EVALUATION OF SNAP SAFETY FOR SPACE REACTOR APPLICATION*

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Abstract

The major operational periods investigated for the safety of SNAP systems for space reactor applications are: (1) Shipment and Integration Period, (2) Launch Pad Period, (3) Launch Period, and (4) Re-entry Period. All areas have been investigated for possible safety problems and the results of these studies indicate that all periods except re-entry can use presently known safety procedures to ensure safety of the SNAP systems. In addition to the routine safety procedures, decontamination and monitoring equipment as well as specific launch pad procedures will be necessary for emergency situations. Only the re-entry period contains areas which may present safety problems due to the uncertainty of re-entry burnup and high altitude dispersal of the SNAP fuel elements. Until re-entry burnup can be assured, orbital startup and high altitude orbits ($\approx$ 700 miles) can be used to assure safe re-entry. When re-entry burnup and high altitude dispersal is proven, the re-entry of SNAP units will not add significant contamination to the biospere.

I. Introduction

The program, Systems for Nuclear Auxiliary Power (SNAP), is under development by the U. S. Atomic Energy Commission Office for Aircraft Reactors and the National Aeronautics and Space Administration. Three nuclear reactor concepts are being developed by Atomics International under the SNAP program for space applications. The SNAP 10 power unit is in the 10 kw thermal power range and utilizes a thermoelectric power conversion system. The SNAP 2 power unit utilizes a similar compact reactor which is cooled with

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*Presented at the Space Power Systems Conference, Santa Monica, California, September 27-30, 1960. Work done under AEC Contract: AT(11-1)-GEN-8

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a liquid sodium-potassium alloy and coupled to a mercury vapor turbine generator power conversion system. The SNAP 2 reactor is rated at 50 kw thermal power. The SNAP 8 reactor is a direct outgrowth of the SNAP 2 reactor and will operate in the 500 kw thermal power range. The electrical power output of the three systems is 300 watts for SNAP 10, 3 to 6 kw for SNAP 2 and 30 to 60 kw for SNAP 8. The electrical power range for SNAP 2 and SNAP 8 depends upon whether one or two power conversion units are employed with the reactor systems. All of these systems will use a hydrided alloy of zirconium and highly enriched uranium fuel elements in the nuclear reactor core. Due to the developments that will be forthcoming in the SNAP program, the SNAP safety program for space reactor applications must be general in its approach to the safety problems of SNAP reactors in space as well as specific in respect to the SNAP reactors that are presently being developed. Therefore, the SNAP safety program has been initiated to determine the general problem areas to be resolved for all space reactor applications as well as the specific problem areas that are to be resolved for the present SNAP reactors.

Table I

Safety Design Criteria for SNAP Reactors

1. Safety and Ease of Handling - Reactor system will be designed so that personnel can handle, install and repair the system before launch with safety and ease.
2. Prevention of Accidental Criticality - Reactor system will be designed to prevent criticality of reactor under any conditions except controlled operation.
3. Inherent Shutdown - Reactor system will have inherent shutdown characteristics, i.e., negative temperature coefficient and hydrogen loss at time of fuel cladding rupture, and fail-safe shutdown mechanisms to prevent reactor operation before or after mission time periods.
4. Orbital Startup - Full power operation may be obtained after suitable orbit has been established.
5. Orbital Shutdown - After mission has been completed and prior to re-entry, reactor may be shut down.
6. Re-entry Burnup - Design of reactor system and components will ensure the probability of re-entry burnup for SNAP fuel elements above 100,000 feet.

The extent of the experimental and analytical SNAP safety program can be determined by examining the safety design criteria for SNAP reactors and by investigating the extent of present knowledge in areas of space reactor safety. Compromises on the system design may be necessary in order to obtain a suitable balance between the safety of the system and the operational characteristics of reliability, simplicity and weight. The safety design criteria for the SNAP reactor systems, and on which the SNAP safety program has been based, is presented in Table I.

II. Safety Evaluation of Major Operational Periods

The four major operational periods for possible release of radioactivity from a SNAP reactor that are to be investigated by the SNAP Safety Program are: (1) Shipment and Integration Period, (2) Launch Pad Period, (3) Launch Period, and (4) Re-entry Period.

