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SNAP-III

MND-P-2513

**THERMOELECTRIC GENERATOR
RADIOLOGICAL SAFETY ANALYSIS**

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THERMOELECTRIC GENERATOR RADIOLOGICAL SAFETY ANALYSIS

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ABSTRACT

A radiological safety analysis is presented for the SNAP-III thermoelectric generator. Since the fuel of the device is Polonium-210, a toxic radioisotope, certain safety measures have been designed into the device and its shipping container to prevent a release of the contaminant into any environment during normal operation or a catastrophic accident. Once containment is assured, the direct radiation problem is considered. It has been shown that the direct radiation from the thermal source is kept within tolerance limits by surrounding materials and spatial and temporal factors.

It must be emphasized that this device should not be deliberately abused or mishandled since this would serve to increase the probability of accident. The device has been evaluated with respect to internal forces such as heat and helium pressure and external forces such as impact and chemical attack. The mechanical, thermal and chemical integrity of the thermoelectric generator is shown to be quite reliable.

The basic physical, chemical, thermal, atomic and nuclear characteristics of Polonium-210 have been presented. Potential internal and external radiation hazards have been set forth.

FOREWORD

This report has been prepared by the Nuclear Division of The Martin Company for the United States Atomic Energy Commission. It presents an objective discussion of the radiologic safety of the SNAP-III thermoelectric generator which has been demonstrated in the United States.

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SUMMARY

The demonstration unit of the SNAP-III thermoelectric generator consists of a Polonium-210 thermal source rated at 2,000 curies at the time of fueling. The containers are designed to prevent any leakage of Polonium-210 to the environment. An analysis of the containment methods employed demonstrates that the containment will withstand all normal environmental conditions. The probability of a leakage of the containers would increase only through inadvertent or deliberate abuse.

By means of an adequate container the potential internal radiation hazards have been virtually eliminated. The potential external radiation hazards that exist are relatively minor because of the small amount of gamma radiation emitted by the Polonium-210 source.

The thermoelectric generator must be transported in full compliance with all United States Atomic Energy Commission regulations as they pertain to radioactive materials. Other regulations from the United States Interstate Commerce Commission, the Civil Aeronautics Administration and the Bureau of Explosives must be complied with to provide maximum safe handling.

I. INTRODUCTION

This report provides a radiological safety analysis of the SNAP-III thermoelectric generator designed by The Martin Company. It states the design and operating characteristics and presents the inherent safety factors and safe handling procedures for transporting, handling and demonstrating the unit. It is a prototype device which is fueled by Polonium-210, a toxic radioisotope, which will remain properly contained throughout all normal operation and under most rigorous conditions. It must be emphasized, however, that this device should not be deliberately or inadvertently abused or mishandled since this would tend to increase the probability of accident.

One of the basic criteria for the safe design and operation of a radioisotope power unit, such as SNAP-III, is the absolute containment of the radioisotope fuel. Once that containment is assured, there is no problem of environmental radioactive contamination. Therefore, the hazard, from internal biological intake through ingestion, inhalation and absorption, is essentially eliminated. There remains the problem of direct radiation from the fuel. Since Polonium-210 is essentially an alpha emitter, and the range of alpha particles in air is only a few centimeters, the alpha radiation is completely attenuated within the device. The gamma radiation due to the infrequent 0.8 million electron volt gamma photon from the bare source contributes a dose rate of 0.006 milliroentgen per hour per curie or a total of 12 milliroentgens per hour at one meter. However, in the device, the gamma radiation is somewhat attenuated by the materials surrounding the source. Further, the direct radiation from the device can be kept to a minimum by the surrounding materials by spatial arrangements and by temporal factors.

A discussion of Polonium-210, the thermal characteristics of the source, containment, potential external radiation hazards, potential internal radiation hazards and handling procedures are given.

II. POLONIUM-210

In 1898 the natural radioactivity of the isotope Polonium-210, extracted from pitch blende ores, drew M. Curie to the discovery of the element polonium. Today it can be produced artificially by the neutron irradiation of bismuth, and remains the most dominant of the 24 isotopes of elemental polonium. Polonium-210 is separated, prepared and encapsulated by the Mound Laboratory of the United States Atomic Energy Commission and shipped to various users for heat standards, alpha particle absorption studies, biological irradiation studies, neutron sources and other applications. It is used in the SNAP-III thermoelectric generator for the production of thermal energy through alpha particle emission from radioactive decay.

