ATTACHMENT A

ADDITIONAL DATA FOR QUESTION 2 & QUESTION 3 OF REFERENCE a:

In order to elaborate further on the ability of the thermoelectric computer code used by INSD to predict the performance of the thermoelectric module, the following data is offered. Six of the couples fabricated for the SENTINEL 100F module were drawn from the production run and assembled and bonded into a 6-couple module for performance and life testing. The 6-couple module was designed to be tested in an electrically heated test fixture specifically tailored for this test. The module itself was fully instrumented, having four hot junction thermocouples, three cold junction thermocouples as well as voltage taps on every element. The test fixture was provided with cold end hardware identical to that being utilized in the 100F module; i.e., pistons, springs and aluminum heat sink. The cold end hardware was also instrumented with thermocouples on the pistons and the heat sink so that the cold end hardware temperature drop could be measured directly. Prior to installation of the module, the parasitic heat losses through the fixture were determined experimentally so that the heat flow through the thermoelectric elements could also be determined from the test data. Parametric testing of this module was performed some months ago and since then it has been on a life test. Arbitrarily selecting one of the parametric data points, it was shown that the performance measured could be predicted by the code. The measured data point for example is shown below:

Hot junction temperature (avg.)	$993^{\circ}F$
Cold junction temperature (avg.)	$226^{\circ}F$
Current	20.08a
Load Voltage	0.486 VDC
Open circuit voltage	1.016 VDC
Load resistance	24.203 mΩ
Internal resistance	26.394mΩ
Electrical power output	9.76 w(e)
Electrical heat input	157 w(th)
Piston temperature (avg.)	$213^{\circ}F$
Heat sink (avg.)	$208^{\circ}F$
∴ Cold end $\Delta T_{CJ-H/S}$	$18^{\circ}F$
Heat to T/E elements (based on parasitic heat loss curve)	122.0 w(th)

When the boundary conditions shown above; i.e., hot and cold junction temperatures and external load are used as inputs to the T/E code, the predicted heat flow to the T/E elements is 121.1 watts which is within less than 1% of the measured heat flow. The conductance of the T/E elements of the module is thus established by computing the ratio of the heat flow to the thermoelectric elements to the temperature drop from the hot-to-cold junction.

The SENTINEL 100F was designed to produce 150 w(e) at B. O. L. when operating at hot junction/cold junction of 1000/225°F. At these conditions, the predicted heat flow to the thermoelectrics at the matched load condition is 1800 watts thermal. Thus the conductance is 7.932 Btu/hr-°F. Since the conductance is essentially $\frac{kA}{L}$, any combination of these parameters which give the proper conductance can be used in the thermal model. For the analyses presented, we elected to hold the conductivity constant (in the tables) and vary the A/L ratio and the electrical power output for the different operating conditions. The electrical power output is dumped to a heat sink at the cold junction in the thermal model. As a general rule, the effective, conductance of the elements on short circuit (Pe = 0) and on open circuit (Pe = 0) is between 20 - 30% higher and lower respectively than when on load.

ADDITIONAL INTERFACE DATA

a. Cold End - As can be noted from the measured data presented earlier, the cold-end temperature drop (i.e., from the cold junction to the heat sink) is 18°F. The heat flowing through this cold end hardware is the heat to the thermoelectrics less the electrical power output or 122 - 10 watts = 112 watts. The conductance per unit area based on element area is thus

$$\frac{112\ (3.4152)(144)}{(18)(2.9316)} = \frac{Q}{\Delta T\ (Ael)} = 1044\ \text{Btu/hr-ft}^2\text{-}^\circ\text{F}.$$

Although conductances this high have been measured on some SENTINEL generators in the past, the fabrication tolerances of the parts making up the cold end hardware causes variations in cold end conductances. Therefore for the SENTINEL 100F analyses we elected to choose a more conservative (and more typical) value of cold end conductance of 425 Btu/ft²-hr-°F as shown in INSD-3080, page 88.