A. Shipment and Integration Period

The SNAP APU will be shipped as a unit with the reflector units detached to ensure subcriticality of the bare reactor. A special shipping cask has been designed to ensure that the reactor system cannot become critical or supercritical due to any accident enroute to the launch site.[1] Adequate safety measures can be designed into the shipped SNAP package without an extensive analytical and/or experimental safety program.

The shipping cask to be used for the shipment of the SNAP APU will be adequately shielded to prevent any overexposure of personnel during handling or shipment. All shipping criteria as defined by the ICC shipping regulations will be satisfied prior to shipment. The possible fission product inventory due to acceptance tests performed by Atomics International will be negligible at the time of shipment and, consequently, at the time of integration.

Safety problems during integration of the SNAP APU with the payload and eventually the missile will be routine and will not present any unique safety problems. Although a detailed procedure for safe integration of the SNAP APU will be necessary, such procedures can be performed safely within acceptable safety criteria. The gamma-ray dose rates during the integration period will be negligible. The total integrated dose to operations personnel during the integration period can be kept at a minimum and at any level acceptable to the responsible agency.[1]

B. Launch Pad Period

For orbital startup of the SNAP reactor, launch pad operations safety problems will be less than those for the integration period. The reactor may be tested on the launch pad prior to launch at a low power level or "zero" power. For this case, the additional fission product inventory produced during such acceptance tests will be negligible from a safety standpoint and will not present additional safety problems.

If a SNAP reactor is operated at full power on the launch pad and during launch, the total dose rate at various distances for a thermal power level of 50 kw is shown in Figure 1.[1] These dose rates are directly proportional to the power level of the reactor and are within safe limits probably up to a power level of 500 kw thermal. A possible SNAP launch configuration is shown in Figure 2. The gamma dose rates given in Figure 2 were determined on the basis of 30 minute operation at 50 kw thermal and 1 hour decay time in order to evaluate maintenance problems. These gamma dose rates, assuming the lead collar maintenance shield is used, are considered reasonable for all maintenance conditions.

Remote removal of the reactor will be possible in case of malfunction or long delays in launch for either the case of orbital or launch pad startup of the reactor. For either case, the safety problems to be resolved will be routine.

C. Launch Period

For orbital startup of the SNAP reactor, the only possible release of radioactive material will be in case of an abort followed by accidental criticality of the reactor. The maximum credible accident for a SNAP reactor could be a 20 Mw-sec burst. Since the design criteria will be based on prevention of such accidental criticalities, only a remote probability will exist that such an accident could occur. In Figures 3, 4, and 5, the gamma dose rate and integrated dose that would be present from a 20 Mw-sec burst have been shown. Figure 3 shows the results of a burst contained in the missile prior to launch and Figure 4 shows the results of a burst occurring during launch. Figure 5 shows the results of a burst at an altitude of 10,000 feet. None of these cases would occur near populated areas and probably only on the controlled area of the launch site.[1]

If a SNAP reactor is operated at full power on the launch pad during launch, the maximum credible accident decreases in intensity, but the fission product inventory increases due to reactor operation. At a power level of 50 kw thermal, the integrated dose from a 30 minute operation fission product inventory is approximately equal to the integrated dose from a 20 Mw-sec burst.[1]

Although several hazardous conditions could exist during the launch sequence, the extent of hazards is controllable and these situations would only exist for short durations. Continued analysis will be needed in respect to the specific safety evaluation of each SNAP reactor and the radiological monitoring system needed for launch.

D. Re-entry Period

Two methods can be used to ensure that a re-entering SNAP APU will not present a safety problem to the general population of the world. Until re-entry burnup and high altitude dispersal of the radioactive particles (less than 1 micron size above 100,000 feet) can be assured, the method of long-lived orbits to guarantee adequate decay of the radioactivity in the SNAP APU can eliminate re-entry hazards.

