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NEUTRON, ALPHA, AND SPECIAL SOURCES FROM POLONIUM

(Information Report)

BY

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Date: June 11, 1954

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ABSTRACT

Polonium-210 (138.4-day half life, 5.30 Mev alpha) neutron, alpha, and special sources are made at Mound Laboratory for Atomic Energy Commission contractors and can now be furnished for other organizations. The high specific activity, hence negligible self-absorption of alphas, and the low gamma emission ($1\gamma/100,000\ \alpha$) make polonium attractive for use in such sources. Neutron sources are usually made from beryllium, boron, or mock-fission powder. The neutron yield of a polonium-beryllium source is about 2.5×10^6 n/sec/curie; the yield with other target materials is much less. Sources are furnished in nickel-sealed metal cylinders 1/8 to 1-1/8 inches in diameter by 1/4 to 2-1/2 inches in length. Beryllium sources can be used at temperatures as high as 800°C by placing the source in a second, welded container. Practical size limits for sources are 5×10^8 n/sec for beryllium, 10^8 for boron, and 2×10^7 for mock fission. Alpha sources are made by depositing polonium on a metal backing which may be uncovered or covered with mica, stainless steel, gold, or tantalum. Alpha sources can be furnished with amounts of polonium ranging from a few micromicrocuries to several curies. Special heat sources can also be furnished. The specific needs of the user in regard to physical configuration, specific activity, and similar details of construction for any source using polonium can generally be met.

INTRODUCTION

Until recent years, polonium-210 was a scarce element obtainable only from natural ores. It is now produced in uranium reactors by irradiation of bismuth. The amount of polonium produced has been gradually increased to meet the needs of contractors within the Atomic Energy Commission. Polonium can now be furnished in sufficient quantity to meet the demands of most other organizations.

At the present time, polonium is used with certain light elements to produce neutron sources. It is also supplied as an alpha emitter under a variety of conditions. Recently polonium has been supplied in small capsules as calibrated heat-sources.

It is the purpose of this report to give information on polonium and the properties, associated radiations, and uses of the sources produced from polonium.

PROPERTIES OF POLONIUM AND HANDLING PRECAUTIONS

Polonium, first known as radium-F, is a metallic element having a half life of 138.4 days. There is one gamma of 0.8 million electron volt energy emitted per approximately every 100,000 alphas. The properties of polonium are given in Table I.

The maximum permissible level of polonium in the body (155-lb man) is 0.02 microcurie.[1] Polonium is readily airborne, and every precaution must be taken to keep it confined. The use of enclosed or well-ventilated hoods and the wearing of masks, protective clothing, and rubber gloves are essential for handling polonium.

Polonium is soluble in the common acids and in sodium hypochlorite. Should any polonium be spilled, the spread of contamination can be minimized by immediately covering it with water. The solvents mentioned, scouring powders, and metal polish aid in decontaminating surfaces upon which polonium has been spilled.

TABLE I

PROPERTIES OF POLONIUM

ATOMIC WEIGHT	210
HALF LIFE	138.4 DAYS
MODE OF DECAY	α WITH 1 γ/100,000 α
MELTING POINT	254° ± 5° C
BOILING POINT	962° ± 2° C
DENSITY	9.2 9.4 G/CC
VALENCE	2 AND 4
GRAMS/CURIE	0.000222
CURIES/GRAM	4505
ENERGY OF ALPHA	5.30 MEV
RANGE OF ALPHA IN AIR (STP)	3.84 CM
ENERGY OF GAMMA	0.8 MEV
CALORIES/CURIE/HR	27.538
WATTS/CURIE	0.032

PERMISSIBLE RADIATION LEVELS AND SHIELDING OF SOURCES

The amount of radiation which the human body can withstand without detrimental effects is under continual investigation. The present dosage levels for various types of radiations were set at the 1949 Chalk River Conference[2] and are given in Table II. Relationships between the units of radiation are given by Glasstone.[3]

TABLE II

PERMISSIBLE RADIATION LEVELS

TYPE OF RADIATION	REPS/WEEK	RELATIVE BIOLOGICAL EFFECTIVENESS	NUMBER OF PARTICLES/SEC/CM^2/MREM/HR
X- AND γ-RAYS	0.3	1	530 (1 MEV)
ALPHA PARTICLES	0.015	20	-
FAST NEUTRONS	0.03	10	5 (2.5 MEV)
THERMAL NEUTRONS	0.06	5	234

The permissible 8-hour fast-neutron dosage for total body exposure was decreased a few years ago from 150 neutrons per second per square centimeter to 75 neutrons per second per square centimeter and was recently decreased to 35 neutrons per second per square centimeter. Exposure to higher levels of neutron radiation for short periods is permissible if the total exposure of an individual does not exceed the equivalent of 3.9 roentgen in a three-month period (35 n/sec/cm^2 for 520 working hr). Maximum permissible exposure times and working distances for given neutron-source strengths are shown in Figure 1.

