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## **NUCLEAR BY-PRODUCTS:**

### **A RESOURCE FOR THE FUTURE**

#### INTRODUCTION

On the afternoon of December 2, 1942, a group of expatriate scientists headed by Enrico Fermi huddled anxiously around their instruments in a laboratory underneath the University of Chicago's Stagg Field. Suddenly their anxiety turned to elation: they had achieved the world's first controlled chain reaction and, in so doing, heralded the birth of the nuclear age. Today, some 35 years after their breakthrough, a debate rages over whether it represents the greatest boon in history or the engine of mankind's destruction.

To a large degree, the nuclear debate has focused on the question of what to do with the by-products of nuclear fission. These by-products include a wide range of materials, both radioactive and non-radioactive, which traditionally have been viewed as waste. As a result of this attitude, considerable effort and expense have gone into the search for an optimum method of disposing of them. Recently, a new school of thought has developed. This line of reasoning suggests that these by-products may constitute a valuable resource, conceivably worth hundreds of billions of dollars. Considering these wastes in a context apart from the nuclear fission process which creates them represents a radical departure from previous views of these materials. In many ways, however, it has a parallel in the early history of the petroleum industry.

When oil first came into widespread use, the natural gas frequently found in conjunction with it was seen as a nuisance. It was not at all uncommon for drillers to "flare" or burn off the gas in order to get to the oil underneath it. Pillars of smoke and fire rising hundreds of feet in the air were a common sight in oil fields around the world. In time, it was discovered that natural gas was a convenient clean-burning fuel and that it was an excellent feedstock for petrochemicals. Suddenly, what had been thought of as a waste by-product of oil drilling became a valuable resource in and of itself. Similarly, thoughtful scientists are beginning to see ways in which nuclear by-products currently regarded as wastes can be put to productive purposes, transforming them, as was the case with natural gas, into a valuable resource.

#### TOWARDS A NEW DIRECTION

Paradoxical as it seems, the very characteristics which make nuclear by-products a thorny disposal problem when thought of as wastes are the ones which hold the key to converting them to useful purposes. Among the most important of these are the heat they generate and the radioactivity they emit; but most contemporary research concerning these materials focuses on shielding this radioactivity and dissipating this heat so that by-products can be safely stored for long periods of time. The parallel with natural gas is striking. Because it was a volatile, flammable substance and posed a danger to oil drilling operations, it was burned off. In burning it off, however, the drillers overlooked its obvious potential for burning as a fuel. In the case of nuclear by-products, the obvious is also missed: the heat and radioactivity they generate are forms of energy -- forms with tremendous potential. To the degree that this energy can be harnessed and wastes used, the amount to be disposed of is minimized and the drain on other energy resources reduced. Also, because of their long lives, nuclear by-products open up options which would otherwise not exist. Several examples of this can be found in their contemporary uses.

#### PLUTONIUM 238

There are three isotopes of Plutonium. One is Plutonium 238, which is already being used to a degree in certain specialized applications. Because of the low penetrating nature of the radiation it emits and its long half-life, it has been recognized as an ideal fuel for cardiac pacemakers. These devices, without which thousands of heart patients could not survive, utilize the heat generated by the radioactive decay of Pu-238. Based largely on the positive experience with this substance as a power source for cardiac pacemakers, ERDA and the National Heart and Lung Institute have been researching the possibility of using it to

power artificial hearts. Should this research prove successful, the potential for saving human life would be enormous. Each year, according to estimates, there would be from 12,000 to 32,000 otherwise terminal patients whose lives could be extended by a Plutonium powered artificial heart. There would also be from 100,000 to 150,000 seriously disabled heart patients who could live far more normal lives with the assistance of such devices. In other words, potential for alleviating the suffering of as many as 182,000 persons each year is inherent in this one use of Pu-238.<sup>1</sup>

Non-medical uses of Pu-238 are also on the horizon, and some exist today. This is especially true of military and scientific applications. The Navy, for example, uses Pu-238 to power navigation satellites. The Air Force uses it for both communication and weather satellites. Much of the information sent from our neighbors in the solar system by various space probes has come from units powered by Pu-238. A short listing of them is impressive. The five Lunar monitoring stations which have been transmitting data to Earth for as long as seven years are all powered by Plutonium. Similarly, the Mars Landers which sent us the first television pictures of the fourth planet, Pioneer 11 and 12 which sent us the first data from Jupiter, and the Voyager spacecraft all use this substance as a fuel.