As shown in Figure 6, the principle radioactivity in the SNAP APU will be the fission product inventory.[2] In addition to the radioactivity given, the NaK coolant will contain ~60 curies of Na^{24} and K^{42} at shutdown. However, the half-life of Na^{24} and K^{42} is only 15 hours and 12.5 hours, respectively, and will decay much more rapidly than any of the radioactivity given in Figure 6. If long-lived orbits are used as the method to guarantee safe re-entry of a SNAP APU, the only radioactivity to consider as a source of contamination will be the long-lived fission products. The decay period necessary to ensure adequate decay of the SNAP APU radioactivity will depend upon the thermal power level and length of operation. Based upon the analysis for intact re-entry,[2] the necessary decay time to ensure a radiologically safe intact re-entry for any SNAP reactor is ~300 years or a circular orbit of ~700 miles.

The use of SNAP reactors in low altitude, short-lived orbits is being investigated in respect to re-entry burnup and high altitude dispersal to ensure the safe re-entry of such SNAP reactors. Three primary areas of uncertainty exist in the use of this re-entry method. The first area is the ability to release the fuel elements to the upper atmosphere to accomplish burnup.

The results of preliminary re-entry analytical studies[3,4] indicate that individual SNAP fuel elements will burn up and disperse above 100,000 feet if released from the rest of the APU prior to 280,000 feet. Approximately one-half of the energy available to the fuel elements due to re-entry heating is necessary to burn up the fuel elements prior to 100,000 feet. A more refined analysis will be necessary as more information becomes available from the simulated re-entry experimental studies.

Preliminary studies have been completed in arc-jets in which SNAP re-entry conditions have been simulated on models of SNAP fuel elements and materials. Based upon the results of these experiments, one can predict that the SNAP fuel elements will burn up and disperse prior to 100,000 feet if released from the rest of the APU prior to 280,000 feet. These results agreed with the preliminary re-entry analysis within ±10%.[5] Other results indicate that at least 95% of the residue will be dispersed as less than 1 micron debris. The remaining debris would have a size of 5 to 10 microns.

Safety evaluation analysis assuming re-entry burnup and high-altitude dispersal has been completed.[1,2] If the recommended acceptable contamination levels in the atmosphere from SNAP re-entry is based on the maximum permissible concentration in air for Sr^{90} ($10^{-10}\ \mu c/cm^3$),[2] the maximum acceptable re-entering thermal power inventory would be 12 to 120 Mw-year per year or an equilibrium fission product inventory equivalent to 500 to 5000 Mw-year thermal power inventory. Also, based on the concentrations present in the upper atmosphere due to nuclear tests, the dilution factors assumed in this analysis seem to be quite reasonable. In Figure 7, the inventory of Sr^{90} present in the atmosphere due to nuclear tests has been compared to various SNAP APU re-entering power inventories. The assumption made on the graph is that further nuclear testing would not occur and that the various power inventories would re-enter each year. As can be noted from Figure 7, the equilibrium value would not be reached for ~60 years. For the possible space program in which 1 to 3 Mw-year thermal power inventories would re-enter each year, 100 to 300 SNAP 10, 20 to 60 SNAP 2, or 2 to 6 SNAP 8 reactors could be allowed to re-enter each year and the contamination level noted in Figure 7 would not be exceeded. These calculations assumed that only natural radioactive decay would decrease the inventory and no assumptions were made in regards to dilution, deposition or entrainment in the soil.

III. Future SNAP Safety Studies

Based upon the preliminary investigation of the various operational periods of the SNAP APU, the future SNAP safety studies will primarily consist of the various aspects of SNAP re-entry. Thus, only the re-entry period contains areas which may present safety problems due to the uncertainty of re-entry burnup and high altitude dispersal of the SNAP fuel elements.

The following studies have been initiated to furnish the necessary data to ensure safe re-entry of a SNAP APU:

1) Re-entry analysis studies
2) Re-entry heating computer code
3) Simulation re-entry arc-jet studies
4) Emissivity determination for the fuel element material
5) Oxidation and ignition properties of SNAP fuel element material
6) Fuel element properties during re-entry
7) Actual re-entry studies
8) Separation studies on re-entering SNAP APU.

