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Westinghouse Astronuclear Laboratory

PHASE 1

Quarterly Progress Report

December 1, 1969 through February 28, 1970

Prepared for the

U.S. ATOMIC ENERGY COMMISSION

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MASTER

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PREFACE

This report is the twelfth and final quarterly progress report on the SNAP-23A Project, Advanced Terrestrial Radioisotope Power Systems, under Contract AT(30-1)-3800 authorized by the United States Atomic Energy Commission. Phase I, which covered the period from December 2, 1966 through February 28, 1970, was conducted by the Astronuclear Laboratory of the Westinghouse Electric Corporation under the direction of the Atomic Energy Commission.

This document reports progress for the period from December 1, 1969 to February 28, 1970.

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1.0 PROGRAM MANAGEMENT

Subtask 110 - Project Management

This is the last Phase I Quarterly Progress Report, covering the period December 1 through February 28, 1970. The Phase I final report is in progress, is continuing, and covers the total Phase I effort from December 2, 1966 through February 28, 1970.

The EMS life test has continued through this reporting period. As of February 28, 1970, the total operating time for the EMS unit was approximately 12,570 hours. A gradual downward trend in the system temperature levels over a several month testing period was identified and which exceeded the prior data scatter band. Earlier life test data had indicated a gradual cyclic shifting of system temperatures within a bandwidth of $\pm 20^{\circ}\text{F}$. The downward trend had decreased to a level $20\text{--}30^{\circ}\text{F}$ lower than any previous data. Based on the evaluation of test data, potential causes, such as increasing converter thermal conductance, changes in helium leak rate and changes in the base assembly gas composition were ruled out. Further investigation of the trend toward decreasing system temperatures led to the examination of the input power wattmeter since this effect could be explained by a change in the total power input. Recalibration of the wattmeter indicated that only a minor adjustment was required. However, when the wattmeter was reinstalled in the EMS data system, the same indicated power level produced system operating temperatures higher than were experienced immediately prior to the recalibration. The conclusions were that the cause of the drift was due to the wattmeter or the connections to the wattmeter. Recent data prior to the recalibration of the wattmeter were, therefore, of questionable value due to the uncertainty of the power input level. The EMS life test will continue as a Phase II effort and will be terminated during April 1970.

The FPMS heat source was received at WANL early in December. During transport and upon arrival at WANL, the heat source stud temperature was approximately 1275°F . Radiator brazing problems were identified and the vendor was given permission to re-braze. Final braze and heat treat operations were completed. The reworked PMC-2 converter was received from 3M on January 23, 1970. Fabrication of the power conditioner was completed

and the converter/radiator/power conditioner subassembly was completed. The base assembly fabrication was completed; the hermetic seal fabrication was completed and welded into the base assembly. During the evacuation of the base assembly, a number of small leaks were discovered. All leaks were repaired except one which is on the backside of the hermetic seal and could not be reached without complete disassembly. However, it is felt that the leak is very small since a high vacuum level was easily attained and maintained without difficulty. After assembly and backfill of the base assembly was completed, a gas sample was taken and analysis confirmed a 99.95 percent Krypton atmosphere. The FPMS was assembled and installed into the test area. Initial testing was completed utilizing the PMC-2 converter. Since the converter is not a typical SNAP-23A converter, these tests were conducted primarily for the purpose of evaluating the thermal performance of the system. Since some of the components for the VIDAR data acquisition system had not been received, provisions were made for interim methods of data acquisition and safety monitoring. Four data points were obtained with system temperatures varied from EOL to BOL levels. This was accomplished by varying the converter load resistance, which varied converter current from 1.5 to 5.3 amps, and thus the thermal impedance of the converter. Initial analysis of the FPMS system was performed by using the WANL converter code, adjusted to fit 3M test data (see Subtasks 340 and 350), to calculate converter heat input. The FPMS test program is continuing as part of the Phase II program.

Spherical insulation testing of Min-K TE 1400 has continued through this reporting period and will continue as part of Phase II. As of February 28, 1970, 345 days (8280 hours) of testing have been accrued. Testing of fusible (borosilicate E-type microfiber) insulation is also continuing. The remaining compatibility test will be terminated early in Phase II. The fusible insulation mockup test has been completed and a detailed evaluation of this test is found in Subtask 410. Initial corrosion test samples have been forwarded to Naval Underseas Research and Development center for hot salt water aerosol chamber tests. These samples represent the first of an approximate 6 part test series, the balance of which will be conducted in Phase II.

At AEC request, a WANL representative visited 3M on December 18 to monitor and maintain cognizance of the PMC-2 converter rework and plans to build a converter using PMC-1B parts. The latter converter has been identified as PMC-3. Details of the schedule for the delivery of the reworked PMC-2 converter to WANL were reviewed.

An interface meeting was held at 3M Co. on January 13. The meeting was concerned primarily with the definition of a test and evaluation program which would establish the thermal characteristics of the rebuilt PMC-2. This program was necessary to enable the PMC-2 to be operated so that it will simulate thermally a typical PMC-2 converter and thus permit the FPMS thermal evaluation to proceed prior to the receipt of PMC-3.

On February 5, an interface meeting was held at WANL with the AEC also attending. The following items were on the agenda:

- FPMS Test Program
- Presentation of PMC-1B and PMC-2 Investigation Results
- PMC-3 Status and Schedule
- Phase II Planning

A summary of the pertinent discussions on each of these topics are covered in Subtask 140.

WANL attended a briefing by 3M for RDT on February 20, 1970 concerning the PMC-1B and PMC-2 failure mechanisms and the engineering recommendations applicable to PMC-3 and subsequent converters. A detailed outline on this briefing is covered in Subtask 140. The effect of the use of all iron electrodes in PMC-3 is predicted to reduce converter power output by 0.3 watts (e).

During this quarter, the following documents were prepared for submittal to the AEC:

- 1) WANL-3800-43, "SNAP-23A December Progress Report", February 1970.
- 2) WANL-3800-42, "Preliminary Safety Analysis Report", February 1970.
- 3) WANL-3800-24, "SNAP-23A EMS-Electrical Heat Source Failure Analysis Report", February 1970.
- 4) WANL-3800-44, "SNAP-23A January Progress Report", March 1970.

Subtask 140 - Liaison Engineering

3M Company

At AEC request, a WANL representative visited 3M on December 18 to monitor and maintain cognizance of the PMC-2 converter rework and plans to build a converter using PMC-1B parts. The latter converter has been identified as PMC-3. Details of the schedule for the delivery of the reworked PMC-2 converter to WANL were reviewed. To meet the scheduled delivery to WANL (the week of January 19, 1970), the pacing event was the start of the 500 hour converter "seat in", which had to occur no later than December 31, 1969. Actual start of the converter "seat in" began December 30 and was accomplished under a tight schedule that permitted only minor schedular delays. The PMC-2 converter was delivered to WANL on January 23, 1970 as scheduled.

The critical event in the proposed schedule for delivery of the PMC-3 converter to WANL by March 31, 1970, is the identification of the PMC-2 and PMC-1B failure mechanisms and the corrective action required. These investigations were expected to be completed by January 31, 1970. Like the PMC-2 schedule, the schedule for the building of the PMC-3 converter using the PMC-1B cold frame and followers was success oriented and extremely tight. The investigations were actually completed on February 20, 1970, and the delivery schedule of the PMC-3 to WANL has been redefined as April 27, 1970, including a 750 hour seasoning period.

An interface meeting was held at 3M Co. on January 13, 1970. The meeting was concerned primarily with the definition of a test and evaluation program which would establish the thermal characteristics of the rebuilt PMC-2. This program was necessary to enable the PMC-2 to be operated so that it will simulate thermally a typical PMC-2 converter and thus permit the FPMS thermal evaluation to proceed prior to the receipt of PMC-3.

Variations from the interface control drawing were identified in the areas of instrumentation, hot frame diameter, and hot frame taper. All deviations were accepted since they will not significantly impair the compatibility of the PMC-2 with the FPMS. Two items were identified which require further definition to avoid differences in interpretation in future converters.

On February 5, an interface meeting was held at WANL with the AEC also attending. The following items were on the agenda:

- FPMS Test Program
- Presentation of PMC-1B and PMC-2 Investigation Results
- PMC-3 Status and Schedule
- Phase II Planning

A summary of the pertinent discussions on each of these topics follows.

FPMS Test Program

To aid in the analysis of FPMS performance data, 3M will provide Seebeck and Resistance Ratio values corresponding to the FPMS nominal and short circuit test conditions.

WANL will measure PMC-2 converter leg performance while on FPMS system test. The data will be obtained using existing converter instrumentation; a once/month schedule will be satisfactory.

Presentation of PMC-1 and PMC-2 Investigation Results

The 3M converter investigations had not been completed and were continuing. Equipment availability was primarily responsible for the schedule slip from that identified at the start of the investigation.

As a result of detailed hot junction electrode and leg examination of PMC-1B and PMC-2, it was postulated that copper rich nodules on the electrode were touching the leg materials. It has been established that there were no reversed couples or P-legs and that the copper contamination did not originate at the cold cap. The investigation also showed the presence of tin, however, the origin of this material has not been identified. Free sulfur was found between the nickel plate and the copper. Copper attack was initiated at the N-legs and the P-legs were cross-contaminated from the N-legs.

It is clear that the copper originates at the hot junction electrode. The cause could be either the result of the known porosity of the iron plate or a plating process deficiency.

The cause of the failure appears very localized. The investigations are expected to be completed by the end of February 1970.