A. PHYSICAL PROPERTIES

The Polonium-210 capsule temperature is approximately 593 degrees centigrade. This is beyond the melting point of 254 degrees centigrade and below the boiling point of 962 degrees centigrade of polonium. Since it is quite volatile at 593 degrees centigrade, a large amount of Polonium-210 is diffused throughout the volume of the innermost capsules. It has a rather high density (9.4 grams per cubic centimeter) in its solid state.

B. CHEMICAL PROPERTIES

Polonium forms both soluble and insoluble compounds. Elemental polonium will oxidize to form compounds and is slightly soluble in water. It is soluble in concentrated and dilute nitric, hydrochloric and sulfuric acids. It is only slightly soluble in dilute potassium hydroxide. It will not diffuse through encapsulating materials such as nickel, stainless steel and molybdenum.

C. ATOMIC AND NUCLEAR PROPERTIES

Polonium-210 has an atomic number of 84 and an atomic mass of 210.049. It has a half-life of 138.39 days and decays according to the following scheme:

It decays with a 5.3 million electron volts alpha particle 0.999988 percent of disintegration and with a 4.5 million electron volt alpha particle 0.000012 percent of the disintegrations. A 0.8 million electron volt gamma is essentially coincident with the 4.5 million electron volt alpha. The radiation due to the gamma photons at one meter is 0.006 milliroentgen per hour per curie from the bare unshielded source. The alpha particles have a range of 3.84 centimeters and a velocity of 1.59×10^9 centimeters per second in air.

The alpha particles resulting from the radioactive disintegration of Polonium-210 collect orbital electrons and become helium atoms. At 40 degrees centigrade under standard pressure the helium production is about 0.0259 cubic centimeter per curie or about 51.8 cubic centimeters for 2,000 curies. Polonium-210 decays to Lead-206 at a lead buildup rate of about 0.5 percent per day. Figure 1 shows the source strength in curies with respect to time for a 2,000 curie Polonium-210 source.

Table 1 presents the properties of Polonium-210.

Figure 1. Decay of 2,000 Curies Polonium-210

TABLE 1
Properties of Polonium-210

Density	9.4 grams per cubic centimeter
Melting Point	254 ± 5 degrees centigrade
Boiling Point	962 ± 2 degrees centigrade
Volatility (in air at 500 degrees centigrade)	50 percent (45 hours)
Purity	90 percent plus
Solubility:	
H ₂ O	slightly soluble
KOH (dilute)	very slightly soluble
HNO ₃ (hot, conc)	soluble
HNO ₃ (dilute)	soluble
HCl (dilute)	soluble
H ₂ SO ₄ (dilute)	soluble
Lead-206 Production	~ 0.5 percent per day
Helium Production (per curie at 40 degrees centigrade (1 atmosphere)	~ 0.0259 cubic centimeters
Oxidation	yes
Diffusivity (in 0.1N Acid at 18 degrees centigrade)	0.78 - 1.06
Atomic Number	84
Atomic Weight	210.049
Half-Life	138.39 days
Grams per Curie	0.000224

TABLE 1 (continued)

Curies per Gram	4,460
Mode of Decay	α with 1 γ per $10^5 \alpha$
Alpha Energy	5.298 million electron volts
Alpha Range (in air)	3.84 centimeters
Alpha Velocity	1.59×10^9 centimeters per second
Gamma Energy	0.8 million electron volt
Gamma Radiation (at one meter from bare source)	~ 0.006 milliroentgen per hour per curie
Calories per curie per hour	27.538
Watts per curie	0.032

III. THERMAL SOURCE

The thermal source for the SNAP-III thermoelectric generator consists of 2,000 curies of Polonium-210 sealed within two capsules each containing 1,000 curies. The total weight of the Polonium-210 fuel is 0.448 gram. Since the fuel has a value of 0.032 watt per curie, there are a total of 64 thermal watts present in the generator. This results in the production of approximately three watts of electric power which gives a unit efficiency of about five per cent. The thermoelectric generator operates at a capsule temperature of 593 degrees centigrade. In air, at standard temperature and pressure, the heat source would reach an equilibrium temperature of about 500 degrees centigrade. The operating temperature of the heat source is far below the melting point of encapsulating materials such as stainless steel, molybdenum and copper. In short, the generator has very good thermal integrity from within.

After one half-life (138.4 days) there would be 1,000 curies within the heat source. This would represent approximately 32 thermal watts. The operating temperature of the source would decrease accordingly. The magnitude of potential temperature excursions within the device, due to external forces, decreases with time. As a safety precaution the device should not be insulated during transporting, handling or while demonstrating it.