Shipping regulations[4] of the Interstate Commerce Commission (ICC) specify a maximum radiation of 200 milliroentgens-equivalent-man per hour at the surface of a shipping container and 10 milliroentgens-equivalent-man per hour at one meter from the source of radiation.

Neutrons lose their energy by collisions with nuclei. On the average, a neutron of two million electron volts energy is thermalized (0.025 Mev) by 18 collisions with hydrogen, 114 collisions with carbon, or several hundred collisions with the heavier elements. The half-thicknesses (distance required to stop one-half the incident fast-neutrons) lie between 5 and 8 centimeters for most materials. Since hydrogen is the most efficient element (atom-wise) for the slowing down of neutrons paraffin and water are generally used as neutron shields. It has been found that using a half-thickness of 6 centimeters for paraffin enables design of shipping containers which meet ICC regulations. (Figure 2).

Steel drums of the appropriate size filled with paraffin are used for shipping neutron sources.

Alpha sources made from polonium have only a small amount of gamma radiation. They are placed in metal holders which are packed in boxes made of wood.

TYPES OF NEUTRON SOURCES

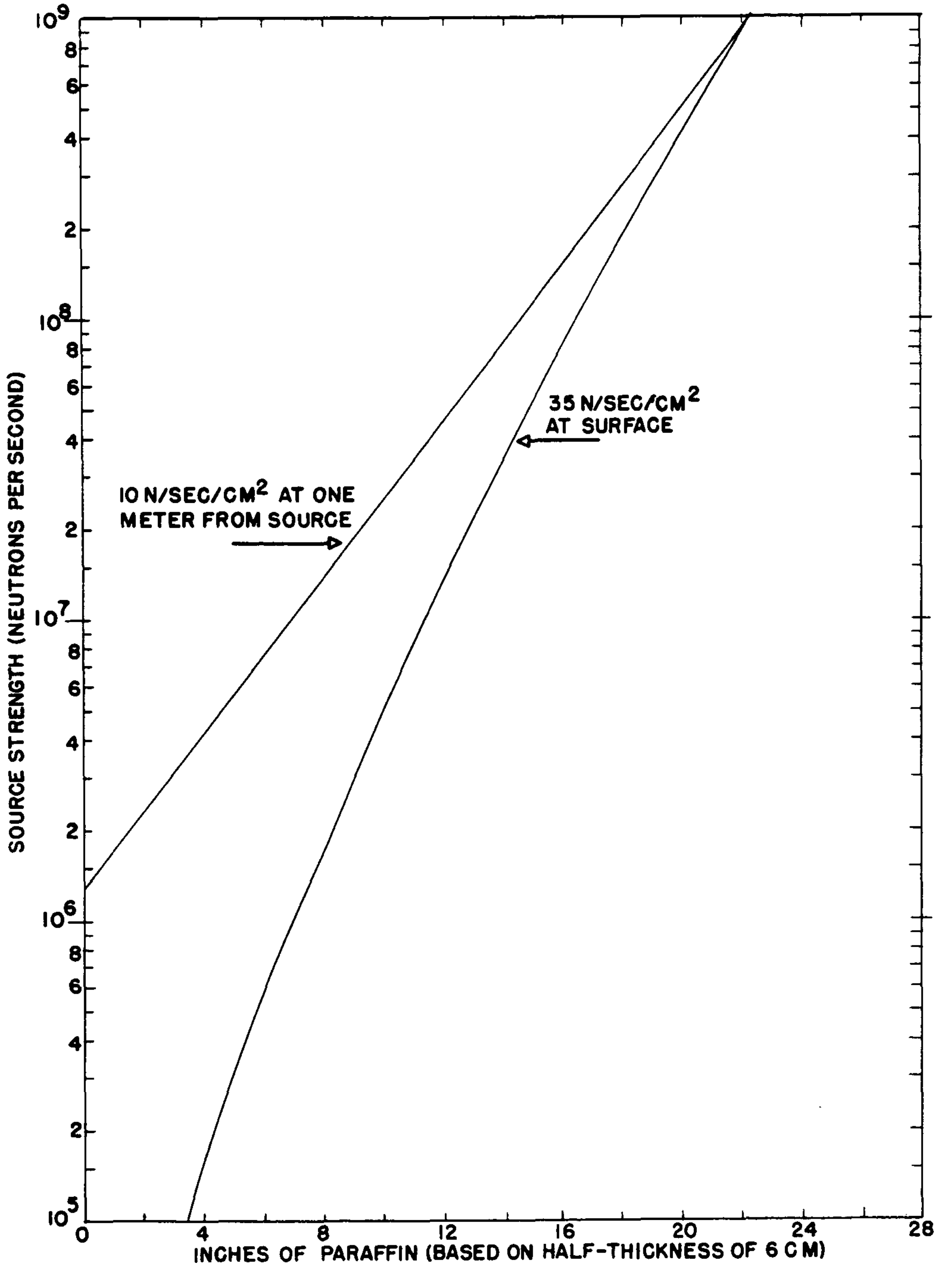
Light elements with threshold energies less than the energy of the alpha impinging on them give alpha-neutron reactions. The neutron yield is a function of the target element, alpha energy, and degree of mixing. Beryllium boron, and fluorine give the largest neutron yields in the order given. Pertinent data are given in Table III.