PMC-3 Status and Schedule

With the investigations performed to date, 3M will probably recommend to the AEC that PMC-3 be fabricated with a one piece iron electrode/button as the near-term solution to the copper contamination problem. Material compatibility appears to be no problem since previous converters have direct contact between the iron hot button and the legs. Uncertainty exists as to the net quantitative effect of this substitution on thermopile resistance.

Two-couple bell jar tests have been initiated at 3M which are intended to provide comparative resistance data on the all-iron electrode versus the iron/copper electrode. This test will also be used to evaluate the performance of the leg materials. The bell-jar tests had been successfully used to verify leg material properties as used in prior converters and the proposed bell-jar test appear to provide an adequate check on resistivity recognizing that the answer would not be fully known until fabrication and initial testing of the converter had been completed. The bell-jar test data would be available in approximately one week.

Although TEMPS tests using a TELPS type of test fixture on the PMC-3 leg material are planned, 3M does not intend that the build of PMC-3 be constrained by this data due to the uncertainty in the date by which results would be available since the equipment was not yet fully operational.

The current 3M schedule projects delivery of PMC-3 to WANL on April 15, and is based on the following:

- a) Verification of material properties, and immediate AEC approval to proceed, on the basis of the bell-jar test data
- b) Seasoning duration of 500 hours
- c) Use of all-iron electrodes

With regard to the long term solution to the copper contamination problem, 3M will investigate methods of overcoming the contamination experienced in PMC-2 and PMC-1B while maintaining use of a copper electrode; however, this could not be done in time for PMC-3 and would be effective only for subsequent converters, if feasible.

3M will submit PMC-3 ICD variations to WANL for review and specifically identified the cold frame diameter and taper as being ICD variations.

Phase II Planning

With regard to the WANL/3M Interface Document, it was agreed that this document should contain a mutually agreed upon schedule, definition of required technical interchanges, interface definition and change mechanism. WANL and 3M will prepare draft documents for review and then submit an agreed upon document to the AEC for approval.

WANL will define all converter internal instrumentation or data requirements, required for systems integrations. The internal instrumentation in the APC series of converters is to be minimized. WANL and 3M will investigate their respective schedule and scope areas with the AEC to insure compatibility.

WANL attended a briefing by 3M Co. for RDT on February 20, 1970 at AEC Germantown. At the briefing the following were identified:

1) The cause of failure in PMC-1B and PMC-2 was copper contamination of the thermoelements initiating in the N-elements and cross contaminating to the P-elements. The source of copper was the hot electrode and the mechanism was residual sulfur from incomplete neutralization of the plating bath for the nickel flash and iron plating of the electrodes.

2) PMC-3 will be built using all iron, low carbon steel, hot junction electrodes to prevent the possibility of failure due to copper contamination. The iron electrodes will be 0.047 inch thicker than the previous 0.055 inch thick copper to help compensate for the increased material electrical resistivity. However, investigations would continue to develop means of covering copper electrodes with iron because of the more desirable resistance and output power situation.

3) Five year stable performance has been achieved from couples containing iron electrodes.

4) Bell-jar tests using PMC-3 couples in contact with all iron and iron plated copper electrodes indicated that PMC-3 converter is expected to produce from 60.2 to 62.2

watts after stabilizing. An output of 59 to 61 watts is expected prior to stabilizing. A 0.750 hour stability conditioning period is recommended with 500 hours at a constant 1080°F average hot junction temperature. Initial and final data taking would be done during the first 100 and last 150 hours. The PMC-3 converter would be delivered to WANL on April 27, 1970.

ORNL

The third and final test capsule was subjected to a hydrostatic pressure of 16,000 psi on December 11, 1969. Inspection reports indicated that the only measurable changes in the capsule resulted from a minor dishing of the capsule end caps (about 0.02 inch on one end, and 0.030 inch on the other). This pressure is approximately 1.75 times the design pressure of 9040 psi and is equivalent to submergence in the deepest portions of the ocean.

ORNL has performed limited sectioning of the capsule to verify ultrasonic measurements of weld penetrations and defects. Two small apparent flaws, detected in the EB welded end in both the pre- and post-test ultrasonic scans, were found to consist of a small unwelded area inside the weld zone and a small crack. There was no evidence of defect propagation in either case.

As a result of these tests, the fuel capsule is considered to be fully qualified for use in SNAP-23A systems.

2. PRODUCT ASSURANCE

Subtask 220 - Quality Assurance

During this period, the following significant activities occurred:

- 1) Budget requests and tasks to be accomplished for Phase II were prepared for Project Management.
- 2) The base assembly was dimensionally inspected and accepted. The special functional type gage indicated that there would not be an interference between the heat source assembly and the bucket.
- 3) The last welding qualification was completed.
- 4) The radiator, as brazed, exhibited discrepancies of the following types:
 - a. Fins separated from shroud.
 - b. Braze joints not filletted or not brazed.
 - c. Excessive braze metal and running of the braze metal.

The evaluation by the Engineering Review Board concluded that the radiator would likely perform its most critical function of dissipating heat, and therefore it was accepted for use.

5) Difficulty was encountered in leak testing the base assembly in the hot condition (heat source assembly inserted). The unit would not pump down to a vacuum which would allow a mass spectrometer leak check to be performed. After removal of the heat source assembly and a slight pressurization of the base assembly, the hermetic seal was leak checked with a commercial bubble liquid. This indicated several leaks which were repaired. After this, the mass spectrometer was again connected to the base assembly and, by probing with helium from the outside, leaks were systematically located in the hermetic seal and repaired. The base assembly was finally accepted with one (1) leak remaining in the "backside" hermetic seal weld (could not be reached for repairs). It was not possible to calculate an actual leak rate for the base assembly as a steady background reference could not be obtained, due to the leak. This made it impossible to judge the effects of the standard leak when inserted in the

system. However, based on the "hardness" of the vacuum pulled on the base assembly, it is possible to state that the leak is very small. The unit was accepted as - is by ERB.

6) A visit was made to 3M by a Quality Engineer to witness the dimensional inspection of the converter. This inspection was accomplished without incident. However, questions have arisen about the compatibility of the converter, as defined by the interface drawing, with the jacket stud. This problem will be discussed at the next interface meeting.

7) Prints for the safety/alarm system for SNAP were reviewed and approved.

8) The entire FPMS unit was completely assembled. Inspections were performed as deemed necessary and the unit was accepted.

3.0 SYSTEM DESIGN

Subtask 310 - Systems Engineering

The EMS Life Test has exceeded 10,300 hours and the total EMS operating time is approximately 12,600 hours. It is planned that the EMS will be shut down permanently in April, 1970.

The FPMS was installed in the test area and initial thermal data points were obtained. Data were being recorded manually because of late delivery of portions of the data acquisition system.

EMS Life Testing

A summary of the mean performance of the EMS over the life test is given in Table 3-1; the values shown represent arithmetic means of 15 life-test data acquisitions. Four life-test acquisitions were made during the reporting period. These data are presented in Table 3-1. Graphic display of important system parameters over the life tests are shown in Figures 3-1 and 3-2.

Recent life-test data acquisitions coupled with 49 point data have indicated that there is evidence of long term drifts in some system parameters. These drifts appear to be cyclic in nature and may in fact be related to bias errors introduced to the instrumentation or data acquisition equipment. Detailed data and a summary of efforts under this and other subtasks to resolve apparent discrepancies in the data are discussed in detail under Subtask 340.

The EMS Life Test is scheduled for completion during the month of April. The EMS will then be disassembled and subjected to detailed inspection and both destructive and non-destructive tests. As part of the non-destructive testing, the PMC-1A converter will be returned to the 3M Co. for thermal recalibration. The final analysis of the EMS thermal data, which is part of the Phase II effort, will include re-evaluation of the final EMS tests, if necessary, as a result of the converter recalibration. It is planned that another series of BOL, EOL, and off-load tests will be performed prior to system shutdown.

TABLE 3-1

SNAP-23A EMS SYSTEM PERFORMANCE SUMMARY

	<u>Mean Value During Life Test</u>
Net Conditioned Power, watts (e)	64.9
Gross Converter Output, watts (e)	79.2
Net System Thermal Power, watts (t)	1254.
Total Heat Power, watts (e)	1440.
Conditioned Voltage, VDC	24.0
TE Converter Voltage, VDC	24.9
Converter Current, amperes	3.2
Current Through Load, amperes	2.7
Converter Internal Resistance, ohms	6.8
<u>Key System Temperatures, °F</u>	
Heat Source Surface	1204.
Mean Stud	1087.
Mean Hot Cap	984.
Mean Cold Cap	180.
Mean Radiator Base	141.
Ambient	64.

Figure 3-1. SNAP-23A Converter Output Characteristics for Constant Hot and Cold Cap Temperatures

Figure 3-2. SNAP-23A EMS Converter Output Characteristics for Constant System Thermal Input and Thermal Equilibrium for Load Variation

EMS Off-Load Test

The converter off load equilibrium tests were performed during December. Converter electrical loads equivalent to normal load with power conditioner, short circuit, one-third normal load, and a nominal three times the normal load were tested in a fashion similar to the tests performed in July, 1969. Figure 3-1 shows the measured output characteristics for constant converter hot and cold cap temperatures. Figure 3-2 shows the output characteristics for the thermal equilibrium conditions for the load variations under constant system input as expected during a fueled system operation and similar to those obtained during the July tests. The results obtained are as expected. One peculiarity noted is, that although the system power was controlled at a 1430 to 1438 watt level, which is slightly higher than the 1414 to 1423 watt level tested during the July test, the converter temperature differential across the thermopile was 32 to 40°F lower than that of the July test. The net result is that a slightly reduced output is obtained from the system. Since this test was performed prior to recalibration of the input wattmeter (see Subtask 340), the indicated power may be erroneous. Additional discussions and comparisons are presented in Subtasks 340 and 350.