Additional studies will be performed in the other major operational periods in order to refine the preliminary analysis. Additional analytical and experimental studies will be necessary if the restriction of orbital startup for the SNAP reactor is removed for specific missions.

IV. Summary

The major operational periods investigated for the safety of the SNAP systems for space reactor applications are: (1) Shipment and Integration Period, (2) Launch Pad Period, (3) Launch Period, and (4) Re-entry Period. Only the re-entry period contains areas which may present safety problems due to the uncertainty of re-entry burnup and high altitude dispersal of the SNAP fuel elements. All other areas have been investigated for possible safety problems but the results of these studies indicate that known methods for safety evaluation can be used.

The re-entry period has been investigated by both preliminary analytical and experimental studies which indicate that re-entry burnup and high altitude dispersal of the SNAP fuel elements can be achieved. An extensive analytical and experimental safety program has been initiated in this area. The safety evaluation of SNAP re-entry, whether intact or burnup re-entry, has been performed. The safety criteria for each of these cases has been established. If intact re-entry is possible, high altitude orbits of $\sim$700 miles (300 years orbital lifetime) will be necessary to ensure safe re-entry. If re-entry burnup and high altitude dispersal is proven, a maximum re-entering thermal power inventory of 12 to 120 Mw-year per year would not exceed the acceptable contamination levels for the biosphere.

References

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2. F. D. Anderson, "Evaluation of Radiological Hazards Due to Re-entry of SNAP APU," NAA-SR-5482. (Company Official) (To be published)
3. P. D. Cohn, "The Preliminary Investigation of SNAP 2 Re-entry Burnup," NAA-SR-MEMO-4890, February 12, 1960. (Secret)
4. P. D. Cohn, "The Preliminary Investigation of SNAP 10 Re-entry Burnup," NAA-SR-MEMO-5036, March 2, 1960. (Secret)
5. P. D. Cohn, "Evaluation of the Simulated Re-entry Tests of SNAP 2 Fuel Elements," Conducted at Plasmadyne Corp., NAA-SR-MEMO-5159, April 11, 1960. (Secret)

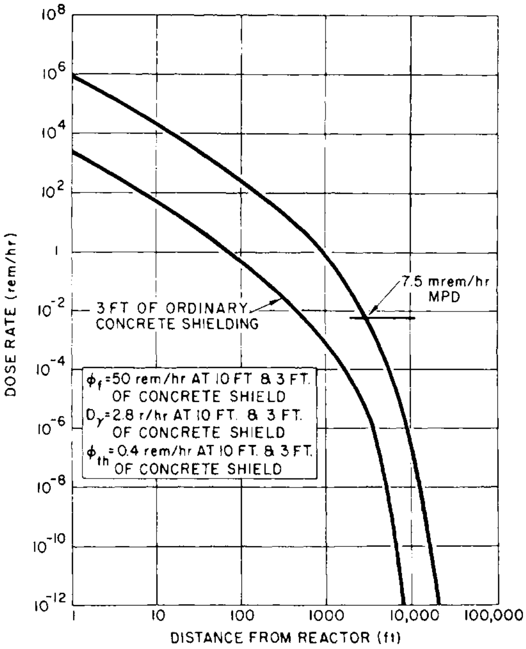

Fig. 1. Total dose rate as a function of distance in air from SNAP APU during 50 kw reactor operation

