UNCLASSIFIED [redacted] LP-175

This document consists of 12 pages
No. 4 of 49 Series A

36148

M91040619

OSTI INV 89

LEXINGTON PROJECT REPORT

NO. 175

POLONIUM-POWERED AIRCRAFT FOR MILITARY PURPOSES

[redacted]

This document is
PUBLICLY RELEASABLE
Jerry E. Keyes
Authorizing Official
Date 3-23-98

DEPARTMENT OF ENERGY DECLASSIFICATION REVIEW	
1st REVIEW-DATE: 8-25-97	DETERMINATION [CIRCLE NUMBER(S)]
AUTHORITY: ☐ AOC ☐ ADC ☑ ADD	1. CLASSIFICATION RETAINED
NAME: Jerry E. Keyes	2. CLASSIFICATION CHANGED TO:
2ND REVIEW-DATE: 3-23-98	3. CONTAINS NO DOE CLASSIFIED INFO
AUTHORITY: ADD	4. COORDINATE WITH:
NAME: Ted Davis	⑤ CLASSIFICATION CANCELED
	6. CLASSIFIED INFO BRACKETED
	7. OTHER (SPECIFY):

p.71-1

[redacted]

UNCLASSIFIED

DISCLAIMER

UNCLASSIFIED

[redacted]

Lexington Project Report #175

Title: Polonium-Powered Aircraft for Military Purposes
Author: A. R. Kaufmann*
Date: September 28, 1948
Place: Lexington

SUMMARY

Polonium power is probably adequate for propelling aircraft at high speed and with unlimited range. It appears to involve fewer engineering difficulties on the aircraft phase than does airborne-pile power, but it involves large ground installations and would be costly. A small polonium-powered reconnaissance and guidance plane might direct a number of one-way chemically fueled bomb carriers to the target. This might even make pile-powered planes unnecessary. A 5,000 to 10,000-pound plane capable of carrying 1300 to 2700 pounds of equipment (radar, reconnaissance, or payload) might be powered with polonium at a probable cost of about 100 million dollars and the consumption of about 100 to 300 grams of uranium 235 per day.

The use of polonium to propel a plane large enough to carry the bomb should be made the subject of an economic and military study.

INTRODUCTION

Polonium is of possible interest for propelling long-range aircraft since it develops 86 heat horsepower per pound due to its radioactivity, and this power from a given initial amount decreases at the rate of only 1/2% per day. Hence, the weight of fuel required for a sizeable plane is negligible, and the range of such a plane would be unlimited for all practical purposes. The great advantage of polonium over a pile is that almost no shielding is required. In addition, the engineering problems associated with its use appear fairly simple of solution as compared with airborne-pile operation.

Polonium can be made in appreciable amounts by exposing bismuth to neutrons in a pile. One neutron is consumed for each polonium atom made and this means that if the excess neutrons from fission can be utilized, approximately one atom of uranium 235 or plutonium must fission for each one of polonium made. It follows immediately that polonium will be very expensive if it is made from enriched uranium 235 or from plutonium. This expense can be reduced if the polonium is obtained as a by-product from power piles which are designed to creat approximately as many fissionable atoms as they consume, but the rate of polonium production (per unit pile power) would be correspondingly decreased.

*This report has been prepared by Dr. Kaufmann to present his personal views. The subject has not been investigated by the Lexington Project group as a whole.

[redacted]

UNCLASSIFIED

p-71-2

The maximum power obtainable from polonium is about 1/37 the power of the pile required to maintain the polonium, and in practice the figure would be closer to 1/100. This loss of power is a serious disadvantage of polonium as is also the fact that the material cannot be stored for future use. However, the technical advantages of polonium as compared with a mobile pile are great enough to warrant a serious consideration of this material. These advantages are little shielding, easy control of the heat engine, availability of materials of construction, and probably no trouble from radiation damage.

The difficulties of pile construction will not be avoided through the use of polonium since piles must be operated on the ground to produce it. However, land-based piles present many less engineering problems than airborne units and may also have advantages in lower uranium investment, both in the pile and tied up in reprocessing. In this respect the advantage appears to lie with polonium production for the mobile power.

The problems of producing and using polonium will be discussed in a general way in the following pages. The data presented are intended merely to outline the problem with no attempt at precise calculations which would prove feasibility. The intention is to show that there are ample reasons for seriously considering the use of polonium for propelling a few special aircraft; and to indicate the need for a detailed study by some competent group of people who will concern themselves not only with science and engineering but also with military strategy and economics.