FPMS Weight Analysis

During the assembly of the FPMS, many component weights were measured in order to provide a basis for weight analyses of future systems. No direct measurement was made of the base assembly weight, although the combined heat source and base assembly were weighed on a crane scale as 1070 lb. Subtracting the known weight of the heat source assembly, the base assembly weight is approximately 206 lb. This is the only place where there is a large discrepancy between the measured and calculated weights, which are compared in Table 3-2.

FPMS Test Preparation

A significant effort was made to expedite procurement of components as well as fabrication of the FPMS data system. The complete system consists of two automatic monitoring circuits and a VIDAR data acquisition system. Delays in delivery of some components have prevented full operation of the system. However, provisions were made for interim methods of data acquisition and safety monitoring.

TABLE 3-2
FPMS WEIGHTS

	Calculated	Measured
Heat Source Assembly	877.7	863.6
Fuel Capsule	34.4	30 (est)
Fuel	13.4	13.3
Liner	1.5	
Shell	19.6	
Diffusion Barrier	3.8	4.9
Shield	702.5	696.3
Body		620
Plug		75.5
Bolts		.8
Accumulator	98.4	102.2
Barrier Plate	1.1	0.9
Jacket	37.5	29.3
Head and Body		26.3
Closure Plate		3 (est)
Base Assembly	264.2	(206)
Inner Bucket and Ring	49.5	
Struts	11.6	
Hermetic Seal	2.4	
Outer Shell and Rings	121.5	
Insulation	79.2	
(Heat Source and Base Assembly)	(1142)	(1070)
Rain Shield	8.2	8.1
Rain Shield Insulation	----	5.0 (est)
Instrumentation Rings	25.9	25.0
Converter	52.0*	52.0
Radiator	45.0	45.3
Power Conditioner	2.0*	2.0 (est)
Protective Cover	33.5	33.0
Total	1309.	1240.

* Not calculated.

FPMS Test Preparations

The assembled FPMS was placed in the test area on February 5, 1970. The test area is a completely enclosed room with monitored access to control personnel exposure to the relatively low level radiation field and to provide a constant ambient temperature. The local and site alarm warning systems were connected and checked out to assure operation. All data acquisition and performance monitoring has been done manually since some of the components required for the VIDAR automatic data acquisition system have not been received.

FPMS Performance Test

At the end of February, the FPMS had been on operation approximately 575 hours at WANL. Four manual data points have been taken. A summary of the data points is given in Table 3-3 while a more detailed analysis of the performance of the system is given in Subtasks 340 and 350. The first data point was taken at a converter load close to what would be anticipated for a typical thermal simulation of a PMC-2 converter operating on an FPMS system. The second data point was taken with the converter operating in a normal condition with the 24 volt regulator connected. The third data point was taken with a current of 1.5 amps through the converter. This is as close to open circuit as could be operated without exceeding the design BOL hot cap temperature. The final data point was for short circuit operation. Converter hot side and system heat source temperatures below predictions were noted and are being investigated.

SNAP System Computer Code

The updating of the SNAP code was continued during this reporting period. The analytical description of the FPMS heat source assembly was completed and included in the code. The code revision will be completed during Phase II.

Phase II Planning

Under direction of the SNAP-23A project office, planning of Phase II system engineering and application engineering tasks was performed during the reporting period.

TABLE 3-3

SNAP-23A FPMS SYSTEM PERFORMANCE SUMMARY

	Test Point M1	Test Point M2	M3	M4
Net Conditioned Power - watts (e)	----	60.3	----	----
Gross Converter Output - watts (e)	52.03	67.5	56.4	2.5
Conditioned Voltage - volts DC	----	23.3	----	----
TE Converter Voltage - volts DC	13.80	24.3	37.6	0.469
Converter Current, amps	3.77	2.78	1.50	5.32
Load Current, amps	7.72	7.80	----	----
<u>Key System Temperatures, °F</u>				
Bucket Support Ring	1158	1197	1246	1118
Stud	987	1027	1086	945
Hot Cap	897	936	998	855
Cold Cap	180	176	178	187
Radiator Base	144	144	144	150
Ambient	81	82	80	88

Task statements and manpower estimates were prepared for the January - June 1970 period predicated on several alternative program objectives. Assistance was also provided in the preparation of the overall Phase II engineering program.

Subtask 320 - Mechanical Design

Mechanical design follow-up was provided during the reporting period for the completion of FPMS component fabrication and system assembly. The conceptual design effort on the system shipping container was monitored and preliminary Phase II planning was performed.

Base Assembly

Difficulty was experienced in forging the ends of the heat source support truss tubes. The EMS Inconel 600 tube ends were forged before the gusset slots were cut (See Figure 3-3A) without experiencing any cracking of the tube ends. However, when an attempt was made to forge the FPMS Inconel 718 tubes in the same manner, cracking of the tube ends was observed. This difficulty was eliminated by cutting the gusset slots before forging the ends (see Figure 3-3B).

A number of small leaks were discovered during the helium leak check of the base assembly. These leaks were repaired except for one on the underside of the hermetic seal which could not be reached without complete disassembly of the unit. The leak was of very small magnitude since a high vacuum level in the base assembly was easily attained and maintained with no difficulty.

In order to provide for increased flexibility during FPMS testing and to permit monitoring of the base assembly only two of the four evacuation tubes were crimped and sealed; the two remaining tubes were retained to permit base assembly evacuation and back-filling. These evacuation tubes were bent with appropriate radii to extend radially outward from the system and have been connected to a manifold system. The protective cover was slotted to accommodate the evacuation tubes.

A) End forged first and then slotted. (EMS Technique)

B) End slotted first and then forged. (FPMS Technique)

613195-5B

Figure 3-3. Heat Source Support Truss Tube End

Radiator Assembly

Difficulty was experienced in brazing the radiator assembly. In the initial braze operation approximately one-fourth of the fins had separated from the upper shroud. This difficulty was attributed to fixturing difficulties. The vendor was given permission to slot the upper shroud and to rebraze the assembly with improved fixturing. After dip brazing the shroud was rejoined by welding. While the general appearance of the radiator was poor, the unit was accepted on the basis that critical dimensional requirements had been met and that the radiator was satisfactory with regard to expected thermal performance.

During an assembly check, and prior to radiator anodizing, additional fin cutouts were provided in the radiator fins to provide adequate wrench clearance.

Subtask 340 - Thermal Analysis

During this period EMS life testing was continued. Data was obtained for normal load and off load operation. Several problems were experienced with the data acquisition system which resulted in erroneous test data. Spherical insulation life testing on Min-K 2002 continued indicating stable performance. Measurements were obtained from spherical tests with the fusible insulation indicating no change with data previously presented. FPMS testing was initiated with 4 data points taken over a range of systems temperatures for EOL to BOL temperature levels. This data indicated that the heat delivered to the converter may be 45 watts less than predicted.

EMS Life Tests

Four data points were taken with EMS on life test under normal load conditions. Table 3-4 summarizes these data. As of the last data point on February 16, 1970, 12,300 hours of EMS testing have been accumulated of which 10,100 hours were on life test. Figures 3-4 and 3-5 show the system input power, converter power output, converter hot cap temperature and system efficiency over the life test period. A gradual downward trend in the system temperature levels testing over several months was identified. Earlier life test data had indicated a gradual cyclic shifting of the system temperatures within a bandwidth of $\pm 20^{\circ}\text{F}$. The gradual downward trend had decreased to a level $20 - 30^{\circ}\text{F}$ lower than any previous data.

TABLE 3-4

SNAP-23A EMS THERMAL TEST POINT SUMMARY LIFE TEST

Test Point	C10 Ninth Life Test Point	C11 Tenth Life Test Point	C12 Eleventh Life Test Point	C13 Twelfth Life Test Point	C14 Thirteenth Life Test Point	C15 Fourteenth Life Test Point
System Input Power	1432 watts	1447.8	1455.6	1430.2	1447.7	1423.4
T Heat Source	1303.8°F	1302.8	1283.4	1277.4	1277.	1399.
T Maximum Heat Source	1314°F	1313.	1292.	1286.	1285.	1409.
T Bucket Bottom	1243°F	1239.7	1217.3	1211	1209.5	1326.
T Bucket Mounting Ring	1203°F	1202.	1178	1170	1150.	1295.
T Base Center	183°F	176.	176	165	173.	149.
T Base 6.5" Rad	141.5°F	135.8	134	120	106.	123.
T Side Base Assembly	91.5°F	88.	88	82.5	62.5	106.
T Stud	1084°F	1082.	1066	1063	1059.3	1163.8
T Hot Frame	995.5°F	998.5	975.5	976.5	971.	1049.
T Hot Cap	976.4°F	979.1	953.4	954.1	946.7	1020.5
T Cold Cap	173.7°F	175.3	166.9	173.2	168.4	174.3
T Cold Frame	144.3°F	146.	141.8	146.3	141.3	154.5
T Outer Case	138.3°F	141.	131	136	129.5	127.
Radiator Base	139.7°F	136.3	139.3	140	139.3	163.3
Ambient Temperature	54.5°F	60.	55	69	60.	70.
Converter Voltage	24.90 volts	24.91	24.84	24.82	24.83	25.09
Converter Current	3.18 amps	3.19	3.08	3.034	3.05	3.42
Converter Ins. O-C Voltage	46.32 volts	46.57	45.22	44.91	44.79	50.77
Converter Power Out	79.18 watts	79.46	76.51	75.30	75.73	85.81
Converter Internal Resistance	6.74 ohms	6.79	6.62	6.622	6.54	7.51
P.C. Voltage	23.96 volts	23.96	23.95	23.95	23.96	23.99
Load Resistant Current	2.69 amps	2.69	2.70	2.67	2.67	2.72
P.C. Power Out	64.45 watts	64.45	64.67	63.95	63.97	65.25
Power Dissipated in P.C.	11.74 watts	11.98	9.10	8.718	9.10	16.79
Power Loss in Leads	2.99 watts	3.03	2.77	2.640	2.65	3.76
Estimated Instrumentation Losses	125 watts	126.	120	120	119	134.
Estimated Helium Leakage Effect	60 watts	60.	60	60	60	60.
Net System Input Power	1247 watts	1261.8	1275.6	1250.2	1268.7	1229.4
Estimated System Efficiency	6.35%	6.3	5.99	6.02	5.97	6.98
Time After Start of Life Test	7224 hours	7584.	8256	84.78	9290	10058
Start Date 12-24-68 8:00 A.M.	10-21-69	11-5-69	12-3-69	12-12-69	1-15-70	2-16-70
Total Elapsed Time	9458 hours	9818.	10490	10712	11524	12292