IV. CONTAINMENT

The Polonium-210 source material is encapsulated in four successive containers to prevent the release of contamination to the atmosphere. First, the two polonium sources are encased in two stainless steel capsules with welded tops each 0.290 inch in diameter and 0.590 inch long with an inside volume of 0.279 milliliter. Second, these two steel capsules are encased in a single steel canister 0.360 inch in diameter and 1.30 inches in length with a welded top. Third, this canister is placed in a molybdenum block which is capped by a solid steel tapered plug. Fourth, this block and the 27 pairs of semiconductor thermoelectric conversion elements are encased in a copper container which is hermetically sealed. As an added safety precaution, the container is evacuated so that a negative pressure exists within it. This negative pressure allows air to enter if a leak should occur and prevents contaminants from leaving the container immediately. Figure 2 shows the inner containment and Figure 3 shows a cutaway view of the complete containment for the device.

A. MECHANICAL INTEGRITY

An analysis of the mechanical integrity of the device must encompass the helium pressure accumulation within the source capsules, the structural integrity of the four containers and the critical temperature at which the device will not support the internal helium pressure. Calculations show that the accumulated helium pressure is at a maximum about one year after the source material has been encapsulated. This pressure is 106.7 atmospheres or 1,560 pounds per square inch. The structural integrity of the three inner containers is shown by the fact that each capsule can contain a pressure equal to a minimum of ten times the expected helium pressure throughout the life span of the device. The molybdenum block will withstand all external low and high velocity impact conditions up to an impinging velocity of about 200 feet per second. The critical temperature of the device is above 1,100 degrees centigrade.

In summary it can be seen that the only possible structural hazard of the device would be a temperature excursion from external sources or from within the capsule itself.

The probability of the device experiencing temperatures above that of the critical one from external sources under ordinary conditions are

Figure 2. Internal Containment of SNAP-III

Figure 3. Artist's Concept of SNAP-III Generator

extremely remote. Fires which might occur in buildings do not reach such a temperature. Fire resulting from aircraft crashes, however, may result in temperatures above that of the critical one. A molybdenum shipping container has been designed to detain such a temperature from reaching the internal capsules. This molybdenum container will be capable of maintaining its complete integrity under extremely high temperatures and impact conditions; thus, preventing the polonium from escaping beyond its confines.

Temperature excursions from within the generator are not plausible under any ordinary conditions. However, if the device is encapsulated in a perfect insulation, it is possible for the device to undergo an internal temperature excursion. Therefore, as a safety precaution the device should not be insulated during transporting, handling or during demonstrations.

1. Helium Pressure Accumulation

The original operating temperature of the device is 593 degrees centigrade. Since helium gas is generated within the inner capsule by alpha decay of the fuel, it is necessary to determine the internal gas pressure when considering the mechanical integrity of the device. In fact, it is this pressure that is the basis for the design of the capsule. To find this pressure, the following equation was utilized:

$$P = \frac{m R T}{VM} \quad (1)$$

where:

P = pressure, atmospheres

m = mass of helium gas generated, grams

V = volume of container, liters

T = absolute temperature, degrees Kelvin

M = molecular weight of the gas generated

R = constant = 0.08207 liter-atmosphere per mole, degrees Kelvin

In the isotopic heat source being analyzed, the mass of helium gas generated and the temperature vary with time as a function of the decay

constant of Polonium-210. The mass increases and the temperature of the device decreases with an increase of time by the following relationships:

$$m = m_{\text{He}} N_o (1 - e^{-\lambda t}) \quad (2)$$

$$T = (T_o - T_A) e^{-\lambda t} + T_A \quad (3)$$

where:

m = mass of helium gas generated, grams

m_{He} = mass of a single helium atom = 6.6456×10^{-24} grams

N_o = number of original Polonium-210 atoms in the 2,000-curie source = 6.03×10^{20} atoms

λ = decay constant of Polonium-210 = 5.795×10^{-8} second⁻¹

t = time, seconds

T_A = ambient temperature = 300 degrees Kelvin

T = temperature after t seconds, degrees Kelvin

T_o = initial temperature, 866 degrees Kelvin

Figure 4 shows these variations. By substituting these values into Equation 1, it is possible to obtain the pressure dependent upon time.

$$P = \frac{m_{\text{He}} N_o R}{VM} \left[1 - e^{-\lambda t} \right] \left[(T_o - T_A) e^{-\lambda t} + 300 \right] \quad (4)$$

In substituting known values, this equation takes the form:

$$P = 0.3221886 \left[1 - e^{(-5.795 \times 10^{-8} t)} \right] \left[566 e^{(-5.795 \times 10^{-8} t)} + 300 \right]$$

Figure 4 shows this relationship. By differentiating the pressure with respect to time, it is possible to find the maximum helium pressure experienced by the device. This maximum pressure occurs at 2.5×10^7 seconds (about 90 days) and it is equal to 106.7 atmospheres or 1,560 pounds per square inch. The structural integrity will be based on this maximum pressure accumulation.