PROPERTIES OF POLONIUM

Polonium occurs in the same column of the periodic table as selenium and tellurium but is more metallic than these elements. Its density is 9.3 grams/c.c. and its melting point is 250°C (480°F). No quantitative data are available on vapor pressure but it must be fairly high since appreciable vaporization occurs at 700-800°C (1230-1410°F). Nothing is known about alloys of polonium except for some evidence that there may be a compound and also solid solution with lead. The oxide of polonium is decomposed by heat at about 700°C (1230°F). Very little is known about other chemical compounds of polonium.

Polonium is radioactive and has a half-life of 140 days. It emits alpha particles of 5.4 Mev. energy and occasionally a gamma ray of 0.8 Mev. The ratio of gammas to alphas is 2×10^{-5} and hence polonium is practically a pure alpha emitter. This is the reason why polonium presents very few problems in shielding. After emitting the alpha particle, polonium turns into stable lead.

The decay of polonium is expressed by the following equation:

p.71-3

Amount on hand = $N = N_0 e^{-bt}$

where N_0 = amount of Po at "t" = 0

b = a constant with value 5.75×10^{-8} if t is in seconds or 4.95×10^{-3} if t is in days

The rate of decay is $\frac{dN}{dt} = -bN$

With these equations and the above data the following useful information can be obtained:

(a) Po liberates heat at the rate of 85.5 hp. (64.5 kw.) per pound or 1320 watts per c.c.

(b) The daily decay is 0.50% of the amount on hand.

(c) There are 2.2×10^{-4} grams per Curie
" " 2.0×10^{6} Curies per pound
" " 4.5×10^{3} Curies per gram
" " 4.1×10^{4} Curies per cubic centimeter

PRODUCTION OF POLONIUM

Polonium is made by exposing bismuth to neutrons in a pile. When a bismuth atom absorbs a neutron it changes into radium E which decays with the emission of a beta particle (half-life 5.0 days) to form polonium. Upon removal from the pile, the polonium is extracted from the bismuth by a chemical process and may then be put into the form required. These two production steps may be discussed separately.

(a) Creation in a pile. The build-up of Po in a pile operating at steady power is given by the equation

$$N = \frac{A}{b}(1-e^{-bt})$$

where A is the rate of production of Po in the pile. This equation is accurate only after about 20 days since the intermediate production of radium E has not been taken into account. The amount of Po approaches a limiting value determined by the rate of decay becoming equal to the rate of production. For maximum efficiency the Po should be removed continuously from the pile. If it is removed every 200 days, about 1/3 of the Po made will have decayed in the pile and 2/3 will be available for extraction.

A pile of 100,000 kw. power output can continuously maintain in existance 40 pounds of Po, if one Po atom is assumed to result from one fission. There are two ways of utilizing the excess pile neutrons for polonium production: (1) The bismuth can be irradiated in the pile core. A 100,000 kw. thermal pile containing 12 kg. of U^{233} has an average thermal neutron flux of $2 \times 10^{14}/cm^2$-sec. in the core. A sample of bismuth irradiated in this flux would contain only 40 parts per million of Po after 200 days. Thus, in order to achieve the possible 40 pounds of Po, the pile core would have to contain 500 tons of bismuth. Since 500 tons of bismuth occupies approximately 50,000 liters (1800 cubic feet), this method would involve piles of very large volume and large critical mass. (2) The pile core can be maintained small and undiluted by surrounding it with a bismuth blanket into which the excess neutrons escape and are absorbed. The thickness of the bismuth blanket required to absorb most of the escaping neutrons is determined by the diffusion length of the escaping neutrons in the blanket. For pure bismuth, the diffusion length is about 100 cm. (approximately independent of the neutron energy) and this distance can be decreased by adding a scattering but non-absorbing diluent (like heavy water) to the bismuth. Assuming a 100 cm. layer of bismuth metal around a 2-foot cubical core, about 200 tons of bismuth would be required.

The pile power required to make and maintain a given amount of Po will be smaller the greater the ratio of Po atoms made to U^{235} fissioned. In Table 1 four different possibilities are listed and the pile size required for each 1000 pounds of airplane is shown. Example B appears to be the most economical possibility (from the point of view of the economic utilization of fissionable material) for production in the distant future; but Examples C or D are the most practical (in terms of time and effort) for any immediate consideration for a small plane.

(b) <u>Extraction from bismuth.</u> The chemical process now in use involves dissolving the Bi and Po in aqua regia, removing the excess nitric acid and then plating the Po out of solution onto a small amount of Bi powder. By carrying this process out twice, the concentration of Po is increased from about 1 part per million to 4%. The process is carried out in small batches in glass-lined or plastic vessels. The Po is removed from the 4% mixture with Bi by oxidizing both metals and then heating to about 800°C. The Po oxide decomposes and the metal distills off while the Bi oxide remains behind. A separation from the small silver impurity is also obtained in this step. This is important since only 0.2 parts per million Ag in the original bismuth give three times as many gamma rays as the Po itself. The overall recovery of Po including decay from the time of leaving the pile is about 85%.