Figure 3-4. EMS System Performance on Life Tests

Figure 3-5. EMS System Performance on Life Tests

Based on the evaluation of test data, potential causes such as increasing converter thermal conductance, changes in helium leak rate, and changes in the base assembly gas composition were ruled out. The wattmeter for measuring system power input was, therefore, removed from the system and recalibrated. Data taken subsequent to recalibration and reinstallation of the wattmeter indicated that the system temperature had reached equilibrium at levels corresponding to the maximum levels experienced at previous periods during the life test. The conclusions were that the cause of the drift was due to the wattmeter or the connections to the wattmeter. Recent data prior to the recalibration of the wattmeter were, therefore, of questionable value due to the uncertainty of the power input level.

The full data point taken subsequent to the recalibration on February 16, 1970 indicated significant changes in the interface temperature drops of the order of 40°F. Although the I/C thermocouples were consistent to each other on the converter, the converter temperatures had changed relative to C/A thermocouples on the stud and radiator base. A spot check of T/C readings on the converter stud and radiator base with a potentiometer indicated that the I/C thermocouples were all reading high in the neighborhood of 40°F. As a result, the reference junction for the I/C thermocouples was removed and sent for recalibration.

Three steady state data points were taken during the off load tests with the converter external resistance set nominally at short circuit, 1/3 normal load resistance, and 3 x normal load resistance. Table 3-5 presents the data point summaries for these tests. As a result of the drift induced by the wattmeter, system temperatures were approximately 60°F lower for these off-load tests than for the previous set of off-load tests. These two sets of data were taken at periods in time when the system temperature levels were at the highest and lowest levels under normal load conditions during the entire life test period.

Spherical Insulation Life Tests

The observed performance of Min-K 2002 material from the spherical insulation tests is shown in Figure 3-6. The temperature differential between the hot and cold surfaces were slightly lower than previous measurements and even when one percent power fluctuation is accounted for, the measured temperature differential is slightly outside of the previous data scatter but still well within the uncertainty of the measurements. After approximately 2800 hours of

TABLE 3-5
SYSTEM STEADY STATE PERFORMANCE AT OFF LOAD CONDITIONS

<u>Test Point</u>	<u>C-13 RL</u>	<u>Short Circuit</u>	<u>1/3 RL</u>	<u>3 RL</u>
System Input Power	1430.2 watts	1432.3	1431.7	1437.8
$\bar{T}$ Heat Source	1277.4 °F	1205	1236	1343.6
T Maximum Heat Source	1286. °F	1214	1245	1352
$\bar{T}$ Bucket Bottom	1211. °F	1137.3	1169	1278.5
$\bar{T}$ Bucket Mounting Ring	1170. °F	1098	1131	1244
T Base Center	165. °F	163	164	182
$\bar{T}$ Base 6.5" Rad	120. °F	121	125	136
$\bar{T}$ Side Base Assembly	82.5 °F	83	85	88.5
$\bar{T}$ Stud	1063. °F	979.5	1017.4	1113.2
$\bar{T}$ Hot Frame	976.5 °F	892.5	929.5	1046.
$\bar{T}$ Hot Cap	954.1 °F	866.3	904.2	1022.7
$\bar{T}$ Cold Cap	173.2 °F	180.1	172.0	165.9
$\bar{T}$ Cold Frame	146.3 °F	146.8	142	139.8
$\bar{T}$ Outer Case	136. °F	137	132	129.5
$\bar{T}$ Radiator Base	140. °F	141.7	138	136.3
Ambient Temperature	69. °F	57	60	60
Converter Voltage	24.82 volts	1.6	14.74	40.10
Converter Current	3.034 amps	5.89	4.24	1.45
Converter Ins. O-C Voltage	44.91 volts	38.53	41.86	50.31
Converter Power Out	75.30 watts	9.39	62.50	58.29
Converter Internal Resistance	6.622 ohms	6.27	6.404	7.024
Load Resistance	8.18 ohms	0.271	3.48	27.96
Time After Start of Life Test	8478 hours	8574	8646	8738
Start Date 12-24-68 8:00 A.M.	12-12-69	12-16-69	12-19-69	12-23-69
Total Elapsed Time	10712 hours	10808	10880	10972

Figure 3-6. Temperature Measurements vs Time for Min-K 2002 (Krypton Backfilled) During Life Test

life test the measured temperature differential remained within 2 percent of the value representing the first data point.

The measurements from spherical tests with the fusible insulation (microfibers felt) during this month indicated no significant change in either the temperature profile of the Min-K 2000 portion or the temperature differential across the microfibers felt material. The mean thermal conductivity, $\bar{k}$, of microfiber felt material was determined by the following equation, as described in Reference 2.

$$\bar{k} = \left(\frac{Q_f}{2\pi} \right) \left(\frac{1}{r_i} - \frac{1}{r_o} \right) / \Delta T$$

where Q_f = heat transferred through the fusible insulation portion

$$Q_f = (Q_{\text{input}}) - (Q_{\text{thru Min-K 2000}})$$

r_i, r_o = radii of the two radial locations of the thermocouples

ΔT = temperature differential between these two locations.

The resultant, $\bar{k} = 0.041 \text{ BTU/hr-ft}^{\circ}\text{F}$, is unchanged from the previously reported value for the fusible insulation.

FPMS Testing

FPMS testing was initiated this month with the use of the PMC-2 converter. Since the PMC-2 converter is not a typical converter, the initial series of tests were conducted primarily for the purpose of evaluating thermal losses in the system. Four data points, summarized in Table 3-6, were accomplished by varying the converter load resistance which varied converter current from 1.5 amps to 5.3 amps and thus the thermal impedance of the converter. Initial analysis of the FPMS system was performed by using the WANL converter code, adjusted to fit 3M test data by the procedure described in Subtask 350, to calculate converter

TABLE 3-6
TIME TEST POINT SUMMARY

TEST POINT	M-1	M-2	M-3	M-4
A. Converter Performance				
Voltage - volts	13.80	24.3	37.6	0.469
Current - amps	3.77	2.78	1.50	5.32
Power Output - watts	52.03	67.5	56.4	2.50
Open circuit voltage - volts	42.92	46.0	50.9	39.77
Internal resistance - ohms	7.72	7.80	8.9	7.39
B. System Output (P.C. out)				
Load voltage - volts	----	23.3	----	----
Load current - amps	----	2.6	----	----
Net power output - watts	----	60.3	----	----
C. Converter Temperatures °F				
T hot frame	943.	984	1045	900
T hot cap	896.9	936	998	885
T cold cap	180.1	176	178	187
T outer case	158.0	155	158	161
D. Base Assembly Temperatures				
T external bottom	130.0	139	142	136
T external side	125.4	129	132	124
T bucket bottom	1162.3	1212	1261	1133
T bucket support ring	1158.	1197	1246	1150
T inner ring-seal	1133.0	1183	1228	1098
E. Radiator/Ambient Temperatures °F				
T radiator fin base	143.8	144	144	150
T shroud	121.5	128	128	131
T power transistor cover	119.8	127	126	129
T ambient	81	82	80	88
F. Heat Source Temperatures °F				
T stud	986.8	1027	1086	945
T neck	1129.0	1165	1222	1089
G. DATE	2-23-70	2-27-70	3-1-70	3-4-70
H. WANL TEST TIME	449.00 hrs.	550	600	665 hrs.

heat input. Heat losses could then be determined by subtraction of the converter heat input from the system power level. Figure 3-7 compares the converter heat input calculated for the first four data points to the predicted heat delivered to the converter. The net system heat input was estimated to be 1088 ± 22 watts based on a conservative 3 watt instrumentation loss estimate and a gross system input of 1091 ± 22 watts calculated for February 15, 1970 based on Oak Ridge data taken November 1, 1968. The predicted heat to the converter was determined from the net system heat losses for EOL and FPMS start of test. (WANL 3800-37, page 3-35). As shown in Figure 3-7 the measured converter heat input was 403 ± 20 watts at an EOL corresponding to a converter hot cap temperature of 852°F . The predicted heat input was nominally 45 watts higher. Subtraction of the converter heat input from the system heat input indicated system losses of 185 ± 45 watts as compared to predicted losses of 140 watts. A nominal PMC-2 converter operating at 24 volts load would require 811 watts as thermal input from the system. At the indicated system losses of 185 ± 45 watts, the system would be delivering the heat to the converter at an 82 percent thermal efficiency, rather than at 85 percent, which is based on the predicted 140 watts system thermal losses.