It will be seen that the theoretical neutron yield from beryllium is 3.5 times that from boron. Hence, beryllium neutron sources are used for most purposes. Actual neutron yields depend on the method of preparation, purities of target and polonium, and mass ratio of target to polonium.

The efficiency of beryllium sources is higher than the efficiency of other types of sources. Boron and mock-fission sources must be prepared by evaporation methods which give poorer and less consistent distribution of the polonium.

The efficiencies of beryllium sources vary but little when less than 10 curies of polonium per gram of beryllium are used. At 50 curies of polonium per gram of beryllium the neutron efficiency is about 75 per cent, compared to a maximum of 95 per cent for much smaller polonium-beryllium ratios. The efficiency of other types of sources varies similarly as the ratio of polonium to target is increased.

Polonium has several advantages over radium in neutron sources. The amount of polonium per curie is so small that self-absorption of alphas is negligible. There is no radioactive



SHIELDING BY PARAFFIN FOR NEUTRON SOURCES

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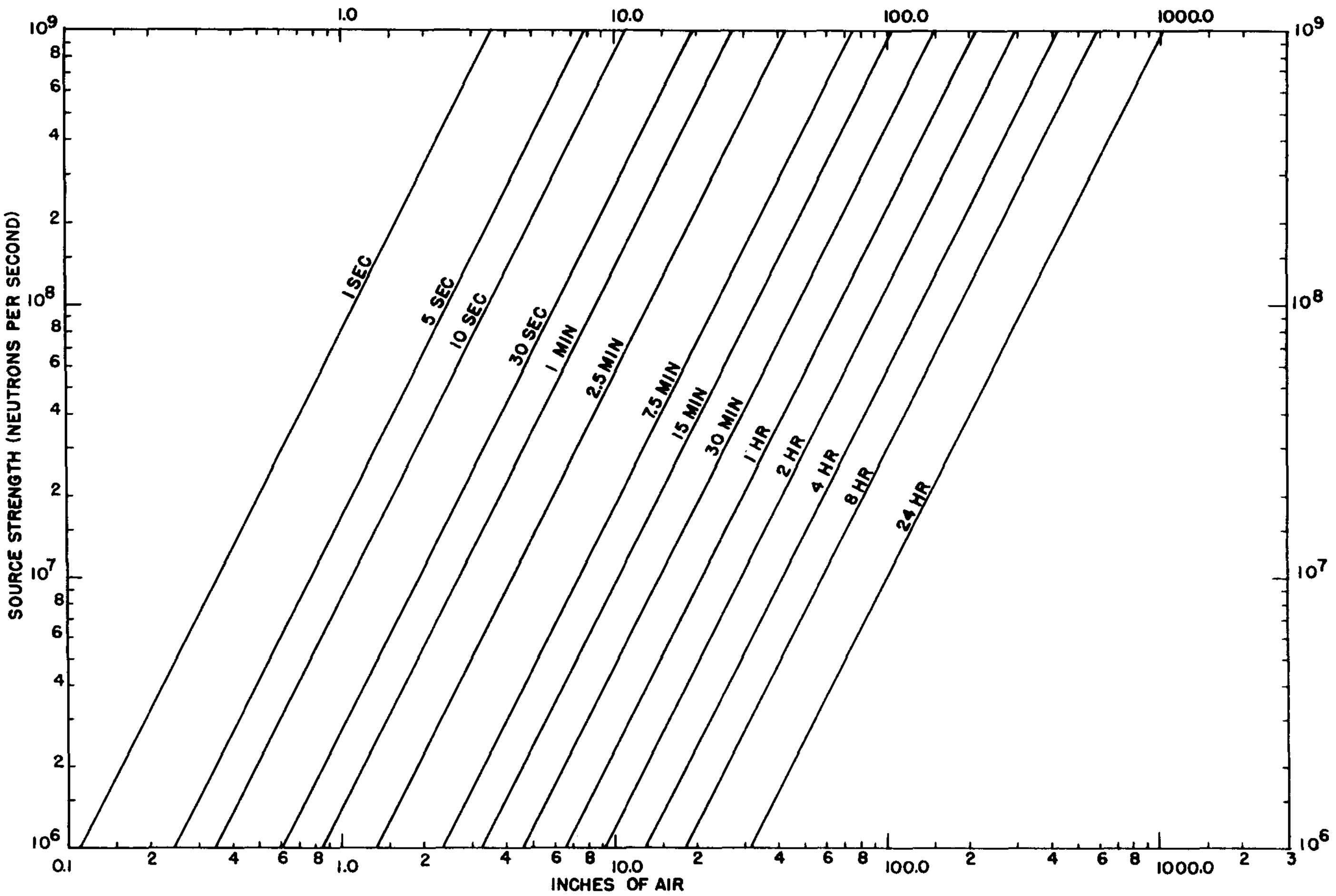
FIGURE 1