b. Module Heat Sink-To Housing Lid Interface - This interface is an aluminum-to-aluminum interface with Dow Corning 340 grease in the interface. Interface tests were conducted at INSD in March and April of 1971 using a calibrated test apparatus on the effects of various types of thermal greases or compounds on the conductance of aluminum-to-aluminum interfaces when compared with a dry interface. The test apparatus was designed to measure the heat flow through the interface and the temperature drops. The tests were conducted using plain silicon grease, aluminum grease, Dow Corning 340 grease and others and were conducted over a range of interface heat fluxes and interface temperatures. The Dow Corning 340 grease, which is also utilized in our standard TELAN generators, was found to be as good as any of the compounds tested and better than most. The value of conductance shown in INSD-3080, page 88, of 1500 Btu/hr-ft²-°F is typical of measurements made during these tests. The tests encompassed interface heat fluxes as high as 45 watts/in^2 which are considerably higher than anticipated for this interface. The interface pressure (mechanical) for the tests was low and of the order of 25 - 30 psi which is typical for these interfaces. This data is also applicable to the interface between the finned shipping head and the housing lid.

to module Hot Plate

c. Biological Shield - This path encompasses four interfaces as well as the module hot plate. These are the interface between the biological shield and hot plate, hot plate and getter, getter and mica, and the mica to hot shoe interface. The exact breakdown of the total temperature drop between the biological shield and hot junction is not known, but the overall effect has been measured on several generators. For example, the SENTINEL 8S electrically heated generator was instrumented with thermocouples on the biological shield, hot junction, cold junction, etc. and was tested extensively. The table shown below compares the data taken on the SENTINEL 8S with the assumptions used in the thermal model for the SENTINEL 100F (see case 1, INSD-3080).

	8S	100F
Q_{inv}(w)	301	2100
Biological Shield T(^oF)	959	1090.6
Hot Juntion (^oF)	900	1001.6
Total ΔT (^oF)	59	89
Interface Q(w)	250	1873
Common Area (in^2)	25.967	132.733
Effective Btu/hr-ft^2-^oF conductance	80.25	78

hot plate area or Bio. Shield area

The conductances shown in INSD-3080, page 88, for the module hot plate-to-hot junction and biological shield-to-hot plate interfaces are obtained by making allowances for the conductances of the hot plate and biological shield portion of the path (based on published data), and assuming the individual interface ΔT to be one quarter of the total interface ΔT. As shown in the table above, the net result is to give an effective conductance close to that measured for the SENTINEL 8S.

d. Other Tests - In addition to the previous test data, each thermoelectric module is tested in a thermally calibrated electrically heated test fixture prior to installation in a fueled generator. This test is primarily intended to check the electrical performance without the restrictions required when using a radioactive heat source. However, it is instrumented for thermal evaluation also and, in fact, is verification for the radioactive fuel inventory selection.

ATTACHMENT B

TAP-3 USER'S MANUAL

received 12/10/71 RHO

TELEDYNE ISOTOPES 3288

110 WEST TIMONIUM ROAD
TIMONIUM, MARYLAND 21093
TELEPHONE (301) 252-8220
TELEX 87-780

Refer to: TPS-CNY-239
30 November 1971

RECEIVED DEC 2 1971 U.S. ATOMIC ENERGY COMMISSION Regulatory Mail Section

71-5862

Mr. D. A. Nussbaumer, Chief
Fuel Fabrication and Transportation Branch
Division of Materials Licensing
U. S. Atomic Energy Commission
Washington, D. C. 20545

Gentlemen:

In response to your letter of 15 November 1971, reference DML:RHO (19-01398-34), we are submitting the enclosed data. Each item has been answered individually; but, because of the general nature of some requests, it has been necessary to limit the reply to what we believe to be the pertinent facts. Complete documentation would require a very lengthy report.

The TAP3 Computer Program Users Manual (Item 9 in your letter) is currently being rewritten to incorporate all existing amendments. It is expected that this work will be completed within the next two weeks. Two copies will be forwarded to you as soon as the manual becomes available.

We trust that this data will meet your requirements. If you have further questions, please do not hesitate to ask.

Sincerely,

NUCLEAR SYSTEMS DIVISION

C. N. Young

C. N. Young

/mb

Enclosure

Enclosure to TPS-CNY-239 dated 30 November 1971

1. References for all relevant thermal properties for all the materials listed on pages 84 through 86. Information concerning the fuel, bioshield, MIN-K, glassrock, and the emissivities of all materials, is essential to our review.