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Figure 4. Pressure--Temperature History of Thermal Source

Figure 5. Structural Integrity of Stainless Steel Capsules

2. Structural Integrity of the Containers

A conservative estimate of the allowable stress of each cylindrical container encapsulating the Polonium-210 source can be obtained by using Equation 5. Tensile strengths at various temperature of the materials that make up the thermoelectric generator are shown in Table 2.

TABLE 2
Some Significant Physical Properties of Containment Materials

<u>Temperature (degrees centigrade)</u>	<u>Molybdenum (pounds per square inch)</u>	<u>Tensile Stress Type 304 Stainless Steel (pounds per square inch)</u>	<u>Copper (pounds per square inch)</u>
Standard	113,000	85,000	55,000
400	91,000	63,000	
595	85,000	47,000	
870	78,000	17,000	

The allowable internal pressure of a thin-walled cylindrical container can be obtained from the following equation:

$$P = \frac{2 \sigma t_h}{d} \quad (5)$$

where:

- P = allowable internal pressure, pounds per square inch
- σ = tensile stress of material, pounds per square inch
- d = diameter of cylinder, inches
- t_h = wall thickness of cylinder, inches

Using Equation 5 to derive allowable pressure in the containment capsules, Figure 5 expresses the structural integrity of these capsules as a ratio of the allowable pressure to actual pressure at various times. The helium pressure is based on the data in Figure 4 and the tensile stresses of the material at the various temperatures are taken from Table 2. The following is a summary of the structural analysis made of each capsule:

(1) Inner containers (Type 304 stainless steel)

Under normal operating conditions, these capsules are designed to contain a minimum of 9.7 times the actual helium pressure as indicated by Figure 5;

(2) Outer Type 304 stainless steel capsule

This capsule will contain a minimum of 9.2 times the actual helium pressure as indicated by Figure 5;

(3) Molybdenum block

The walls of the molybdenum block will resist a pressure of over 28,000 pounds per square inch; but the steel plug shown in Figure 2 will eject under a pressure of 17,000 pounds per square inch. This is the outermost pressure container so the overall structural integrity for the device must be based on the ability of this container to resist the maximum normal helium pressure of 1,560 pounds per square inch. This factor of safety is equal to 11.8.

It should be understood, however, that this plug experiences a pressure stress only when the helium escapes from the inner capsules.

(4) Outer copper container

The outer container is designed to withstand external pressure due to the induced negative internal pressure. If it fails structurally, the only danger involved would be the loss of one of the safety features designed into the device. If this does occur, no radioactive contaminants would be released to the environment.

(5) Overall Impact Considerations

Under impact conditions, the outer copper container, although very ductile, will not withstand significant impact loads. It will, however, withstand all normal impact conditions, such as a free fall from several feet and moderate impact from external impinging objects. The molybdenum block is quite impact resistant. In fact, it is estimated that the molybdenum block in SNAP-III will withstand impact loads equivalent to impacting on solid granite with a velocity of about 200 feet per second.

3. Critical Temperature

In the event of an accident, such as a fire, it would be desired to know the critical temperature at which the device would not support the internal pressure. These calculations show that this temperature is above the melting point of the stainless steel canisters. Should these innermost containers undergo a temperature excursion within the molybdenum block, the pressure accumulation within this block would far exceed the allowable strength of the tapered plug. This incident, however, would not result in an explosion in that the friction plug would act as a relief valve. It would release contaminants into the environment; therefore, it is essential that the inner capsule does not reach a temperature of over 1,100 degrees centigrade as a safety precaution. This temperature can be considered the critical temperature of the device.

B. THERMAL INTEGRITY

The internal thermal integrity of the SNAP-III device has been discussed in the context. Thermal energy applied from external sources will first be evenly distributed throughout the outer copper shell. Since insulation material is present between the outer copper shell and the molybdenum block, heat transfer into the fuel capsule is inhibited.