What is perhaps most important is that Plutonium is but one of a whole family of nuclear by-products called "transuranics." Transuranics have atomic weights higher than uranium and all of them hold tremendous potential for development of a multitude of useful applications. Some of these, like Pu-238, are in use today.

## OTHER TRANSURANICS

One of the more widely used transuranics is Americium-241. Perhaps the most important use is for logging oil wells. Other applications include its use in certain types of gauges, in metering devices and in the manufacture of smoke detectors. Currently, there is a worldwide shortage of Americium-241; and as a result, its value has been steadily increasing. It presently sells for around \$210 per gram, but this price is likely to increase significantly as the shortage becomes more severe.

Neptunium-237, one of the largest constituent elements of waste, also has considerable value. It is estimated that by 1990, stores of this element, which currently sells for \$100 per gram, could reach some 36 million grams. This would have a value of \$3.6 billion at the current price. Presently, Neptunium-237 is

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<sup>1</sup>The statistical and other data cited in the following three sections of this study are derived principally from Proceedings of the 12th Intersociety Energy Conversion Engineering Conference, Washington, D.C., August 28 through September 2, 1977, published by the American Nuclear Society, Vol. 2, esp. p. 1049.

primarily used in generating Plutonium-238, which is accomplished through bombardment of Neptunium-237 with high speed neutrons. As medical and scientific applications of Pu-238 multiply, our stores of Neptunium-237 will help to insure that adequate supplies of this valuable isotope of Plutonium are available.

A third transuranic which holds considerable, although unrealized, value is Curium-244. This material has a moderate half-life and generates considerable heat energy. For example, one gram of Curium-244 produces 2.84 thermal watts. It also has a number of useful applications in the area of special purpose electrons.

Americium-241, Neptunium-237, and Curium-244 are only three of the elements in the transuranic group. Others also hold potential for development in scientific, medical, and energy-related applications. Further, the transuranics constitute only a portion of the total volume of nuclear by-products. A second, equally important segment consists of what are termed "fission fragments." Fission fragments get their name from the fact that they are created by the splitting or "fissioning" of a uranium atom during the process of a chain reaction. As they are actually pieces of the fissioned atom, they are termed "fragments." Among the most important of the fission fragments are the platinum-group metals.

## PLATINUM-GROUP METALS

Platinum-group metals are of special importance as they are not found in significant quantities in the United States. Nearly all of our domestic needs come from imports, and over 90 percent of the world's production is from nations with which our political relationships are volatile. Specifically, 49 percent of the world's production takes place in South Africa and 44 percent in the Soviet Union. These metals, which include platinum, palladium, rhodium, iridium, ruthenium, and osmium, are essential as catalysts and corrosion inhibitors. Nuclear by-products include significant amounts of palladium, rhodium, ruthenium, and an element called technetium which does not occur in nature. Considering the fact that in 1974 the U.S. spent \$503 million on importing platinum-group metals for industrial processes, the value of the metals contained in what are currently termed wastes becomes evident. In fact, between now and the year 2000, it is estimated that the United States will require 1.7 billion grams of platinum-group metals, although domestic reserves are only 30 million grams. Utilizing the metals generated as fission products could go a long way toward alleviating this potential for shortage.

The United States is expected to require between 746 million and 1 billion grams of palladium through the end of this century. Domestic reserves of palladium, however, are only estimated at

between 300,000 and 600,000 grams. This means that virtually all supplies will have to be imported if purely natural deposits are depended upon. On the other hand, if the palladium present in fission products is utilized, there will be a domestic inventory of 60 million grams by 1990, 80 percent of which would be non-radioactive. Even Palladium-107, which constitutes the radioactive isotope of this element present in nuclear by-products, is so slightly radioactive that it can be safely used in many industrial processes. Further, this 60 million gram inventory can be expected to increase by a factor of five to ten by the end of the century. As this occurs, domestic reserves contained in nuclear by-products will be adequate to supply all domestic demand.

The U.S. is expected to require from 59 million to 87 million grams of rhodium by the year 2000. Domestic reserves are virtually non-existent. Domestic production of rhodium peaked at 62,000 grams per year in 1967 and has declined ever since. Again, large amounts of this metal will have to be imported if the vast amounts of it present in fission products are not utilized. By 1990, there will be some 31 million grams of rhodium isotopes present in nuclear wastes. While some of these isotopes are highly radioactive and must be stored for up to 20 years prior to their use, substantial amounts of usable rhodium are also present in waste. The stable isotopes can be separated from the isotopes which must be stored through known technologies. In the face of a substantial U.S. demand and insignificant natural endowment, it makes sense to do so.

