NOV 9 1965

AEROSPACE NUCLEAR SAFETY
V. E. Blake, Jr.
Sandia Corporation, Albuquerque, New Mexico

SC-DC-65-1752

RELEASED FOR ANNOUNCEMENT IN NUCLEAR SCIENCE ABSTRACTS

ABSTRACT

MASTER

CONF-651026-1

This presentation provides a brief history of the Atomic Energy Commission program to introduce nuclear power into space and the results of early flights. The problem of safety will be discussed, as will the direction taken by early designers to achieve safety. The discussions will also cover alternate approaches to safety which were initially considered. There will be a discussion of power supplies currently under development, and the approaches being followed to achieve safety. A series of charts will be presented which categorize the main safety approaches, and will provide the basis for a systematic safety assessment. Finally, a safety philosophy for future design will be presented. It will be shown that safety is not the responsibility of any one agency but rather a problem of all. A challenge will be presented to all parts of the aerospace industry to work together to provide not just adequate safety, but the most safety that present and future technology can provide.

In 1958 the United States placed its first satellite in an earth orbit. The signals from this satellite were heard for about two weeks, the limit of the battery supplied power. Since then the United States has put forth a major effort in space. Satellites weighing many tons have been orbited which have required electrical power plants producing as much as several thousand watts. It became apparent early in the space program that the operation of electrical payloads in space for extended periods of time would dictate that some form of nuclear energy would be required.

The Atomic Energy Commission, in the early 1950's, studied a number of nuclear energy power source concepts from the viewpoint of establishing their feasibility for use in future spacecraft. Both reactors and radioisotope generators were considered. Although ground-based reactors are inherently large and heavy and require massive shielding, it appeared possible that smaller compact versions could be designed for space use. Likewise, the high specific power available from several of the radioisotope materials made it probable that reasonable power levels could be obtained from isotope power sources.

The first space atomic power source was demonstrated in 1959. Called the SNAP-3, it used Polonium-210 as a fuel, weighed four pounds and produced in excess of $2\frac{1}{2}$ watts of power for 30 days. The total power available from this four pound generator was equivalent to nearly one ton of nickel cadmium batteries. In 1961 a version of the SNAP-3 generator fueled with Plutonium-238 was used to power a portion of two navigational satellite

DISCLAIMER

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

DISCLAIMER

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

systems. One of these nuclear powered systems is still operating. The condition of the other is unknown since it ceased transmitting after eight months of operation, apparently due to an electronic failure.

In 1963 larger plutonium fueled power supplies were flown on three navigational satellites. These power supplies were designed to develop 25 watts for five years. Two of these are still in orbit while a third was destroyed as a result of a failure of the missile to place the satellite in orbit.

This year the first reactor power supply, designated SNAP-10A, was placed in orbit around the earth. This unit produced in excess of 500 watts of electrical power for a period of 43 days. The reactor was then apparently shut down by an onboard sensor which malfunctioned. Until shutdown, the power supply performance exceeded expectations.

These systems are members of a family of atomic power supplies designed for use in space. Figure 1 shows the different systems under development. The left side of the chart shows the higher powered systems which are reactors and include units to produce heat as well as those to produce electricity. The right side of the chart shows the lower powered systems, again divided between those to produce heat and those to produce electricity. Figure 2 gives the characterization of the various systems including weight, fuel, and power level. Figure 3 is a partial listing of isotope fuels of interest along with some of their important characteristics.

There is some hazard associated with the use of radioactive materials as an energy source. This is also true of other useful energy sources, like steam or gasoline. The public has learned to take certain safety precautions to live with these more common energy sources, and a similar pattern will evolve with radioactive materials.

The hazards with radioactive materials can arise from the close association between the material and man, or his environment. The hazard can result from inhalation, ingestion, or from direct radiation. To use nuclear power in space, the power supply designer must take steps to reduce the possibility of involving man with the material in a manner which can be harmful.

The ability of any nation to successfully pursue the exploration of space is most certainly governed by the amount of electrical energy which can be carried into space. Figure 4 shows a spectrum of power levels versus lifetime for various space systems. The higher levels of power can be met only by use of reactors. Clearly, there is no competition with atomic energy in this area. In the high intermediate levels, solar dynamic systems, isotope dynamic systems, or reactor systems, all using rotating machinery for energy

conversion, can meet the power levels. Here, the simplicity of atomic power sources, particularly isotope dynamic systems, would clearly seem to offer significant advantages. The low intermediate power levels can be handled by either solar static or isotope static systems. The isotope systems have an advantage since they do not require the erection or precise orientation of large energy gathering mirrors. In the low levels, either solar cells or radioisotope systems can be used. The dollar costs and weights for either system seem about comparable at this power level, but clearly the isotope systems are superior if reliability is a prime consideration.