Thermal shock is another potential hazard. Molybdenum has been subjected to very extreme thermal shock tests such as immersion in liquid oxygen at 815 degrees centigrade and water immersion without significant failure.

Both the internal and external thermal integrity of the SNAP-III thermoelectric generator are good.

C. CHEMICAL INTEGRITY

The metals used in the fabrication of the SNAP-III thermoelectric generator will not undergo a significant amount of corrosion during normal operation. Under extreme conditions chemical reactions imposed by the environment will accelerate the rate of corrosion. To insure the chemical integrity of the device, optimum materials were selected and preventive techniques were employed. The following presents some of the corrosive reactions that might be encountered and the countermeasures utilized to inhibit such reactions.

Stainless steel is resistant to most normal chemical attack throughout its useful temperature range. It has extremely good oxidation resistant characteristic. It is not particularly resistant to some molten metals, to certain concentrated acids at elevated temperatures and to concentrated halogen gases when subject to these conditions for sustained periods. However, for normal operating conditions stainless steel will not undergo significant corrosion.

Molybdenum, at standard temperature, is resistant to most chemical agents. It is particularly subject to attack by hot concentrated acids and fluorine. At temperatures beyond the operating temperature of the SNAP-III device, elemental molybdenum is subject to rapid oxidation. As a safety precaution, a chromium-nickel (Colmonoy No. 5) alloy has been flamed-sprayed upon the molybdenum container. This coating will prevent oxidation of molybdenum specimens at 1,100 degrees centigrade even when they are immersed in liquid oxygen.

Copper will resist corrosion under the normal operating conditions of the device. Copper is soluble in nitric and hot sulfuric acid.

In general, the thermoelectric generator possesses excellent chemical properties for normal operating conditions and for many extreme chemical conditions.

V. RADIATION HAZARDS ANALYSIS

As shown previously, Polonium-210 is primarily an alpha emitter but does emit an 0.8 million electron volt gamma ray essentially coincident with the 4.5 million electron volt alpha particle. It will be shown that the greatest potential health hazard would result from internal exposure, that is, the ingestion or inhalation of Polonium-210 into the human body and that the external radiation hazards are relatively minor.

A. EXTERNAL RADIATION HAZARDS

The 0.8 million electron volt gamma ray from Polonium-210 represents less than one per cent of the total radiation emitted. Gamma rays are generally described as highly penetrating radiation and in certain materials are a serious hazard. However, the gamma levels from Polonium-210 are relatively minor and do not represent a serious hazard. Actual measurements of Polonium-210 sources by the Mound Laboratory and others, have shown that the gamma levels vary between 0.003 and 0.006 milliroentgen per hour per curie of Polonium-210 as measured at a distance of one meter. Thus, a 2,000 curie source used in a thermoelectric generator would show a gamma reading of 12 milliroentgens per hour at one meter. As the Polonium-210 decays, the gamma levels would progressively decrease. After one-half life or 138.4 days for example, the gamma level would decrease to six milliroentgens per hour.

Actual measurements of the gamma radiation from the SNAP-III prototype thermoelectric generator on 12 January 1959 containing 1,517 curies of Polonium-210, were as follow:

Position of Detector	Gamma Reading (milliroentgen per hour)
In contact with the source capsule	1,200
In contact with molybdenum cylinder	550
In contact with the copper sphere	350
One foot from the copper sphere	55
Four and one-half feet from the copper sphere	2

Another thermoelectric generator will be constructed in March 1959 which will contain a 2,000-curie Polonium-210 source and will show gamma levels approximately 10 per cent above those listed here.

The permissible limits of exposure as established by the United States Atomic Energy Commission in Title 10, Part 20 "Standards for Protection Against Radiation" of the Code of the United States Federal Regulations are as follows.

The total body exposure is 300 mrem per week or 15 rems per year. The average in any three consecutive years must not exceed five rems per year. The exposure to the hands and forearms is not to exceed 1,500 mrem per week or 75 rems per year.

Unmonitored personnel, which includes those not required to wear monitoring devices, must not receive more than two mrem per hour (average), not to exceed 100 mrem in any seven consecutive days.

Persons under 18 years of age must not receive an exposure in excess of 10 per cent of the values shown or 30 mrem per week. The term "rem" is used to denote the quantity of radiation of any type which produces the same biological effects in man as those of one roentgen of X or gamma radiation. One millirem (mrem) is one thousandth of a rem.