Subtask 350 - Thermoelectric Analysis

The PMC-1A converter on EMS life test was tested during this reporting period under normal and off design load conditions. These data were compared to previous testing and analytical calculations. Results of the comparisons have indicated that the converter thermoelectric performance has remained stable. The PMC-2 component test program was defined. Results from this testing were used to establish a procedure for calculating converter heat input for the FPMS tests using the WANL converter code.

PMC-1A Operation on EMS Life Test - Design Load

The PMC-1A converter thermoelectric performance on EMS life test at design load conditions was examined by comparing the measured thermoelectric performance with the predicted values based on previously reported seebeck and resistance ratios as recommended by 3M Company (Reference 3). These ratios were determined from life test data up to the second life test data point (3290 hours). Using these values and the measured converter hot and cold cap temperature and load voltages, converter performance was calculated for all

Figure 3-7. FPMS Heat Flow

life test data points. Ratios of the measured to calculated values of open circuit voltage and internal resistance are shown in Figure 3-8. The open circuit voltage ratio remained steady over the entire life test period with less than 2 percent difference between calculated and experimental values. The resistance ratio has increased slightly to a level of 6 percent difference in calculated and measured values for the most recent data. This trend suggests that the internal resistance is increasing; however, the slightly lower temperature level in the converter may be contributing to this trend. Off load tests have shown that agreement of calculated and measured resistance diverge as the converter temperature diverges from the normal load temperature level.

These data, therefore, indicate that the converter has remained reasonably stable, thermoelectrically, over the life test period with potentially a slight trend of an increasing internal resistance. The Wiedemann Franz relationship implies that the internal resistance of a material is proportional to the electrical resistance. If the cause of the internal resistance change is due to material property changes then the thermal resistance of the converter could be increasing also. For a fixed heat input the converter temperatures would increase which is contradictory to the present trend in the system. Changes in thermal resistance in the converter causing the observed drop in system temperatures, therefore, could not be inferred from the converter thermoelectric performance.

Off-Design Load Testing of the PMC-1A Converter

Off-design load testing of the PMC-1A converter, while on EMS life test, was conducted. Instantaneous and steady state performance data were obtained at nominal load resistances of R_L , $3R_L$, $1/3 R_L$, and short circuit. Table 3-7 presents a summary of the steady-state thermal and thermoelectric performance at off-load conditions. Figures 3-9 and 3-10 compare these data with data obtained from the previous set of off-load testing. (Reference 1).

The converter hot cap temperature was 75°F lower for this test, and the cold cap temperature was 20°F lower primarily because of the drift in the wattmeter (Subtask 340). As a result of a smaller temperature drop across the converter, the open circuit voltage and power output were lower. Internal resistance and load voltage also dropped. Table 3-8 compares the calculated results to the measured performance data. Figures 3-11 and 3-12

Figure 3-8. PMC-1A Thermoelectric Performance on EMS Life Test

TABLE 3-7
 PMC-1A CONVERTER PERFORMANCE AT OFF-LOAD CONDITIONS
 (12-23-69 - Time on WANL Test - 10970 hrs.)

	Short Circuit		$1/3 R_L$		R_L		$3 R_L$	
	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.
Average Hot Cap Temperature, °F	866.3	866.3	904.2	904.2	954.1	954.1	1022.7	1022.7
Average Cold Cap Temperature, °F	180.1	180.1	172.0	172.0	173.2	173.2	165.9	165.9
Load Voltage, Volts	1.6	1.6	14.7	14.7	24.82	24.82	40.1	40.1
Converter Power Output, watts	10.21	9.39	65.0	62.5	76.4	75.3	54.3	58.3
Converter Internal Resistance, ohms	5.61	6.27	5.84	6.40	6.26	6.62	6.81	7.02
Converter Current, amperes	6.40	5.89	4.41	4.24	3.08	3.03	1.35	1.45
Converter Instantaneous Open Circuit Voltage, volts	37.5	38.4	40.5	41.9	44.1	44.9	49.3	50.31

Figure 3-9 . EMS PMC-1A Converter Performance at Off Load Conditions

Figure 3-10. EMS PMC-1A Converter Performance at Off Load Conditions

TABLE 3-8

COMPARISON OF CALCULATED TO MEASURED PERFORMANCE
FOR PMC-2 COMPONENT TEST DATE

DATA POINT	EOL		BOL		FPMS Short Circuit		FPMS Nominal	
	Measured	Calculated	Measured	Calculated	Measured	Calculated	Measured	Calculated
Hot Cap Temperature °F	858	858	1010	----	889	----	932	----
Cold Cap Temperature °F	169	169	190	----	184	----	175	----
Load Voltage	24	24	24	----	0.0	0.0	14.8	14.8
Converter Current	2.39	2.40	3.22	3.25	5.59	5.60	4.02	4.07
Open Circuit Voltage	40.4	40.4	51.8	52.2	42.7	42.6	46.2	46.4
Power Output	57.3	57.6	77.3	78.0	0.0	0.0	59.6	60.3
Internal Resistance	6.86	6.84	8.64	8.67	7.65	7.80	7.80	7.75
Net Heat Input	784.	796.	967.	1020.	951.	995.	940.	985.
Bias Correction	----	20.	----	51.	----	34.	----	36.
Corrected Heat Input	784.	776.	967.	969.	951.	961.	940.	949.
S_n	----	0.98	----	0.98	----	0.98	----	0.98
S_p	----	0.92	----	0.95	----	0.94	----	0.94
R_n	----	0.99	----	0.97	----	1.02	----	0.99
R_p	----	1.03	----	1.07	----	1.10	----	1.07

Figure 3-11, EMS PMC-1A Converter Performance at Off Load Conditions

Figure 3-12. EMS PMC-1A Converter Performance at Off Load Conditions

compare the measured and calculated performance data as a function of converter current. The calculated open circuit voltage was within 2 percent of the measured values over the full range of converter current, as was experienced in the previous off-load tests. This suggested that the seebeck ratios predicted at design load conditions remained uniform for the limited range of converter temperatures experienced in the off-load tests since open circuit voltage is a function of the seebeck coefficient and converter temperature drop. As was also observed from the previous tests, the measured values of converter internal resistance and converter current deviate from the calculated values significantly as currents approach short circuit conditions. Furthermore, as a possible result of the lower temperature level in the converter, the differences in calculated and measured resistance were larger at each load condition than shown in the previous tests (Table 3-8, Reference '1). Those trends suggest that the resistance is more sensitive to the temperature level than the seebeck coefficient in this temperature range, and use of the PRAM code for analysis over a wide range of temperature may require a temperature varying resistance ratio.

Life test data subsequent to this analysis indicated that the I/C, thermocouple reference junction went out of calibration (see Subtask 340). Inspection of data indicates that the temperatures measured for this series of off load tests were low by approximately 10°F because of the reference junctions.

PMC-2 Converter Component Test

A meeting was held at the 3M Company on January 13, 1970 to establish a test and evaluation program. The program would characterize the "as built" PMC-2 converter to be an adequate thermal representation on the FPMS which would provide useful information for the thermal performance evaluation of the FPMS. At this meeting it was indicated that the typical change in thermal performance of the converter during the seasoning period was approximately 30 watts over a period which might be as great as 2000 hours. During the first 300 hours as much as 10 watts change might be noted, whereas over a 600 hour period as much as a 20 watt change could be noted. Since the system heat input is accurate to ± 22 watts at initial fueling, assuming Sr^{90} , and since the heat input to a fully seasoned

PMC-2 converter is accurate to ± 20 watts, the effect of a reduced seasoning period would not significantly reflect on the accuracy of system thermal performance evaluation.

Based on the above objectives and reasoning, the following test program was developed which provided the minimum necessary information and had no impact on the delivery schedule for PMC-2. The following program was developed:

A. Program

- 1) Generate a curve of Q_{in} versus T_{HC} based on:
 - a. Nominal seebeck and resistance adjustment factors
 - b. Bias heat loss averaged from PMC-1A, PMC-1B and PMC-2 tests
 - c. 24 volts load voltage
- 2) Conduct a test at 940 watts Q_{in} and a T_{HC} as defined on the generated curve of 1, by adjusting load characteristics.
- 3) Conduct a test at 960 watts Q_{in} and a T_{HC} of 852°F , by adjusting load characteristics (data generated for evaluation of FPMS at EOL conditions).

B. Test Sequence

- 1) BOL conditions - 24 volt load at approximately 350 test hours
- 2) FPMS conditions (940 watts) at approximately 400 test hours
- 3) FPMS, EOL conditions (960 watts and 852°F) at approximately 450 hours
- 4) EOL conditions - 24 volts load at approximately 500 test hours.

The test results for PMC-2 were presented to WANL at the WANL/3M interface meeting on February 5, 1970. Included in this package was a summary of the thermal and thermoelectric parameters for the four test points identified above plus initial and intermediate test point summaries. Recommended seebeck and resistance ratios and heat flow correction factors were also provided for use with the converter code. Table 3-7 is a summary of the data for the four test points.