Material	Property	Reference
(1) FUEL	Conductivity	(a)
($SR_2T_10_4$)	Specific Heat	(b)
(4.93 g/cm^3)		
(2) LINER	Conductivity	(c) Vol. I.
(304SS)	Specific Heat	(c) Vol. I.
(8.029 g/cm^3)	Emissivity	(c) Vol. I.
(3) CAPSULE	Conductivity	(c) Vol. II.a.
(Hastelloy-C)	Specific Heat	(c) Vol. II.a.
(8.492 g/cm^3)	Emissivity	(c) Vol. II.a.
(4) BIO-SHIELD	Conductivity	(c) Vol. II.a.
(Tungsten)	Specific Heat	(c) Vol. II.a.
(19.3 g/cc)	Emissivity**	(g)
(5) INSULATION	Conductivity*	(e)
(Johns-Manville)	Specific Heat	(f)
(Min-K 1301)		
(20 lbs/ft^3)		
(6) HOUSING, HEAT SINK, SHIPPING HEAD	Conductivity	(c) Vol. II.
(6061-T-6 Aluminum)	Specific Heat	(c) Vol. II.
(169 lbs/ft^3)	Emissivity**	**Specified as .8 for fire analysis
(7) SHIELD SUPPORT INSULATION	Conductivity	(d)
(Glass Rock #50)	Specific Heat	(d)
(45 lbs/ft^3)		
(8) SHIELD BASE PLATE & HOLD DOWN RING	Conductivity	(c) Vol. II.a.
(Inconel 750)	Specific Heat	(c) Vol. II.a.
(8.253 g/cm^3)		

* Thermal conductivity is modified to account for our experience with argon gas filled Min-K formulations. Analysis of RTG performance data indicates R-values should be about 10% higher than published values.

** The tungsten biological shield is chrome plated on all inner & outer surfaces.

REFERENCES FOR ITEM 1.

(a) "Properties and Fabrication of Curium-244 and Strontium-90 Fuel Forms," by R. E. McHenry, Oak Ridge National Laboratory. Published in Symposium on Materials for Radioisotope Heat Sources 10/2/68, Vol. 14 Nuclear Metallurgy.

(b) ORNL-4043, AEC Research & Development Report, "Strontium-90 Data Sheets," by S. J. Rimshaw and E. E. Ketchen (Conf.)

(c) Aerospace Structural Metals Handbook, ASD-TDR 63-741, Vol's I, II and IIa, March 1967, Air Force Materials Lab., Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.

(d) GlasRock Products, Inc. Bulletins dated 1/6/70, GlasRock Products, Inc., 2210 Marietta Boulevard N.W., Atlanta, Georgia 30318.

(e) Johns-Manville Product Bulletins IN-758A and ALO-3633-7, AEC Research and Development Report Phase I Final Report, Oct. 2, 1967, by J. O. Collins, J. M. Research and Engineering Center.

(f) Johns-Manville Product Bulletin IN-502A.

(g) Thermophysical Properties of Matter, The TPRC Data Series Vol. 7, Thermal Radiative Properties, Metallic Elements and Alloys, by Y. S. Touloukian and D. P. Dewitt, IFI/Plenum NY-Wash. 1970.

2. Descriptions of experiments, computer code, and calculations used for evaluating the effective thermal properties of the thermoelectric elements.

The thermoelectric code used by Teledyne Isotopes NSD is called "VINCE-TOM" and is based upon the evaluation of the following differential equation for the temperature distribution through the T/E elements:

$$\frac{d}{dx}\left(k A \frac{dT}{dx}\right) + \frac{I^2 \rho}{A} + \tau I \frac{dT}{dx} = O$$

This equation considers all heat transport effects including conduction, Joule heating and Thompson heating and is solved by the code for both elements of the couple. The code also calculates the heat required for the thermoelectric elements, and the electrical power output for any number of couples in any series, parallel or series-parallel configuration for any external load situation. The major inputs to the code are couple geometry and material properties. The property data for the 2N/TAGS/SnTe materials system used in the SENTINEL 100F module is well known and documented. These materials have been utilized in a number of the SNAP 19, Viking and Pioneer space generators, and in the SNAP 29 generators. Numerous tests and correlations of generator and couple performance have established the validity of the thermoelectric property data and the ability of the code to predict their performance.