To comply with the regulations pertaining to permissible levels of exposure, the following procedures should be diligently followed whenever the SNAP-III thermoelectric generator is placed on display to the general public:

- (1) A closed-off area at least five feet in diameter should be maintained to prevent access by those viewing the device.
- (2) An attendant should be present at all times to assure that this spacing is maintained.
- (3) Those attending the display and located within the five-foot area should not remain longer than five hours during any seven consecutive days within a distance of one foot from the device or touch the copper sphere with the hands or forearms in excess of four hours in any seven consecutive days.

If these procedures are followed all external radiation exposures will remain within permissible limits.

B. INTERNAL RADIATION HAZARDS

The human skin is a very effective shield against alpha particles impinging on the outer part of the human body. Upon entering the human body, however, this shield no longer exists. When accidental ingestion or inhalation of alpha emitting radioactive materials occurs, the alpha particles may be extremely injurious. The high degree of specific ionization possessed by the alpha particle results in a very rapid dissipation of energy over an extremely limited area. This results in a serious condition as the alpha particles may expend a large portion of their energies within individual cells. The National Bureau of Standards Handbook No. 52 lists the following body metabolism information for Polonium-210:

Permissible body total--0.02 microcuries.

Critical organ (soluble Polonium-210)--spleen.

Critical organ (insoluble Polonium-210)--lungs.

Biological half-life (soluble)--57 days.

Biological half-life (insoluble)--40 days.

Fraction of Polonium-210 going from the gastro-intestinal track and into the blood due to the ingestion of soluble Polonium-210--0.02.

Fraction of Polonium-210 going from blood to critical organ--0.015.

Fraction of Polonium-210 in critical organ to that in total body (soluble)--0.06.

Fraction of Polonium-210 in critical organ to that in total body (insoluble)--1.0.

Fraction reaching critical organ by ingestion--0.0003.

Fraction reaching critical organ by inhalation of soluble Polonium-210--0.004.

Fraction reaching critical organ by inhalation of insoluble Polonium-210--0.12.

Title 10 Part 20 of the Code of Federal Regulations lists the following permissible limits for Polonium-210:

Permissible air concentration for soluble Polonium-210-- 2×10^{-11} microcuries per milliliter.

Permissible air concentration for insoluble Polonium-210-- 7×10^{-12} microcuries per milliliter.

Permissible water concentration, soluble Polonium-210-- 3×10^{-6} microcuries per milliliter.

Permissible water concentration, insoluble Polonium-210--none permitted.

This shows that the most important safety aspect of a Polonium-210 source is adequate containment. The description of the containment method for the SNAP-III generator shows that any leakage of Polonium-210 is highly improbable except by deliberate or accidental rupturing of the source container. To further decrease the possibility of this occurrence the following precautions should be diligently followed:

1. Handling Procedures

The generator unit should be handled with reasonable care at all times to prevent rupturing of the copper sphere. The unit should not be dropped or smashed against other objects.

2. Custody

The entire unit should remain in the custody of authorized personnel at all times to prevent any possibility of sabotage. The unit should be stored in an area under constant surveillance by reliable personnel.

3. Leak Testing

Daily leak tests while the generator unit is on display should be conducted. This may be accomplished easily by wiping a small piece of cloth gauze dampened in water or alcohol over the outer surface of the copper sphere. The gauze is dried and then counted by means of a sensitive alpha detector. Leakages of Polonium-210 sources are generally first observed by a very small amount of alpha contamination on the outside surface of the source container.

VI. TRANSPORTATION

Shipments of radioactive materials by the United States Atomic Energy Commission or under escort by Atomic Energy Commission employees are in many instances exempt from the shipping regulations established by the United States Interstate Commerce Commission. Private companies, however, must comply fully with these regulations. Some of the more important requirements are as follows.

1. Permissible Radiation Levels

The following requirements for radiation levels are:

Must not exceed 200 milliroentgens per hour on surface of package.

Must not exceed ten milliroentgens per hour at one meter distance.

2. Permissible Amounts of Polonium-210

If greater than 2,000 millicuries of Polonium-210 are to be shipped via commercial channels a Bureau of Explosives Permit must be obtained.

3. Surface Contamination

No radioactive contamination on the outside surface of the shipping container is permitted.

4. Packaging

Radioactive material must be packaged in a container, suitable for shipment through commercial channels, as prescribed by the United States Interstate Commerce Commission.

5. Labeling

Packages containing radioactive materials must have the prescribed Interstate Commerce Commission label attached to the outside surface of the shipping container. A 2,000-curie Polonium-210 source, for example, would require a red label.