Since it was considered very unlikely that the PMC-2 component test points would coincide with data taken from FPMS, it was necessary to be able to use the WANL converter code (PRAM-01 equivalent) to calculate the converter heat input. The WANL converter code was, therefore, used to check the four component test points, the results of which are

shown in Table 3-7. Differences of up to 53 watts were noted between calculated and measured converter heat input. To minimize differences and to provide a capability for using the code as a thermal analysis tool, 3M developed a heat input bias correlation versus converter internal resistance. This correlation, defined in Table 3-9 was based on the component test data which covered a wide range of converter currents and temperatures. The procedure recommended by 3M for using the converter code to analyze FPMS data was to adjust the seebeck and resistance ratios to obtain a close fit between calculated and experimental results for internal resistance, open circuit voltage, and converter current. The heat bias curved to correct the calculation, converter heat input could be obtained with an accuracy of ± 20 watts. In analyzing these data, 3M noted that the PMC-2 converter test data did not indicate any time dependent change in thermal impedance as was experienced with PMC-1A and other converters while in component tests.

TABLE 3-9

HEAT BIAS CORRELATORS FOR PMX-2 CONVERTER TEST ANALYSIS

$(Q_{\text{calculated}} - Q_{\text{experimental}})$ is a straight line function of internal resistance and is described to within ± 10 watts by a line passing through the following two points:

R_i	ΔQ
6.25	10 watts
9.18	60 watts

4. MATERIALS AND COMPONENT TESTING

Subtask 410 - Materials Engineering and Testing

The activities of the Materials Department during this reporting period were as follows:

- 1) Technical input was supplied for preparation of the preliminary Phase II program plan and budget estimates.
- 2) Support was provided for the FPMS procurement and fabrication operation with heat treating services for the support struts in the base assembly, welding and leak testing of the hermetic seal, welding of the base assembly and radiator brazing procedures.
- 3) Technical support was provided for the FPMS base assembly through weld qualification approval, consulting on assembly welds and weld repair, and establishing the evacuation and bakeout conditions as well as the leak testing condition.
- 4) Revisions to the EMS Failure Analysis Report were completed and published.
- 5) The fracture of sheathed thermocouple leads inside the brazed feedthrough port of the Base Assembly was investigated. It was apparent that the fracture of the sheathed leads was due to flexing during installation of the insulating material. It is recommended that the closure disc be moved to a position within the cylindrical shell so that a flexible silicone potting cushion could be used on the inside like the potting on the outer end.

Spherical Insulation Testing

Min-K 2002; Life testing on Min-K 2002 is continuing. A total time of 376 days (9000 hours) has accumulated on this test through February 28, 1970. The results of the data points taken are reported and compared to previous results in Subtask 340.

Min-K 2000/Fusible Insulation; the life test of the sphere containing both Min-K 2000 in one half and the Fusible Insulation (borosilicate E-fibre) in the other half as described in WANL-PR(SS)-034 is continuing. A total time of 104 days (2496 hours) has accumulated on this test through February 28, 1970. The results of data points taken are reported in Subtask 340.

Min-K 2002

Thermal expansion tests were performed at Westinghouse Research Laboratory on as-received Min-K 2002. Two inch long samples were machined from a large pressed sheet or block of the insulation. This made it possible to make one specimen, sample 1A, with the longitudinal axis oriented through the thickness of the sheet (i.e., parallel to the pressing direction of the sheet or block). The other sample, 2A, was machined with the longitudinal axis oriented in the long direction of the pressed sheet or block (i.e., perpendicular to the direction of pressing of the sheet). Figure 4-1 shows that up to approximately 900°F the expansion in both directions is similar. Above 900°F, the rate of expansion with further increasing temperature slows down appreciably for the thickness direction of the block or slab. A 0.005 inch (0.25%) contraction was observed for both samples after each full heating and cooling cycle.

Galvanic Corrosion Evaluation - Aqueous Solution Tests

The galvanic corrosion evaluation apparatus described in WANL-PR(SS)-031 (WANL-3800-37) was used to evaluate the effectiveness of using a cathodic coating to inhibit the galvanic corrosion of aluminum in synthetic sea water. Teflon coated Inconel 625 samples were coupled to Aluminum 6061 alloy in both the anodized and unanodized condition. The couples were immersed in both room temperature and 155°F synthetic sea water for 68 hours. A comparison of the 155°F galvanic current in this test with the current measured in earlier tests in 160°F synthetic sea water is shown in Table 4-1.

It can be observed that the Teflon coating on the Inconel 625 (cathodic coating) significantly reduced the corrosion current (rate of corrosion) for both the anodized and the unanodized aluminum. After 68 hours, the corrosion current increased somewhat. This increase in current may have been due to the blistering of the Teflon coating on the Inconel 625 which was observed when the couples were removed from the 155°F synthetic sea water.

The test results for coated and uncoated samples immersed in room temperature synthetic sea water are shown in Table 4-2.

Figure 4-1. Linear Expansion of Min-K 2002 Measured in Air on Heatup

TABLE 4-1

DEPENDENCE OF GALVANIC CORROSION CURRENT ON ELECTRODE COATING AT 155°F

<u>Couple No.</u>		<u>Corrosion Time (Hours)</u>	<u>Avg. Current (ma)</u>
<u>160°F test (WANL-PR-SS-031)</u>			
1	Inconel 625 (bare)/6061 aluminum (unanodized)	24	0.125
4	Inconel 625 (bare)/1100 aluminum (unanodized)	24	0.136
7	Inconel 625 (bare)/6061 aluminum (anodized and sealed)	150	0.115
<u>155°F (this test)</u>			
1	Inconel 625 (Teflon coat)/6061 aluminum (unanodized)	1	0.001
		68	0.005
2	Inconel 625 (Teflon coat)/6061 aluminum (anodized and sealed)	1	0.001
		68	0.009

TABLE 4-2

DEPENDENCE OF GALVANIC CORROSION CURRENT ON ELECTRODE COATING AT ROOM TEMPERATURE

<u>Couple No.</u>	<u>Materials</u>	<u>Corrosion Time (Hours)</u>	<u>Avg. Current (ma)</u>
3	Inconel 625 (Teflon coat)/6061 aluminum (unanodized)	1	0.000
		68	0.001
4	Inconel 625 (Teflon coat)/6061 (anodized and sealed)	1	0.000
		68	0.000
5	Inconel 625 (bare)/6061 aluminum (unanodized)	1	0.050

Again, the importance of a cathodic coating for controlling the galvanic corrosion is well illustrated. The Teflon did not blister in 68 hours of exposure.

The fact that the Teflon coating on the Inconel 625 blistered when immersed in hot synthetic sea water means that more effort is required on improving the method of applying the coating or the search for an improved cathode coating must continue.

Galvanic Corrosion Evaluation - Moist Salt Cake Test

Another galvanic couple was tested using the hot moist salt cake electrolyte to bridge the gap between the samples. This test, which was described in detail in WANL-PR(SS)-031, is intended to simulate a galvanic couple in a marine tropical environment. The couple consisted of Teflon coated Inconel 625 and aluminum 6061 alloy in the anodized and sealed condition. Results of this test after 105 minutes compared with 60 minute tests previously reported (WANL-PR(SS)-031) are shown in Table 4-3.

TABLE 4-3

SALT CAKE CORROSION TEST RESULTS AT 150°F

<u>Materials</u>	<u>Current (ma)</u>
Inconel 625 (Teflon coated)/6061 aluminum (anodized and sealed)	0.000
Inconel 625 (bare)/6061 aluminum (unanodized)	0.120
Inconel 625 (bare)/6061 aluminum (anodized and sealed)	0.010

The Teflon coating on the Inconel 625 appears to have a significant effect in reducing the corrosion rate.

Corrosion Testing - Hot Salt Water Aerosol Spray Test

Initial material base point samples of Inconel 625 both plain and Teflon coated and also aluminum alloys 6061 and 1100 with different surface preparation were sent to the Naval Undersea Research and Development Center for hot salt water aerosol spray tests. Anodized and sealed aluminum alloys were dye penetrant tested to determine if defects were present. The location of observable defects were recorded.

Several galvanic couple test sample designs and assembly procedures have been under study to select a configuration that will contribute the optimum information useful to the SNAP-23A FPMS and APS design configurations.

Fusible Insulation Mockup Testing

The objective of the fusible insulation mockup test was to demonstrate the feasibility of using the fusible insulation (borosilicate E-fibre) for thermal insulation under normal steady state operations and as a self destructing thermal bypass in the event of emergency overheating. The fusible insulation mockup test rig was designed to show how the insulation would behave in the configuration used in SNAP-23A during ordinary steady state conditions and also when the temperature exceeded the melting point, that is, it was intended to show the movement of the insulation and the speed of degradation as well as the changes in the temperature gradient through the insulating layer.

The fixture simulating the heat source jacket, the assembly of the fixture, the test setup and the results of test 1 were described in WANL 3800-41. The following information from test 2 and test 3 completes the "Fusible Insulation Mockup Test".

Test 2 run 1 was conducted with packed insulation to a nominal density of 7 pounds per cubic foot. The test duration was 4.5 hours and the control temperature was 1400°F. Thermocouple locations, in the simulated heat source jacket, are shown in Figure 4-2. The plot of temperature versus time and power supplied is shown in Figure 4-3. The temperature difference between the various positions of thermocouples show that the insulation was substantially intact. An inspection of the insulation after the test revealed some shrinkage at the hot surface and a loss of resiliency as shown in Figure 4-4. The insulation was cut and the cross section shown in Figure 4-5 indicates that approximately 1/4 inch of the inside surface of the fusible insulation had sintered into a hard crust. This shows that some degradation had taken place at the hot surface which was in excess of the safe operating limit of 1200°F.