FIGURE 2



MAXIMUM PERMISSIBLE EXPOSURE TIME FOR DIFFERENT STRENGTHS AT VARYING DISTANCES

(BASED ON M.P.E. OF $35 N/SEC/CM^2$)

TABLE III

ENERGY DATA AND NEUTRON YIELDS OF POLONIUM NEUTRON SOURCES

ELEMENT	α,N REACTION ENERGY[5] (Mev)	THRESHOLD ENERGY (Mev)	THEORETICAL NEUTRONS/ SEC/CURIE[6]	EXPECTED NEUTRON EFFICIENCY (%)	NEUTRON ENERGY MAXIMUM (Mev)	NEUTRON ENERGY AVERAGE (Mev)	ENERGY OF ASSOCIATED GAMMA (Mev)
LITHIUM-6	-3.98	6.64	-	-	-	-	-
LITHIUM-7	-2.79	4.39	1.0×10^5	50 TO 80	1.3	--	0.48
BERYLLIUM-9	5.71	**	2.85×10^6	75 TO 90	10.8	4.5	4.45
BORON-10	1.07	**	8.14×10^5	60 TO 90	6.0	2.3	3.68
BORON-11	0.15	**			5.1		2.36
FLUORINE-19	-1.84	2.22	4.44×10^5	50 TO 80	3.1	-	1.28 & 1.52
SODIUM-23	-3.88	4.55	5.55×10^4	50 TO 80	0.9	-	0.43, 1.13, 1.83 & 2.57
MOCK FISSION*	-	-	4.26×10^5	40 TO 70	-	2.0	COMPOSITE OF Be, B, F & Na

*SODIUM FLUOBORATE AND SODIUM FLUOBERYLLATE, MOL RATIO B:Be = 24:1

**EXOTHERMIC REACTION

gas from polonium. The gamma radiation from a radium-beryllium neutron-source is about 10,000 times that from a polonium-beryllium neutron-source of equal curie value. Gamma radiation from a polonium-beryllium neutron-source which contains one curie of polonium is about 0.11 milliroentgen per hour at one meter.

Radium has a long half life which is advantageous for neutron standards.

SOURCE CONTAINERS

Neutron sources are put in cylindrical or spherical containers of nickel, steel, beryllium, or platinum and the containers are sealed with nickel. If an outer surface other than nickel is requested, a second container, fabricated of the specified material, is used to house the nickel-sealed container. Nickel is used as the container material unless otherwise specified, and cylinders are used in preference to spheres.

Source containers generally vary in size from $\frac{1}{8}$ to $1\frac{1}{8}$ inches in diameter and $\frac{1}{4}$ to $2\frac{1}{2}$ inches in length. A total wall thickness of at least 0.025 inch is required for the finished source, of which at least 0.015 inch is sealing nickel. A standard source-container is a nickel cylinder 0.50 by 0.50 inch inside and 0.70 by 0.70 inch outside.