In summary, there is no source of energy other than nuclear which is as reliable at low power levels, or convenient in the medium power levels, or is even feasible in the high power levels. Nuclear energy will ultimately prove to be indispensable in space. Safety probably represents the greatest drawback to the extensive use of nuclear power in space thus far. Safety is not something that just happens. It must be carefully thought out and positive steps taken to achieve it. There are many ways of buying safety. It is the responsibility of the designers of nuclear space power systems to find and employ the best ways.

The next chart, Figure 5, is shown to present in the form of a multiple path chart, a simplified version of the overall aerospace nuclear safety problem. Given a launch, the chart shows that the flight can result in one of three things. Either the missile achieves a successful orbit, or a short orbit, or it aborts. By definition, all possible eventualities of an attempted launch can be made to fit into one of the blocks. In other words, the sum of the probabilities in this row is one. Since the chart is a simplification, the actual number of blocks in this row can be as many as desired as long as the sum of probabilities totals one. The second row shows what can happen as a result of reentry. Again, every eventuality is covered in these three blocks. The third row shows the form the resulting exposure may take. The final row is a safety index which consists of three items to be evaluated; the number of people involved, the probability of exposure, the severity of exposure. More will be said later about this safety index. The important thing shown by this chart is that each system can be described in a systematic manner which will cover all the possible paths. For most systems, the number of paths will be more than represented by this array. It is important to remember that the probability of exposure is never zero along any path so that some evaluation will always be necessary. For example, a power supply designed to burnup during reentry has some finite possibility of returning intact and it may in fact develop that the greatest potential hazard exists along this unexpected path.

When the critical path or paths are found then attention can be given to these areas to try to reduce the hazard by reducing the number of people involved, the severity of the

exposure, or the probability of occurrence (the three items in the safety index). A plutonium-238 power supply was analyzed recently which illustrates how this evaluation plan can work. A systematic analysis of a similar chart revealed that all the important hazard paths occurred in the short orbit path chain. The critical hazard could occur if incomplete burnup produced particles that would fallout over a limited area producing an inhalation hazard. The probability of a short orbit occurring was calculated to be .03. The long orbit probability was .80, the abort situation was .17. The study further showed that almost all short orbit situations resulted from failure of the second stage engine to restart to circularize the orbit. A Hohmann transfer orbit was being used for the mission where the spacecraft is first injected into an elliptical transfer orbit with a low perigee and a 700 NM apogee. On the first pass through apogee the second stage engine is restarted for a short period of time circularizing the orbit. Failure to restart results in an orbit of only a few months lifetime.

It is also possible to achieve a 700 NM circular orbit by flying a ballistic path in place of the elliptical transfer orbit. In this case the missile flight profile is altered so that a ballistic path is flown with a maximum altitude of 700 NM. The second stage engine is restarted at this altitude and burned until circular orbit velocity is achieved. If the second stage engine fails to restart, the spacecraft simply falls back to earth. The impact point for the mission can be selected so that the radioactive material, if it fails to completely burn up will fall harmlessly over the ocean. By using this ballistic ascent into orbit, the probability of a short orbit is reduced from .03 to .0004 or a decrease of about two orders of magnitude. Since the short orbit was the cause of the greatest hazard, the probability of any hazard occurring was reduced by a factor of one hundred. The ballistic ascent to orbit is not achieved without penalty, however. On this flight it required about 500 pounds of additional fuel on the second stage to fly the altered mission profile since this profile is a less efficient way of achieving orbit. However, the actual mission was not penalized since the missile had a payload capability of over 3000 pounds and the payload for the proposed flight weighed only 1600 pounds. In other words, at no cost to the mission the probability of a hazard was reduced by a factor of over a hundred.

This is not the only way to decrease the number of short orbits and the resulting random reentries. Another way is to use a controlled deorbit package for the nuclear power supply. Here, the intention would be to deorbit the power supply on any mission that failed to achieve the long-lived design orbit. The decrease in probability of a random short orbit for this approach is perhaps one order of magnitude.

Another possibility for improved safety would be to decrease the number of people that could be exposed by intentionally designing the power supply to reenter intact, rather

than burning up. Here, instead of a high probability of exposing many people to a low level of radiation, perhaps it's better to have a low probability of exposing a few to a higher level of radiation. A logical question to be asked is, how does one equate these two perhaps radically different hazard potentials to determine which is the more acceptable? An answer to this question does not now exist. However, nature may have provided a hazard from which some reasonable comparisons can be drawn. This natural hazard arises from the random reentry of meteorites.