Test 3 run 1 was conducted at a radiation dome surface control temperature of 1700°F. The test duration was 2 1/6 hours. The temperature versus time and power supplied is shown in Figure 4-6. It can be seen that thermocouples 11, 16 and 19 all registered temperatures in excess of 1500°F indicating that considerable degradation of the insulation had taken place. This would indicate that at least 2 to 2 1/2 inches of the interior portion of the insulation had

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Figure 4-2. Schematic of Test Fixture Simulating the Heat Source Jacket
Reference: Layout 711J833

Figure 4-3. Temperature vs. Time and Power Supplied Test 2 Run 1

Figure 4-4. Fusible Insulation Showing the Hot Side After Test 2 - Run 1

Figure 4-5. Cross Section After Test 2 Run 1 Showing 1/4 Inch of Dense, Sintered Insulation on the Inside

Figure 4-6. Temperature vs Time and Power Supplied Test 3 - Run 1

completed degraded. Figure 4-7 shows the upper and inner portion of the fusible insulation with part of the test fixture removed. It can be seen that considerable gap exists on the hot surface of the insulation and that the insulation layer had begun to sag down away from the cold exterior surface. Figure 4-8 shows the hot side of the insulation with the location marked for the thermocouples at the $1/3$ distance through the thickness of the insulation, that is, thermocouples 14, 15, and 16. Figure 4-9 shows the insulation after it had been cut. The thermocouple at the top of Figure 4-8 is shown on the left hand side of the insulation in Figure 4-9. With careful examination the tip of the thermocouple for the $2/3$ thickness of the insulation that is the 17, 18, and 19 series can be seen buried in the fused glass near the surface of the remaining insulation material. This readily explains why couples from all three levels, that is, the hot surface, the one third distance, and the two thirds distance as shown by thermocouples 11, 16 and 19 all immediately reached a very high temperature reading and then stabilized. Figures 4-6 and 4-9 from this test show quite clearly that at temperatures expected during emergency overheating significant degradation of the insulation will take place and a significant thermal bypass will then occur.

The best comparison to show the change in effectiveness and durability of the fusible insulation can be illustrated by observing the behavior of the thermocouples at the $2/3$ thickness level, that is, thermocouples 17, 18 and 19. In test 2 where very minor degradation of the insulation occurred, thermocouple 18 shows a very stable behavior in Figure 4-3. In test 3 thermocouple 19 showed complete degradation of the insulation and an almost immediate rise to the maximum temperature of 1500°F whereas in WANL-3800-41 the behavior of thermocouples 17 and 19 in test 1 showed partial degradation which was dependent upon the position and the type of packing of the insulation.

Interpretation and Conclusion

1) It can be concluded that the borosilicate E-fibre or fusible insulation can be used up to 1200°F without shrinkage and would therefore function as a safe and durable insulating material. Thermal conductivity data measured with the spherical insulation tests and using thermocouples 15 and 18 at a temperature of 700 to 800°F in test 2 indicated that the thermal conductivity of the fusible insulation was approximately 0.04 Btu/hr ft degrees F.

Figure 4-7. Fusible Insulation After Test 3 - Run 1 With the Top of Fixture Removed

Figure 4-8. Fusible Insulation Showing the Hot Side After Test 3 - Run 1

Figure 4-9. Cross Section of Test 3 Run 1 Showing That at Least the Inner Two Thirds of the Insulation Had Fuzed

2) In the event that the temperature of the environment exceeds 1200°F , the fusible insulation will begin to sinter or it will contract, densify, get firm, and when temperatures reach $1525 \pm 25^{\circ}\text{F}$, it will melt into a glassy material. The fusible insulation contracts away from the hot surface whether this hot surface would be the heat source on the inside or whether the heat would be externally applied as in a fire which would be equivalent to the fusible insulation sintering tests.

3) In test 3, which had the highest power input, the inside hot surface was approaching 1800°F and at all places the fusible insulation was therefore exposed to temperatures in excess of 1500°F . Under these conditions, thermal analysis has shown that the heat dissipating capacity from the hood surface was approximately $3400 \text{ Btu/hour ft}^2$ of outer surface. This heat transfer was calculated on the basis of a radiative heat transfer mode as would be expected in the actual SNAP-23A system. In other words, the generator can dissipate far in excess of 1 Kw at a peak copper accumulator temperature of 1800°F . Therefore, the insulation is feasible for providing an emergency heat leak path in the event of emergency overheating of the entire system.

5. SYSTEM DEVELOPMENT

Subtask 510 - System Testing

EMS life test and preparations for receiving the FPMS assembly continued through this report period. On January 27, 1970, the EMS temperature controlled environment was discontinued. Room modifications for FPMS testing, in accordance with safety procedures, were initiated.

The Thermal Performance Test for Fueled Prototype Mockup System, FPMS-1, was issued on January 30, 1970. This procedure was amended to include the thermal performance test of FPMS with the PMC-2 and PMC-3 converter since baseline converter data was not available at the time of issue. The revised document was issued on February 25, 1970 as FPMS-1, Revision 1.

The following chronology of events is a summary of the progress attained during February, 1970:

<u>Date</u>	<u>Event</u>
February 4, 1970	After assembly of the FPMS, monitoring, in accordance with the temporary procedure specified in SNAP-23A-1185, was initiated at 18:00 hours.
February 5, 1970	The FPMS unit was transported to the Engineering Mechanics Laboratory and positioned in the permanent test area, see Figures 5-1 and 5-2. Temporary equipment to monitor voltage and current output was set up with the converter load at 3.8 ohms load.
February 6, 1970	Continuous hourly coverage ended when a temporary alarm system was energized. The converter hold-down bolt was retorqued (Reference: ECO 17603).

<u>Date</u>	<u>Event</u>
February 13, 1970	In accordance with SNAP-23A-1185 "FPMS Interim Test Procedure", the multi-point recorders were set up to obtain thermal performance data. The recorders were used to monitor 20 iron-constantan and 23 chromel alumel thermocouples.
February 23, 1970	A full data point was taken by using a high accuracy millivolt potentiometer. A 3M representative was present during this test.
February 25, 1970	The temporary alarm system was discontinued when the instrumentation and control console was placed in operation. The open circuit condition test described in "Interim FPMS Test Procedure" SNAP-23A-1191 was initiated. Twenty-four hour technician coverage was provided for this test.
February 26, 1970	The EMS and FPMS base assembly and lower rain shield temperatures were compared for equivalent system operating conditions at 32 locations on the base assembly.
February 27, 1970	A full data point was taken for the normal load condition with the power conditioner in the circuit. The converter load was adjusted so that the current was 1.5 amperes and was held constant.
March 3, 1970	After the EMS temperature controlled environment was discontinued, cold frame temperatures increased and the high limits were exceeded causing system shut off. Air circulation was increased around EMS by use of a floor fan and by opening ceiling vents. Ten minutes later, the cold frame temperature was below the high limit and power was restored.

<u>Date</u>	<u>Event</u>
February 2, 1970 and February 16, 1970	Full data points were taken on EMS.
February 26, 1970	An EMS base assembly gas sample was taken and was shipped to Westinghouse R & D for analysis.
March 1, 1970	A full data point for the 1.5 amp load condition was taken.

Figure 5-1. Test Area Floor Plan

Figure 5-2. FPMS in the EM Laboratory

6. SAFETY ANALYSIS

Subtask 610 - Converter Fire Test Support

Safety related tests to determine the overall thermal conductance of the SNAP-23A converter during and after a postulated one half hour long 1475°F and 1850°F fire were completed. Tables 6-1, 6-2, and 6-3 summarize the data. In each case the overall module conductance increased following exposure to the simulated fire environment post-test disassembly of the modules revealed that:

1) In the 1475°F fire module, the cold end segment of the "p" leg melted. This was expected since the element temperature exceeded the melting temperature of the material. The followers were locked in the cold frame holes, probably due to warping of the material. The reduced length of the "p" legs contributed to increased conductivity observed after the test.

2) In the 1850°F fire module test, the elements (n and p) experienced some melting in addition to that noted for the 1475°F test. The top (upside in the fixture) of the aluminum cold frame melted down to the first couple with the molten material probably running into the follower holes. The followers and some elements were skewed. However, all followers were still in contact with their cold cap. The conductivity increase is probably due to the reduced heat path resulting from the shortening of the legs due to melting and plastic flow.

In no case was the outer case of the module breached and the external appearance was that of a device which had been exposed to a high temperature environment.