Ruthenium, which is used as a corrosion inhibitor and as a superconductor, is also present in large quantities in nuclear by-products. The U.S. currently imports large amounts of this metal at a price of \$2 per gram. This price may well make economic the use of isotope separation techniques to obtain the stable isotopes of this element from nuclear wastes. By 1990, estimated inventories of this metal existing in wastes may well amount to 93 million grams; and by the end of the century, there will be as much as 1 billion grams present in wastes.

One of the most useful of the platinum-group metals, technetium, does not exist in nature. It currently is in widespread use for sophisticated medical procedures such as brain scans. As technetium is only created through the process of a chain reaction, supplies of it are found only in what are thought of as nuclear wastes. Estimates indicate that by the year 1990, there will be as much as 62 million grams of technetium present in nuclear by-products. Since it is particularly valuable as the catalyst for liquid fuels which do not contain additives, demand for technetium can be expected to increase substantially over the next several decades. Also, the fact that it can be used as a substitute for platinum in most

applications tends to give it considerable breadth in terms of potential use.

In considering the magnitude of anticipated imports of platinum-group metals through the end of the century, it rapidly becomes evident that it would be unwise to fail to extract the supplies of them present in nuclear by-products. In fact, using them will have a double conservation effect. These metals are essential to catalytic chemistry. Many new catalytic processes are being adopted by industry, because they require far less energy than conventional ones. Therefore, in addition to utilizing materials which would otherwise be discarded, the extraction of platinum-group metals from nuclear wastes will also have the effect of helping to reduce industrial energy consumption.

Platinum-group metals are not the only portion of fission fragments which holds potential for assisting in the conservation or recycling of resources. Another exciting possibility lies in the use of Cesium or Cobalt-60 for food irradiation.

#### FOOD IRRADIATION AND PEST CONTROL

Both Cesium-137 and Cobalt-60 have been suggested for possible use in food irradiation. Food irradiation serves two basic purposes: pest control and preservation. In the case of pest control, the potential gains from food irradiation are impressive. Current estimates place post-harvest world food losses from pests at as much as 25 percent of total food production. It has also been estimated that as many as 30 million tons of seed foods are lost each year. This loss is approximately equivalent to the production of 50,000 square kilometers of prime farmland. The losses of food, incidentally, are only part of the total loss to society. Energy and fertilizer used in the production of the lost food represent a substantial drain on world hydrocarbon resources, as both are heavily dependent on petroleum and natural gas.

Currently, considerable energy is consumed in refrigerating, heating, and storing various types of food. Also, many of the pesticides which are employed to eliminate pests which attack food stored in post-harvest facilities are petroleum-based. Further, the use of the pesticides has been the subject of increasing scrutiny as fears over potential side-effects proliferate. Food irradiation helps to alleviate both the drain on hydrocarbon resources and the dangers associated with toxic substances.

Experiments to determine the safety and efficacy of irradiating food so that it can safely be stored for extended periods of time have been conducted. Based on data supplied by these experiments,

a joint committee of the World Health Organization, Food and Agriculture Organization, and International Atomic Energy Agency approved five irradiated foods as safe for human consumption as of September, 1976. These five foods were potatoes, chicken, wheat, papaya, and strawberries. In addition to the five which received final approval, three other foods -- rice, fish, and onions -- received tentative approval. As more experimental evidence accumulates, it is likely that the number of approved irradiated foods will markedly increase.

There are several reasons why food irradiation will be of increasing importance in coming years. First, there is the fact that a growing number of nations are finding it increasingly difficult to feed their populations. Given this situation, post-harvest losses of the magnitude suffered today are simply intolerable. Similarly, in a world where energy appears to be growing increasingly scarce, any measure which will assist in reducing the tremendous energy expenditures associated with food storage and preservation is likely to be welcome. Also, a reduction of the drain on hydrocarbons for pesticides is of considerable import. Most importantly, however, it appears that previous questions as to the economic viability of food irradiation on a large scale may be resolved.

In the past, food irradiation techniques employed Cobalt-60 as a radiation source. The problem with this material was that it had to be artificially produced, and its production on a large scale did not seem practical. In recent years, radiocesium has been suggested as the agent for food irradiation. Unlike Cobalt-60, this substance is produced in prodigious amounts during the normal course of operations of a power reactor and is, therefore, present in significant quantities in nuclear wastes. It is the advent of radiocesium which may make irradiation an economic technique. The prolific quantities of cesium may also provide radiation for the production of fertilizer from municipal wastes.