This process could be adapted to the production of large amounts of Po, but it would need to be redesigned for large-scale operation. It is difficult to estimate accurately the size and cost of plant and the manpower that would be required for a given amount of Po, since the unit cost with the present small operation could probably be reduced by a factor of 100 to 1000. This can be readily seen from the fact that one could get an initial concentration of 40 p.p.m. instead of the present 1 p.p.m. and the fact that the manpower requirement per unit of Po would be greatly reduced in a large operation. The present operating cost is almost entirely due to labor. A reasonable estimate indicates that a plant of $100,000 initial cost and $50,000 per year operating cost would be required for each 1000 pounds of plane (10 pounds of Po) that is to be flown. This indicates that chemical processing will be much less expensive than the pile operation required to make the Po.

The possibility of continuously extracting the Po from the liquid Bi surrounding the pile should be explored since this might avoid altogether the need for a chemical processing and would reduce to a minimum the decay of Po within the pile. This might be done, for example, by passing the molten Bi over certain other metals having a strong affinity for Po so that a compound is formed and the Po is removed from solution.

HEALTH PROBLEM

Polonium is a very toxic material if it gets into the body in appreciable amounts. It must be handled at all times in special chambers with all manipulations being done by remote means or by hands inside drybox gloves. Fortunately, the chemical processing is well adapted to remote operation, and it has been found possible to provide adequate ventilation to workers without excessive contamination escaping into the atmosphere above the plant.

It appears likely that Po could be handled for any power plant application by having it dissolved in a liquid metal such as Bi or Pb. This should make it possible to transfer it through pipes and to keep it hermetically sealed at all times. It, therefore, seems possible to eliminate any health hazard from the Po except for the possibility of an accident such as a plane crash.

POLONIUM POWER PLANT

If the Po were dissolved in liquid Bi or Pb it could be placed inside a heat exchanger such as the one described in Chapter III of the Final Report of the Lexington Project. The heat exchanger could be operated at some suitable temperature such as 1500°F (820°C) and the air which is forced through it by a compressor would provide the jet which drives the plane. Presumably the same performance figures mentioned in Chapter III could be obtained with Po power. That is, a 1000 lbs of thrust could be obtained for each 4 sq. ft. of frontal area of the exchanger at 40,000 ft. The weight of fan, turbine and heat exchanger (filled with Bi and Po) would be about 3 lbs. per lb. of thrust. About 25% of the exchanger volume would be occupied by the liquid metal. In this case, the liquid would be about 10% Po by weight.

SHIELDING

The gamma-ray intensity from Po is low enough so that a "shadow" shield next to the heat exchanger which is somewhat larger than the side of the exchanger which faces the pilot should do the job. There is no point in accurately calculating here the weight of shielding required for different sizes of plane. To get an order of magnitude it may be assumed that the pilot is 10 feet from the exchanger and that the Po may be regarded as a point source. For each 1000 pounds of plane, 10 pounds of Po will be required and this will emit 1.5×10^{13} gammas per second. This will be attenuated to 1.5×10^{7} gammas per cm^2 per sec. by the distance. A shield thickness of 1.8 inches of lead will reduce this to 1.5×10^{5} which is about 0.5 r/hr. which is about the same as the figure being used for the pile-powered plane. Assuming that the heat exchanger is 18 in. long and taking a frontal area of 0.4 sq. ft. per 1000 lb. of plane, it appears that a slab of lead 9 in. by 20 in. would give an adequate shadow. A piece of lead of this size and 1.8 in. thick would weight about 130 lb. As a first approximation it could be assumed that for larger planes the shield weight goes up proportionately.

PLANE SIZE

On the basis of the above statements about weight of machinery and shielding, it is possible to make estimates of the amount of payload for different sizes of plane. Assuming that the structure of a plane minus machinery is 30% of the gross weight it appears that the payload per 1000 lb. of plane flying at 600 m.p.h. at 40,000 ft. will be about 270 lb. (1000-300-300-130 = 270). Thus, a 5000 lb. plane could carry about 1350 lb. while a 50,000 lb. plane could carry the bomb.