The test data were then incorporated into the Hittman thermal model to predict the performance of the SNAP-23A system during and after 1475°F and 1850°F fire accident. Radiator effectiveness after a 1475°F fire was given special attention in determining the post-fire steady state temperature levels. The analytical results of the fire analysis indicated that over 80 percent of the fin area did not melt during the half hour fire. Assuming no other damage, this minor fin loss would result in a negligible change to the thermal performance (i.e., less than 15°F rise in fin root temperature). This, however, would be a very optimistic

TABLE 6-1

MODULE CONDUCTANCE, 1475°F FIRE MOCKUP TEST NUMBER 1

Cold Frame Temperature °F	Hot Frame Temperature °F	Overall Conductance, Watts/°F	
		<u>Pre-Test</u>	<u>Post-Test</u>
160	1053	0.83	---
395	1057	0.93	---
400	1054	---	1.14
595	1072	1.07	---
505	1070	---	1.23

TABLE 6-2

MODULE CONDUCTANCE, 1475°F FIRE MOCKUP TEST NUMBER 2

Cold Frame Temperature °F	Hot Frame Temperature °F	Overall Conductance, Watts/°F	
		Pre-Test	Post-Test
156	1043	0.94	---
190	1126	---	0.96
402	1098	0.98	0.96
406	1153	---	1.08
602	1158	1.08	---
156	1043	0.94	---
190	1126	---	0.96
402	1018	0.98	---
406	1153	---	1.08
602	1152	1.10	---
604	1172	---	1.22

TABLE 6-3
MODULE CONDUCTANCE, 1850°F FIRE MOCKUP TEST

Cold Frame Temperature °F	Hot Frame Temperature °F	Overall Conductance, Watts/°F	
		Pre-Test	Post-Test
161	1035	1.04	---
202	960	---	1.97
400	1088	1.15	---
400	1053	---	1.89
601	1130	1.2	---
600	1104	---	1.99

assumption. In all probability, significant fin degradation can be assumed to occur over and above fin melting. Such items as fin warpage and fire residue buildup along the fin surface can block the air flow passages. The exact radiator degradation from the above effects, is unknown. Therefore, for the safety evaluation, the worst case was used. Convection from the fin surface areas was assumed to be zero, and only radiation heat transfer was assumed.

All analytical estimates made to date indicate that the 1850°F fire will completely destroy the radiator. Therefore, the post-1850°F fire results assume no radiator. Heat transfer out of the converter is from the converter can (emissivity of 0.8).

The analytically determined response of the SNAP-23A system to fire using the test data is shown in Figures 6-1 and 6-2. The temperatures of internal components rise somewhat after the fire, because some or all of the radiator has been removed. The end point conditions for the transient plots can be established by referring to the steady state temperature distributions of Figures 6-3 and 6-4. System internal temperatures do not respond significantly during the actual fire. Hence, it is the post-fire steady state temperatures which are of interest from a safety standpoint. Table 6-4 presents some of the system temperature limitations which are applicable to the heat source following a fire. The key temperature limitations are compared with analytical model results. For either fire, the calculated temperatures are less than critical temperature limits.

Note that the 1475°F post-fire temperature profile is somewhat higher than the 1850°F post-fire temperature profile. This occurs even though some effective radiator area remains after the 1475°F fire and none remains for the 1850°F fire. The reason for the results lies entirely in the measured post-fire converter conductance. The thermal resistance of the converter is the predominating influence on internal system temperatures.

Figure 6-1. Response of SNAP-23A System Components
During and Following 1475°F Fire

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Figure 6-2. Response of SNAP-23A System Components During and Following 1850°F Fire

613208-6B

Figure 6-3. SNAP-23A System Steady State Temperatures Following a 1475°F Fire

613208-8B

Figure 6-4. SNAP-23A System Steady State Temperatures Following a 1850°F Fire

TABLE 6-4

COMPARISON OF POST FIRE SYSTEM TEMPERATURES WITH SAFETY LIMITS

<u>Component</u>	<u>Critical Temperature ~ °F</u>	<u>Calculated Temperature ~ °F</u>	
		<u>Post 1475° Fire</u>	<u>Post 1850° Fire</u>
Fuel	3470° melt	2280	2140
Fuel/Fuel Capsule I/F	< 2000° desirable	1870	1720
Hastelloy C Fuel Capsule	< 2310° melt	1860	1710
U-8 Mo Biological Shield	2100° melt	1790	1630
Shield/Copper Accumulate	1742 eutectic melt formation	1730	1580
Heat Source Outer Shell	< 2000 for minimal strength	1730	1570

Subtask 630 - Preliminary Safety Analysis Report

The Phase I safety assessment of the SNAP-23A system was completed and a revised Preliminary Safety Analysis Report drafted for issuance early in Phase II. The studies indicate that the FPMS reference system design is generally in accord with the safety criteria established at the start of the SNAP-23A Program. The significant results of the Phase I safety effort are as follows:

- 1) With one exception, the safety criteria evolved at the start of the program still appear to be attainable design standards. A thorough survey of the explosion-overpressure accident environment has indicated that the original criterion was unrealistic. The overpressure accident model defined in the PSAR is based on conditions present at 30 feet from a 9,000 gallon propane tank truck with a two percent equivalent TNT yield explosion.
- 2) Six tests were completed on the SNAP-23A Program which have a direct bearing on assessing nuclear safety. The results of the tests have been favorable and generally correlate analytical estimates of system behavior and response to adverse accident environments.
- 3) The many impact analyses indicate that the heat source can safely meet handling, storage, test, and transport impact environments. The heat source shipping container offers adequate protection.
- 4) Preliminary studies have been completed for impact of the SNAP-23A system. A specific emphasis has been made to describe the environment, probabilities, and responses associated with air transport of the SNAP-23A system. The data accumulated to date indicate that air transport is feasible but will, however, require a specially designed shipping container and airplane tiedown provisions to ensure fuel containment and shielding integrity for severe impact modes.
- 5) A preliminary system shipping container design is presented in the revised PSAR. The container is made with aluminum, uses honeycomb, and consists of an inner and outer assembly. The inner and outer assemblies are used together for aircraft transportation. The inner container can be used alone for all other transport and storage requirements.

6) Fuel capsule hydrostatic tests have been completed at ORNL. These tests verify analytical estimates of the capsule strength and indicate that fuel containment can be achieved in external pressures of 16,000 psi (greater than the equivalent depth at the deepest known point in the ocean).

7) Galvanic corrosion tests at NRDL have been performed for a mockup of the SNAP-23A heat source materials. These tests have concluded that, if seawater enters the interior of the SNAP-23A system, the fuel will remain contained for 3470 half-lives of strontium-90. The combination of hydrostatic tests, corrosion tests, and seawater release analyses indicate the satisfactory degree of safety which the SNAP-23A system possesses for an oceanographic application.

8) The radiological consequences of an airborne fuel release have been analyzed using an air release source term based upon vapor pressure and a postulated fire environment. A simple body model defines the uptake of the strontium-90 and the dose to critical organs. Doses are well below the allowable critical organ doses for the general public.

9) Shallow and deep water continuous fuel releases have been described. Maximum permissible continuous concentration (MPCC) is the index used to evaluate the severity of the fuel releases. It has been concluded that the underwater fuel release will not present a severe safety hazard.

10) A new analytical thermal model has been prepared, checked out, and used for the safety analyses. Accuracy of analytical temperature predictions obtained with the thermal model has been verified by the test data obtained during EMS testing at WANL.

11) Many analytical studies have been made in order to determine response of the SNAP-23A system to 1475°F and 1850°F one half-hour fires. The studies show that the post-fire converter conductance has a major effect in determining whether the steady state temperatures achieved following the fire will result in fuel capsule and shield integrity. Recent 3M converter fire tests have demonstrated that converter conductance is not adversely affected as a result of either fire. This test result, combined with analytical

studies, indicates that the system alone can meet safety criteria. That is, post-fire steady state temperatures will be within acceptable limits without engineered safeguards or artificial cooling.

12) Siting problems and hazards have been investigated. The general scope of siting accidents can be related directly to the detailed accident analyses contained in the revised PSAR. Other than earth burial, siting poses no unique safety problem. If burial in a very low conductivity soil is a potential hazard then engineered safeguards must be used.

13) Accident analyses have been approached with the aid of accident networks for the primary phases associated with heat source and SNAP-23A system. Probabilities have been assigned to a number of discrete events to aid in judging system response against probability of occurrence.

14) The effect of sequential transportation accidents has been investigated on the basis of the detailed response analyses performed for the various individual accident environments. The postulated heat source accident/series is impact, explosion, fire, thermal shock, and oxidation. The postulated SNAP-23A system accident series is impact, explosion, and fire resulting from an airplane accident on takeoff or landing. For both the heat source and the SNAP-23A system sequences, the analyses presented give confidence that safety criteria can be met.

Subtask 640 - Safety Review

Revised PSAR

Detailed technical review and editing of HAI input to the revised PSAR was completed during this period. Some sections were upgraded to reflect current information and data. The report was issued on 26 February 1970 and a review of this document indicated the need for an errata supplement which is currently in preparation.

Miscellaneous

Support was provided during assembly of the FPMS and during the activities involved in making the FPMS system operational in the designated testing area. Licensing requirements have been satisfied including radiation levels which were found to be significantly lower than earlier predictions.

7. REFERENCES

1. WANL-3800-37, June-August Quarterly Report, Subtask 310, WANL PR(SS)-031.
2. WANL-3800-41, September-November Quarterly Report, WANL PR(SS)-034.
3. WANL-3800-38, Safety Evaluation of SNAP-23A, WANL-TR-(SS)-004.

1. RADIATOR
2. T/E CONVERTER
3. POWER CONDITIONER HARNESS
4. FUEL CAPSULE
5. BIOLOGICAL SHIELD
6. HEAT ACCUMULATOR
7. HEAT SOURCE JACKET, UPPER SECTION
8. JACKET CLOSURE
9. HEAT SOURCE JACKET, LOWER SECTION
10. INSULATED BASE ASSEMBLY
11. INNER BUCKET
12. THERMAL INSULATION
13. HERMETIC SEAL
14. RAIN SHIELD
15. RAIN COVER
16. PROTECTIVE COVER
17. LIFTING LUGS
18. MICA CONE
19. STUD
20. CONVERTER HOT FRAME
21. STRUT MEMBER
22. SHIELD PLUG
23. BARRIER PLATE
24. CAPSULE DIFFUSION BARRIER

FPMS Assembly Drawing