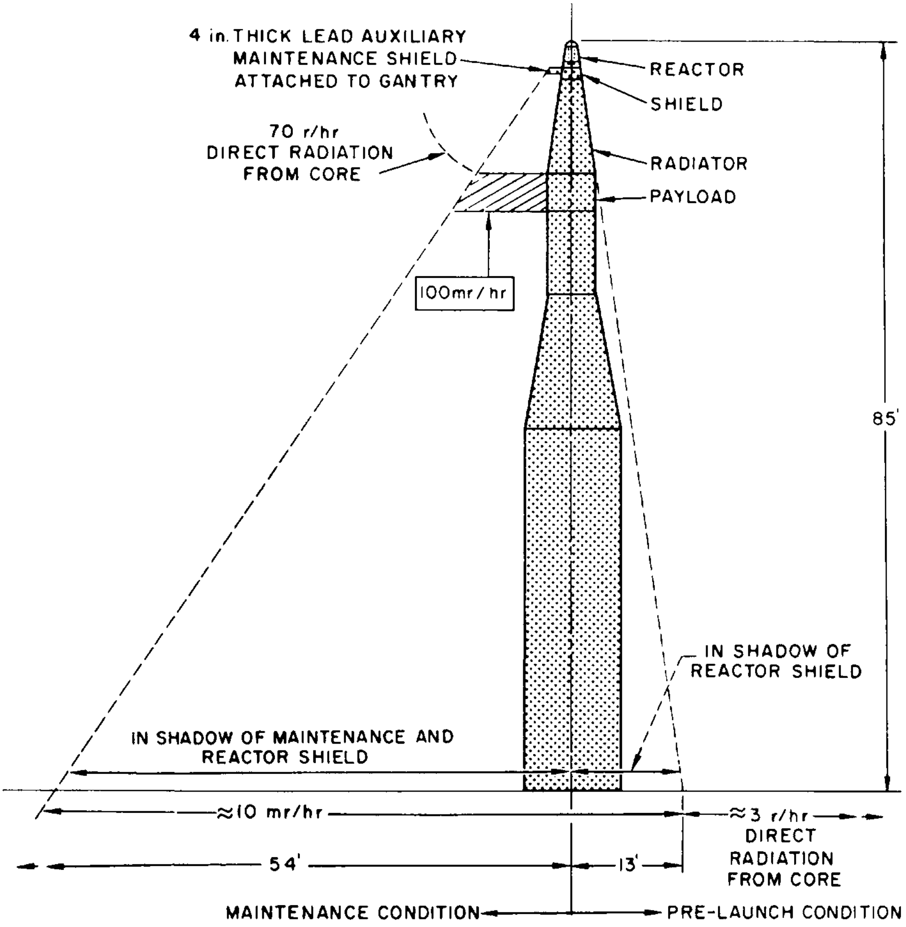

Fig. 2. Tentative SNAP 2 APU launch configuration

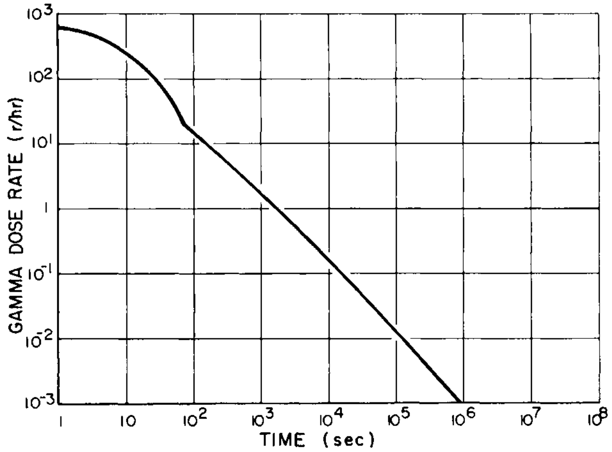

Fig. 3. Dose rate vs decay time at 100 feet from SNAP 2 APU for 20 Mw-sec burst

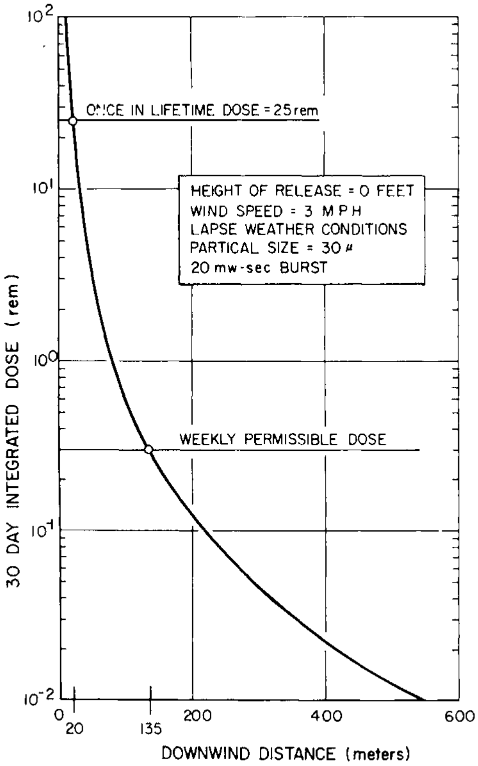

Fig. 4. Fallout pattern for abort on launch pad total dosage (TID)