The 2N/TAGS/SnTe couple used in the SENTINEL 100F is a single doped N-element and a segmented P-element. Since the thermal conductivity of these three materials exhibit different shaped curves as a function of temperature, the only practical way to define the conductance for the thermal code is to use the predicted heat flow and ΔT_{HJ-CJ} from the T/E code; i.e.,

$$C = \frac{Q_{T/E}}{\Delta T_{HJ-CJ}}$$

3. Description of tests and calculations used to evaluate the effective conductances of key interfaces as listed on page 88.

The interfaces listed on page 88 exist on nearly every SENTINEL and SNAP generator built by Teledyne Isotopes and this includes some 25 SENTINEL types and a dozen SNAP type generators.

The hardware in each is practically identical except for size. The properties of the thermoelectric materials are well know using these in our thermoelectric code, good agreement is found between the electrical power generated and predicted at measured hot and cold junction temperatures in a generator configuration. Therefore, the heat flow through the thermoelectric elements is known. Since we also measure hot plate temperature and fin root temperature on our generators, the interface conductances are readily calculated.

In the past, we have conducted heat transfer tests on instrumented cold end hardware and these were found to be in good agreement with values measured in the generator configuration. Currently, we have been testing a partial mock up of the SENTINEL 100F T/E module. This module is fully instrumented to provide cold end temperature drops using the exact hardware that will exist in the SENTINEL 100F module. Analysis of this data indicates that the cold end conductance will be even higher than assumed for the fire analysis so the initial internal temperatures will be lower than those presented.

In addition to the above, an in-house program was conducted about six months ago in which the effective conductance of various generator type interfaces were evaluated. These tests included evaluations of dry interfaces and interfaces employing various types of thermal greases or compounds. The grease currently being employed is Dow Corning DC-340 thermal compound.

4. Does the effective conductivity of the thermoelectric elements given on page 84 include the interface resistances given on page 88? Please explain.

No, it represents the effective conductivity of the T/E elements on open circuit. The interface resistances presented on page 88 represent our experience with the various hardware interfaces presented. The conductances are based on either the common area between the nodes involved or on the element area in the case of the hot plate-to-hot junction and cold junction-to-module heat sink conductances.

5. The thermal properties for nodes 55 through 73 and 158 through 160 as a function of temperature.

Nodes (55, 56, 57), 72 and 73 are the module hot plate, bellows and lower ring of bellows assembly and are 300 series stainless steel. Properties are given in tables presented in INSD-3080 attachment 4. Nodes 58, 60, 62 and 158, 159, 160 represent the thermoelectric elements. Nodes 58, 60 and 62 are the hot junctions and 158, 159 and 160 are the cold junctions. Nodes 59, 61 and 63 represent the Min-K insulation (inside the sealed module) which surrounds the thermoelectric elements and is argon gas filled as is the Min-K insulation in the generator.

- For normal operation; i.e., steady state, with electrical power being generated, the conductance of the thermoelectric elements and the electrical power generation is varied until a match is obtained between the results of the thermoelectric code runs and the thermal code runs. The electrical power is removed at the cold junction in the thermal model since this is thermal energy which has been converted to electrical energy. The flow of current through the thermoelectric elements increases the effective conductance of the elements so it is not possible to use straight conductivity values for tne elements under normal operation. For the fire analysis, open circuit is assumed so there are no current effects.

6. Description of correlations and values used for all the boundary conditions (radiation and natural convection heat transfer coefficients).

- For natural convection from the exterior surfaces of the housing, the following correlations were used:

$$h = C\left(\frac{\Delta T}{L}\right)^n$$

where C = .12 for downward facing and horizontal surfaces
C = .29 for vertical surfaces and upward facing horizontal surfaces
n = 0.25

These equations were programmed into the code runs. Natural convection was only assumed for the steady state runs and for the transient periods after the fire.

The radiation heat transfer from the external surfaces was calculated by the code using the tabular values of emissivity and radiating to 130°F ambient in the case of the fire analysis.