STRATEGY AND ECONOMICS

There are two distinct possibilities for using Po. The first of these is in propelling a small plane of 5000 to 10,000-pound size to be used for reconnaissance, fighter escort for a big plane, radio guidance of a one-way chemically fueled plane, or for germ warfare. It should be emphasized that the existence of an adequate reconnaissance and guidance plane might very well make one-way chemically fueled planes adequate for delivering bombs, and this could mean that the development of pile-powered planes for this purpose might be unnecessary. For this purpose Po is unique since a pile-powered plane must be big. If there is a sufficiently great need for such a plane of unlimited range, it should be possible to achieve this with a relatively moderate investment. For example, the 5000 lb. plane would require one pile of 100,000 to 200,000 kw. capacity (examples D and C) which would burn U^{235}, at the rate of 100 to 300 grams per day, and a chemical processing plant. A cost of 100 million dollars for this development, exclusive of the U^{235}, seems like a reasonable order of magnitude.

The other possible use for Po is in carrying the bomb. Here it competes with pile power and a careful analysis of the advantages and disadvantages of each method is required. From the standpoint of aircraft engineering feasibility the advantage clearly lies with Po. The real question, therefore, is one of cost. The answer here is not immediately apparent since it must be realized that one polonium-powered plane with the necessary sustaining piles could fly indefinitely while a pile-powered plane would last only approximately four days (as now visualized). Thus, a large number of piles with a correspondingly large uranium investiment would be needed to accomplish the same number of flights as the Po plane. It should be noted again that the Po decay goes on whether or not the plane is in the air, while a pile power plant could be shut off when not needed. The question of whether the number of piles and the uranium investment required for the Po would be greater than for an equivalent number of pile-powered planes would require a careful and detailed analysis. In this connection it should be realized that the uranium investment for ground-operated piles may be much lower than for mobile units and that the ground piles offer the possibility of multiplying or at least sustaining the amount of fissionable material while at the same time generating large amounts of useful power. The whole question requires a very careful analysis.

From the military standpoint it should be mentioned that a Po plane could deliver only one bomb per day for an indefinite length of time while 10 or 20 pile-powered planes held in reserve (assuming this much U^{235} were obtainable) could deliver 10 or 20 bombs per day for four or five days. This would be a distinct advantage for a blitzkrieg. Polonium would need to be made continuously if it were to be ready for immediate use. If manufacture were started only at the beginning of a war, it would take six months to a year to get the necessary amount of Po, even if the piles were held in readiness. However, if there were a large atomic-power industry which made Po as a by-product, the Po could be used for various peace-time purposes and still be ready for emergency use.

It should be pointed out that a blitzkrieg would be possible with one-way chemically fueled planes if a few small polonium-powered guidance and observation planes were located over the target area to guide the chemically powered planes in. This is a further argument for the small polonium-powered plane.

CONCLUSIONS

The propulsion of small reconnaissance planes with polonium appears to be feasible from an engineering and economic standpoint. The value of such planes for directing one-way chemically fueled bomb carriers appears to be great enough to warrant further serious study of the proposition. The desirability of a large polonium-powered plane for carrying the bomb should be further studied in comparison with pile-powered planes, particularly from an overall economic and eningeering viewpoint. Should enough of the unsolved problems involved in the construction of pile-powered planes turn out to be unsolvable, the possibility of a polonium-powered plane capable of the desired performance will still remain as another alternative.

p-71-9

UNCLASSIFIED [redacted]

Table I -- Pile Requirements for Polonium Production

Designation	Ratio of Po made to U^{235} fissioned	Pile type and conversion method	Pile power for 1000 thrust H.P. from Po*	Pile power for 1000 lb. of plane at 600 m.p.h. and $\frac{L}{D} = 10$	Investment of U^{235} per 1000 lb. of plane**	Consumption of U^{235} per 1000 lb. of plane
A	2%	Natural uranium thermal pile	7,000,000 kilowatts	1,100,000 kilowatts	None -- natural U	None -- makes plutonium
B	10 to 30%	Bi cooled & blanketed thermal or fast pile using enriched U^{235} and making U^{235} or Plutonium	1,300,000 to 450,000	220,000 to 73,000	5 to 50 kg. depending on pile type	None -- makes as much U^{235} or Pu as U^{235} consumed
C	100%	Bi-cooled & blanketed thermal or fast pile using U^{235}. Operate for maximum conversion to Po and withdraw Po continuously as made	130,000	22,000	5 to 20 kg. depending on pile type	22 grams per day
D	100%	Same as type C but with Po withdrawn every 200 days. 90% recovery of Po in processing.	230,000***	39,000***	5 to 20 kg. depending on pile type	40 grams per day***

* Assumes 20% thermodynamic efficiency in heat engine. 100% recovery of Po from pile for types A, B & C.

** Figures are for U^{235} in the pile. Material tied up in reprocessing is not taken into account.

*** These figures apply only at the time of removing the Po from the pile since the Po power will decrease until the next batch is obtained from the pile.

p.11-10

[redacted] UNCLASSIFIED

LP-175-9