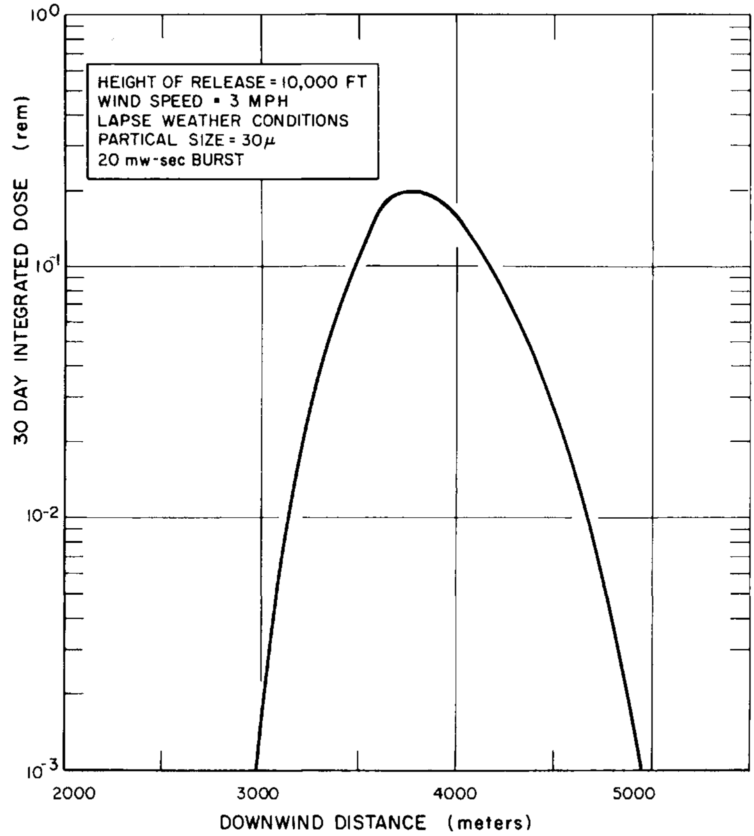

Fig. 5. Fallout pattern for launch abort total dosage (TID)