Figure 6 is a set of curves relating to iron meteorites showing their size, frequency of arrival, and resulting lethal area. It can be seen, for example, that five meteorites weighing ten tons each reenter the earth's atmosphere each year. Picking another size, it can be seen that a meteorite weighing 100,000 tons can be expected to strike the earth at a rate of about 5×10^{-4} per year or one every 2000 years. The well known crater in Arizona was made by a meteorite of this size. The resulting crater was 1.2 km in diameter. It was estimated that all life within a diameter of 10 km was destroyed as a result of the impact. The newspapers recently noted that an asteroid called Ictharus will pass within $4\frac{1}{2}$ million miles of the earth in the summer of 1968. This asteroid, which revisits the earth every 19 years, is about one mile across and will weigh in the vicinity of 10 billion tons. The chart shows that the crater from this meteorite, should it ever strike the earth, would be perhaps 100 km in diameter while the lethal diameter would be in the range of 1000 km. There are two craters in Africa that are 25 and 40 km in diameter, providing evidence that large meteorites do strike the earth. A book on the subject of meteorites states that evidence indicates the earth has been bombarded throughout geological time by meteorites and there is no reason to believe it will not continue.

From these curves, and the population distribution on the earth, the curve shown in Figure 7 was derived. It shows the relation between the number of people that could be killed from a given size meteorite striking the earth and the probability of that even happening. It shows, for example, that the probability of one death per year is about one in 300 while the probability of as many as eight million people being killed is about one in one billion. In spite of the fact that about ten meteorites strike the surface of the earth each day, there has never been a death attributed to a meteorite. An individual's personal hazard is remote, being about one chance in 10^{-12} of being struck in any given year.

Referring back to the last row of the multiple path chart, the three items suggested for consideration in the safety index, were the number of people involved, the probability of exposure, and severity of exposure. As can be seen, Figure 7 provides a form of a safety index guide for the most severe possible exposure, from a naturally occurring hazard. It seems reasonable to assume that this would also prove to be an acceptable guideline for

a man-made hazard. It should be possible to draw other curves on the graph which can represent other levels of exposure (severe injury, slight injury, 100 rem, 25 rem, maximum permissible body burden, etc.) These curves can take the form of

$$P(e) N^x = K$$

where:

$P(e)$ = the probability of the event

N = the number of people involved

x = an exponent controlling the slope
of the curve on the log-log graph

K = a constant depending on the level
of severity

If this chart can be filled in with the curves for other levels of exposure it can then form a basis for safety design as well as evaluation.

The future of atomic power in space is clear. Without it our ability to successfully explore and scientifically examine space will be severely limited. There are hazards associated with these radioactive power systems. However, the designer, by a systematic analysis similar to the one outlined here, can identify the areas of significant hazard. Once identified, positive design action can be taken to reduce these hazards to acceptable levels. Industry should not delegate this responsibility to government but should take the initiative and lead the way by providing safer systems for nuclear power in space.

SNAP, POODLE AND ROVER DATA

<u>SNAP</u>	<u>WEIGHT (lb.)</u>	<u>APPROXIMATE SIZE O. D. x HEIGHT(in.)</u>	<u>FUEL</u>	<u>POWER OUTPUT</u>	<u>LIFE/MISSION TIME</u>
2	1470	----	U-235	3 KWe	1 YEAR
3	4	5 x 6	Po-210/Pu-238	3 We	90 DAYS
8	1500-4500	30 x 50	U-235	30/60 KWe	1 YEAR
9A	27	20 x 10	Pu-238	25 We	5 YEARS
10A	1000	60 x 120	U-235	500 We	1 YEAR
11	30	20 x 12	Cm-242	25 We	90 DAYS
17	30	10 x 36	Sr-90	25-30 We	5 YEARS
19	30	20 x 11	Pu-238	30 We	5 YEARS
25	38	----	Pu-238	75 We	5 YEARS
27	30	17 x 18	Pu-238	50 We	5 YEARS
POODLE	30	4 x 17	Po-210	5 KW	----
ROVER/ NERVA	8500	52 x 96	UC ₂	1000MWT	----

ISOTOPIC POWER DATA

<u>ISOTOPE</u>	<u>POWER DENSITY WATTS/GM</u>	<u>RADIATION</u>	<u>HALF LIFE YEARS</u>	<u>SHIELDING</u>
PLUTONIUM 238	0.56	ALPHA	89.0	MINOR
STRONTIUM 90	0.90	BETA	28.0	HEAVY
CERIUM 144	25.6	BETA-GAMMA	0.78	HEAVY
CURIUM 242	120.0	ALPHA	0.45	MINOR
CURIUM 244	2.8	ALPHA	18.0	MODERATE
POLONIUM 210	141.0	ALPHA	0.38	MINOR

SANDIA CORPORATION

MISSILE
FLIGHT

LONG ORBIT

SHORT ORBIT

ABORT

RESULT OF
RE-ENTRY
AND DIST.
OF FUEL

COMPLETE
BURNUP
WORLDWIDE
DISTRIBUTION

PARTIAL
BURNUP
LOCAL AREA

NO BURNUP
POINT
SOURCE

EXPOSURE
MODE

INHALATION

INGESTION

DIRECT
RADIATION

SAFETY
INDEX

NUMBER OF
PEOPLE
INVOLVED

PROBABILITY
OF EXPOSURE

SEVERITY OF
EXPOSURE

SANDIA
CORPORATION