SIZES OF NEUTRON SOURCES

Neutron sources emitting any number of neutrons up to a practical maximum can be prepared. Present facilities would probably be adequate for sources up to 10^9 neutrons per second, but more practical upper limits are 5×10^8 for beryllium, 10^8 for boron, and 2×10^7 for mock-fission sources.

SPECIAL NEUTRON SOURCES

Sources coated with nickel are sufficiently rugged for ordinary usage but should not be used at elevated temperatures for long periods of time. Beryllium sources are the only ones which may be used at temperatures above 150° C. A beryllium source may be used at temperatures up to 800° C if it is made in a steel or beryllium container, nickel sealed, and placed in a stainless steel container which is then welded shut.

Small neutron sources the size of radium needles have been prepared. The ratio of diameter to length can be varied to suit the user so long as diameters are at least $\frac{1}{8}$ inch and preferably $\frac{1}{4}$ inch or more.

USES OF NEUTRON SOURCES

Neutron sources are used in starting reactors, controlling the power level of reactors, making critical-mass measurements, furnishing approximate fission-neutron spectra, calibrating instruments, evaluating shielding materials, making biological studies, and logging oil-wells.[7,8]

There are possibilities that neutron sources can be used in activation analysis,[9] treatment of cancer, catalysis, and catalyst activation.

ALPHA SOURCES

Polonium is a source of essentially monoenergetic alphas of 5.30 million electron volts. The small amount of polonium per curie permits preparation of thin samples with practically no self-absorption of alphas.

Alpha sources are supplied on metal supports with or without a covering. Polonium nitrate in glass tubes is supplied in small amounts for those wishing to prepare their own alpha sources. Uncovered alpha sources and polonium nitrate are sold only to those with proper facilities for and experience in the handling of polonium.

COVERINGS FOR ALPHA SOURCES

The range of a polonium alpha is 3.84 centimeters (1.51 in.) in air and 0.008 to 0.023 centimeter (0.0003 to 0.0009 in.) in metals. The short range of an alpha particle makes it necessary to use very thin windows in order to retain an appreciable portion of the alpha energy. Gold, stainless steel, tantalum, and mica have been used as alpha windows. Gold, stainless steel, and mica are available in varying thicknesses which will pass, respectively, 50 to 90 per cent, 50 to 80 per cent and 50 to 80 per cent of the alpha energy. Tantalum is available in one thickness which will pass about 35 per cent of the alpha energy.

The type and thickness of window are adjusted to the amount of polonium and to the conditions of use. When the amount of polonium exceeds one curie, it is advisable to use tantalum or the thicker stainless steel windows; the latter are preferable.

In most alpha sources, the polonium is deposited on one end of a metal cylinder which has a shoulder about 0.030 inch in height surrounding the active area. The alpha window rests on the shoulder and is not in direct contact with the polonium. The migration of polonium in most materials is too rapid to make long-lasting alpha sources by depositing the polonium on the alpha window.

SIZES OF ALPHA SOURCES

Alpha sources can be made with amounts of polonium ranging from a few micromicrocuries to several curies.

The holders for alpha sources generally vary in diameter from $\frac{1}{8}$ to 2 inches and in length from $\frac{1}{4}$ inch to any reasonable value. Nearly all alpha sources are individually designed to the requirements of the user.

USES OF ALPHA SOURCES

Alpha sources are principally used in research, much of which is fundamental in nature. Alpha sources may be used in activation analysis, decomposition of chemical compounds, catalysis, sterilization, and elimination of static electricity.

SPECIAL POLONIUM SOURCES

The high heat-output of polonium (0.032 watt/curie or 144 watts/g) makes it valuable for use in standard heat-sources. Such calibrated heat-sources are useful in calorimetry research and for standardizing calorimeters. A polonium heat-source can be used to generate power in a thermopile for special purposes.

Heat sources are mounted in metal containers which are then coated with nickel. When a high-temperature source is desired. the container is made as small as possible. The limits on the size of the container and the amounts of polonium in a heat source are not known. One hundred and fifty curies of polonium have been put in a capsule 0.2 inch in diameter by 0.4 inch long. This capsule, in air, reached a temperature of nearly 400° C. It seems probable that more concentrated heat-sources can be made.

MEASUREMENTS ON POLONIUM SOURCES

The polonium content of sources containing more than 0.3 curie is determined, to an accuracy of to at least ± 1 per cent, in a calorimeter. Small alpha-sources have their polonium content measured, also to an accuracy of at least ± 1 per cent, by an alpha counter.

Autoradiographs of alpha sources can be made.

Neutron emissions are determined to an absolute accuracy of ± 5 per cent and to a comparative accuracy of ± 2 per cent.

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