7. Description of tests conducted for evaluating the heat transfer from the finned shipping head. Also, state the fin dimensions and calculate the actual external surface area.

This question is not pertinent to the fire analysis but only to the steady state cases which were analyzed. In the case of the fire analysis, the volume of the fins was neglected as stated in INSD-3080. The justification for this is that because of the very large exposed surface area of the fins, the fins will reach melt temperature in about 30 seconds if the fire heat flux is assumed to impinge uniformly on their total surface area. Therefore for the fire analysis only the base of the finned shipping head was included in the model.

• For the steady state analyses, the performance of the finned head was based on the results of tests of a typical finned head configuration over a range of fin root temperatures. For this test, the test apparatus consisted of a finned shipping head electrically heated under the base by an insulated heater plate about the size of the module. The parasitic losses were determined and found to be a very small percentage (approximately 0.8 percent) of the total electrical heat input. The test results were analyzed and it was determined that the effective heat transfer coefficient over the range of fin root temperatures of interest (100 to 225°F) could be expressed as $h_{eff} = 0.11 (T_{FR} - T_{AMB})^{0.34}$ BTU/HR-°F-Ft². This equation was programmed into the steady state code runs to simulate the performance of the finned shipping head. The fin configuration consists of 48 anodized aluminum fins, 10 inches high and 1/8 inch thick, located in a 24.25" diameter area and having a total surface area of 125 square feet.

based on actual fin area only for normal conditions includes both radiation + convection. Formula determined by experiment

8. Justification for the value of 65 Btu/hr·ft² used for the solar heat load. State the value of solar absorptivity used for the cask surface.

The solar heat load was determined as follows. From Reference (1)*, a conservative value of direct solar irradiation on a surface normal to the sun's rays at the earth's surface on a cloudless day was selected as 320 BTU/HR-Ft². Since no more than half of the total generator surface area (actually less) can be exposed to the direct rays of the sun this irradiation was reduced to one-half or 160 BUT/HR-Ft². A value of absorptance for solar radiation of 0.4** for the surface was assumed.

$$\frac{Q}{A}\text{solar} = 320\,(.5)(.4) \cong 65 \text{ BTU/HR-Ft}^2 \text{ absorbed}$$

* Reference (1): Heat and Mass Transfer, E. R. G. Eckert & R. M. Drake, Jr., McGraw-Hill Book Co., Inc. 1959.

** The SENTINEL 100F housing is protected by an epoxy-polyamide coating system.

9. Two copies of the latest users manual for the TAP3 computer program. Please indicate and explain all revisions to the program made since the manual was published.

To be forwarded under separate enclosure.

10. Explanation as to how the TAP3 program handles both fire and internal gap radiative heat transfer. The table on page 86 indicates a constant heat flux from 5°F to 1800°F. The fire heat flux is a function of the cask surface temperature and is normally calculated by the program.

The table on page 86; i.e., Table 21, which specifies the fire heat flux in BTU/Ft^{2}Sec should have the abscissa labeled as time instead of temperature. The time is given in seconds and defines the fire as starting at 5 seconds and continuing until 1800 seconds. From 1800 to 1805 the fire heat flux is assumed to decay to the solar heat flux. These tables were spliced together from the computer print out and the time label for this table was inadvertently left out. The abscissa for all the other tables given on pages 84 to 86 is temperature as indicated.

The fire heat flux shown in Table 21 is the heat flux impinging on the exterior surfaces. In the TAP3 program, this heat input is handled by assuming that this heat is internally generated in the surface nodes. The net heat flux is of course a function of the housing surface temperature and is calculated by the program. As can be seen, this method of handling the fire heat input is conservative.

The method by which TAP3 handles internal gap radiative heat transfer is controlled by the programmer. For the analyses presented, equations are programmed into the code which evaluate the emissivity of each of the two surfaces from the tabular input data as a function of their respective temperatures, combine these into an effective emittance or overall exchange factor as desired, and calculate the radiation heat transfer in the normal manner; i.e.,

$$Q_{rad} = F_{12}A_1 \quad \sigma(T_1^4 - T_2^4)$$

where F_{12} is the overall interchange factor.