundary. Inasmuch as this aspect has not been settled, steam generator building hardening costs were obtained by assuming a requirement for a reinforced concrete outer wall at the cost of \$75/ft² (Reference 10) above the 100-ft level. There were no differences assumed for steam generator costs even if they were no longer in the decay heat circuit, i.e., steam generators and mounts are all the same. Hardening costs for the IRACS system came about because our wall of the intermediate building would have to be moved into what is now the steam generator building in order to protect the intermediate pump and expansion tank. As is evident by examining the cost Table 4, hardening costs for those systems requiring a fully hardened steam generator building are about the same magnitude as equipment costs.

7.0 REFERENCES

1. FBR-77-3, Volume II, "Liquid Metal Fast Breeder Reactor Conceptual Plant Design 1000 MWe" (May 1977)
2. N254TI410001, "Decay Heat Removal System Analysis," J. Auleta (February 3, 1978)
3. N222TSR400001, "PLBR Decay Heat Removal System Selection," J. E. Brunings and L. E. Glasgow (July 15, 1976)
4. WARD-D-0051, "Clinch River Breeder Reactor Final Report of CRBRP Technical Support Team" (1974)
5. N222TI11230008, "Initial Plant Transient Analysis Results," G. Drucker (June 21, 1977)
6. Proceedings of the 1977 London Conference on LMFBFR's, Paper No. 16, "Sizing of Decay Heat Rejection Loops for LMFBFR's," Broadley, McSweeney
7. FBR-77-4, "PLBR Follow-on Studies Resolution of Key Issues" (September 1977)
8. N254TI110005, "Decay Heat Removal System Evaluation Briefing Charts," J. A. Hartung, C. W. Sayles, J. J. Auleta (April 4, 1978)
9. N222TSR400002, "PLBR Decay Heat Removal System Evaluation," September 21, 1976
10. Personal Communication with E. Moody (716-720) July 1978
11. Personal Communication with M. Kiley (716-670) June 1978