#### USING MUNICIPAL WASTES THROUGH CÉSIUM IRRADIATION

Increasingly, large cities have been faced with a crisis in the area of solid waste disposal. Expensive filtration and purification facilities have been constructed to insure for the residents a continuing supply of pure water, but recent evidence indicates that some of the chemical additives used in water purification may be carcinogenic. Also, some facilities are beginning to break down under rapidly escalating demands on their capacity. One answer to this problem may lie in using irradiation techniques to turn solid wastes into fertilizer.

The radiation produced by some elements such as Cesium-137 and Cobalt-60 is extremely effective as a sterilizing agent. These isotopes, when encapsulated in impervious substances to prevent

leaching into a water system, can be utilized to convert municipal waste treatment plants into facilities capable of manufacturing high-grade fertilizer and nitrogen fixation agents. Various laboratory experiments have been conducted with considerable success over the last twenty years to determine the practicability of this process. Most encouraging is the fact that since 1975, Munich, Germany has had a full-scale plant in production on a commercial basis.<sup>2</sup> The Munich plant, which uses Cobalt-60 for irradiation, produces approximately 120 cubic meters of high-grade fertilizer and soil conditioner each day.

In the United States, there are a number of projects under way to test the feasibility of commercial irradiation of municipal wastes. In these studies, a number of positive effects have been observed. These effects include such phenomena as an enhanced settling rate, a reduction of odor, and a reduction of pathogens. Should these plants come into commercial operation in the United States, the potential exists to convert sludge which currently costs from \$25 to \$70 per ton into an asset worth from \$25 to \$100 per ton, depending on content and quality.

#### OTHER USES

An obvious use for various fission products is for the generation of power at remote sites. This is already being done to some extent. For the most part, contemporary use of fission products for remote power generation has been accomplished with radiostrontium. At present, the radiostrontium contained in wastes stored at the Hanford facility in Richland, Washington, is being extracted; and after extraction, this isotope is being encapsulated in units producing roughly one thermal kilowatt. These capsules could be suitable as power supplies for thermoelectric generators.

Recently, the Federal Aviation Authority has indicated that it intends to replace the fossil fuel-powered system at Lake Clark Pass, Alaska, with one powered by strontium.<sup>3</sup> This system, which will employ radiostrontium-powered thermoelectric generators, will be used to operate an unmanned navigation station. A number of advantages associated with radioisotope thermoelectric generators apparently led the FAA to its decision. Among those advantages were increased reliability and the elimination of hazards to personnel associated with bringing in tanks of propane gas by helicopter to refuel the station.

The Lake Clark Pass station is not the only application of radiostrontium-powered generators as power sources for remote sites. At present, there are some 40 such generators in operation in the United States. These generators have accumulated over 2,000,000 operating hours to date and have proven themselves especially well-suited to such functions as providing power for

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<sup>2</sup>Proceedings of the 12th Intersociety Energy Conversion Conference, *op. cit.*, p. 1052.

<sup>3</sup>*Ibid.*



remote land or undersea monitoring stations. One example of this may be found in the U.S. Navy's data acquisition station in the Bering Straits. This system, which is located on Fairway Rock, has been powered for nine years by a strontium-fueled generator. During the entire period, the system has remained completely unattended.

It has been suggested that strontium-fueled thermomechanical generators may be used to replace part of the Distant Early Warning (DEW) line. Close to \$40 million is being spent annually to operate this portion of the U.S. defense system. This cost could conceivably be significantly reduced through the use of highly reliable radiostrontium-powered thermomechanical solid state radar stations.

Should the reprocessing of spent fuel rods become a reality, as seems inevitable, there is a possible application for the by-product Krypton-85 in certain special types of illumination. Krypton-85 emits beta radiation, which can be used to irradiate a phosphor such as zinc sulphide, exciting it and causing the generation of visible light.<sup>4</sup> The advantage of such a light source stems primarily from the fact that it requires no electrical energy. It may, therefore, be used in applications in which the use of electricity is either impracticable or undesirable.

The creation of so-called "beta light" through the use of Krypton-85 has been an observed phenomenon for many years. It has not been practical up to now due to the relative scarcity of this element, but reprocessing of spent fuel rods might make it an economically viable technique. This is because relatively large amounts of Krypton-85 would be generated as a normal by-product of such activities. A typical reprocessing plant could be expected to produce 50,000 curies of Kr-85 per day. Light sources utilizing this gas would require from 4 to 60 curies each. This would obviously represent a significant lighting resource.