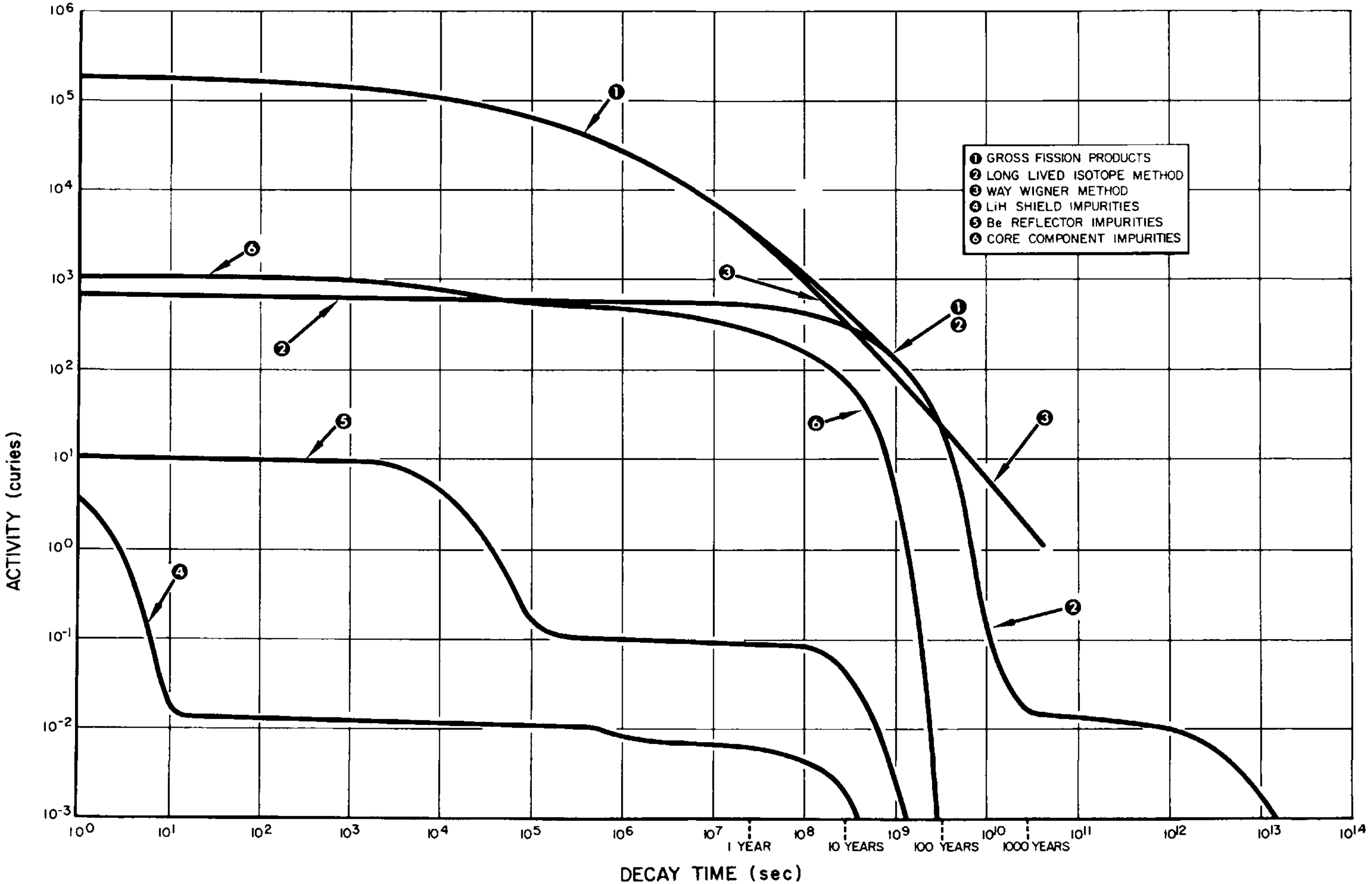

Fig. 6. Radioactivity in SNAP APU after 50 kw-year operation

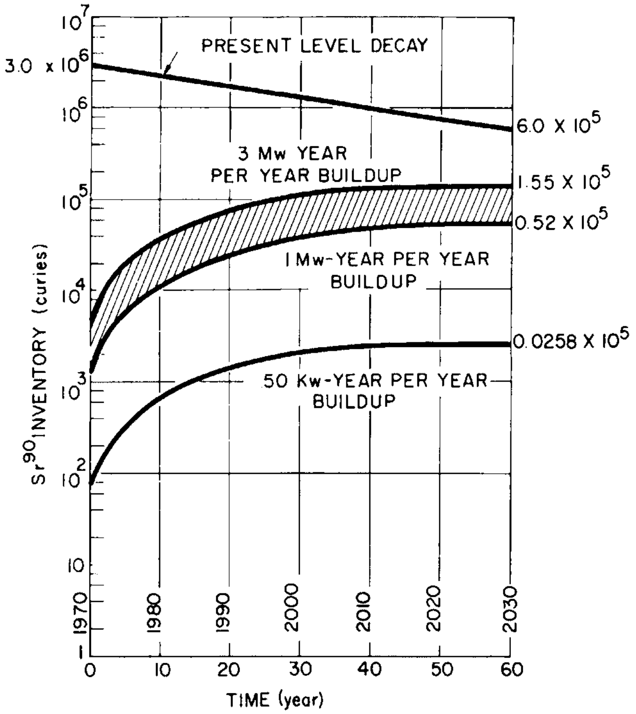

Fig. 7. Comparison of Sr inventory in atmosphere from past nuclear tests and possible space programs