Among suggested applications for Kr-85 lamps are such uses as the illumination of oil wells so that accurate estimates of reserves can be made and fuller extraction of them accomplished and the use of such light sources in deep mines where the presence of natural gas presents a fire hazard when electric-powered light sources are used. Kr-85 lamps could be used to provide illumination for undersea research where the length of cables necessary to transmit electricity is prohibitive and the use of batteries is impracticable due to salt-water intrusion. Kr-85 could also be used to provide emergency lighting in situations where electric power is lost.

While Kr-85 would not be practical as a light source in homes because it emits hard radiation, it is possible to design emergency lighting so that the radiation hazard would be minimized for the relatively short periods of time the Kr-85 lamps would

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<sup>4</sup>Dr. C. A. Rohrmann, formerly of Battelle Pacific Northwest Laboratories, has had a Krypton powered "Beta" light in his home for a number of years.

be employed. Further, in deep mining applications, the hazards presented by more conventional illumination might outweigh those from the remote possibility of radiation leakage.

## THE COST OF NOT CONSERVING FISSION PRODUCTS

In this age of concern for conservation, what is perhaps most astounding is that so little real consideration has been given to the tremendous waste of resources which occurs in disposing of the by-products of nuclear fission. No thorough attempt to estimate the value of these by-products has been conducted since Rohrmann's work in 1965.<sup>5</sup> While it is true that his figures are probably on the low side, as advances in technology have opened increasingly wide areas of application for fission products, they still provide a basis for rationally estimating the loss to society. His original estimate placed the value of the by-products contained in a ton of nuclear waste at \$232,588.<sup>6</sup> Allowing for intervening inflation, this would place the value of the by-products contained in the spent fuel produced by a power reactor of the standard U.S. configuration at around \$14 million per year.

If ERDA estimates of nuclear power construction are in any way nearly accurate, some assessment of the potential value of nuclear by-products in the coming years can be made. Based on ERDA projections of power plant capacity installed by 1980, 1990, and 2000, the total value of the by-products produced by these plants will be approximately \$78.2 billion. The utilization of fission products will also have the effect of reducing our balance of payments by a minimum of \$11.7 billion through the end of the century. All of these figures are in constant 1977 dollars.

As it is not known just what their market price will eventually be, some of the values of by-products cannot be included in these estimates. However, there are some about which there exist ample data on which to base an estimate. For example, Americium currently sells for \$210 per gram. This means that by 1990, we would have stores of this element valued at \$1.4 billion, assuming no increase in price, although there is a shortage of this material and some increase in its real price, possibly doubling the aforementioned figure, may be anticipated. Similarly, Neptunium has a current market price of \$100 per gram. Stores of Neptunium will have a value of \$3.6 billion in thirteen years. Surprisingly, Krypton-85<sup>7</sup> is likely to decline in price, primarily because it currently is not produced in any significant amounts and must go through an enrichment process if it is to be used. As has been said, relatively significant amounts of it will be produced through reprocessing, thereby

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<sup>5</sup> See Isotope and Radiation Technology, Vol. 2, No. 2, Winter 1964-65, pp. 99-123.

<sup>6</sup> Ibid.

<sup>7</sup> For a more thorough discussion of noble gasses found in nuclear by-products, see Isotope and Radiation Technology, Vol. 8, No. 3, Spring 1971, p. 253.

increasing the supply to the point that the price might well decline. Even with a major change in price, the total stores of this gas would have an estimated value of \$2.4 billion by 1990.

All of these figures, of course, are only reflections of the dollar value of the actual materials contained in fission by-products. These numbers do not take into consideration the secondary benefits society will derive in terms of energy savings, enhanced quality of life, or the reduction in the absolute volume of material which must be disposed of.

## SUMMARY

To summarize just a few of these benefits, there are the 180,000 lives which could potentially be extended or improved through the use of plutonium-powered artificial hearts; the reduction of world food losses which could be accomplished through the use of cesium-137 for irradiation of foodstuffs during post-harvest storage; the new vistas of knowledge which could be explored through the use of strontium-powered remote monitoring devices; and the solution of our municipal waste problem through the conversion of wastes to fertilizer and nutrients by cesium-137 irradiation.

All of the benefits discussed in this paper are potential benefits. They will only be realized if previous attitudes and prejudices can be set aside long enough to allow an objective appraisal of their merits. Some uses of nuclear by-products will prove economically viable almost immediately, while others will need development time. The important point, however, is recognition of the fact that the potential exists. Today, the waste of vast quantities of natural gas during early oil drilling operations is regretted. Hopefully, future generations will not have cause to regret the waste of nuclear by-products.

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