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STORING NUCLEAR WASTES

INTRODUCTION

The current debate over energy alternatives has presented Congress with what is perhaps one of the most emotion-charged issues it has ever had to deal with: The future of nuclear power. Until recently, most Americans took for granted the increasing role of the atom in furnishing energy to meet our needs. Promises of safe, cheap power from an environmentally clean source made the development of nuclear reactors particularly attractive. Further, as Americans have traditionally favored technological solutions to problems, it would, therefore, only seem logical that our nation harness the atom on a widespread scale. The previously favorable climate for the development of nuclear power has changed, however. The change came about as increasing attention was given to questions concerning our ability to cope with the disposal of High-Level Wastes created by nuclear installations.. The critics of nuclear power who have raised these questions are not merely concerned about the waste problem but, rather, are opposed to further development of atomic energy under any circumstances. Whatever their overall philosophy regarding nuclear energy, it has become apparent that the most attention is given to their warnings concerning waste disposal. Both in the halls of the Congress and in the media, it is evident that solution of the waste disposal question is necessary if nuclear technology is to become an important part of our energy mix.

It is essential that this question be resolved in one way or another, as the consequences of a wrong decision would be disastrous. The opponents of nuclear power would have one believe that the disposal of nuclear waste materials presents a threat to the very existence of mankind. If they are incorrect, their efforts to block development of the atom may condemn our nation to totally avoidable economic dislocations which could ultimately result in a severe and permanent decline in our standard of living.

One of the most difficult problems to overcome in attempting to reach some rational decision on the question of nuclear waste disposal is the lack of unbiased information on the subject. It is difficult for legislators to deal with such a highly technical question on which there is considerable disagreement among experts. Rhetoric only serves to create confusion and mistrust, while adding nothing substantive to the debate. It is, therefore, useful to take a dispassionate look at the facts regarding nuclear waste disposal.

UNDERSTANDING RADIATION AND RADIOACTIVITY

In order to deal rationally with the question of nuclear waste disposal, one must fully understand the nature of radiation and radioactivity. Radiation is merely energy which is traveling in wave motion. It may take the form of particles or photons. We are literally surrounded by various forms of radiation in our everyday life. When we turn on a television set, the image we watch has been transmitted to us through the use of a form of radiation. The microwave ovens used to cook food utilize microwaves, a form of radiation which is transmitted in waves. Even the sunlight we take for granted is actually photon radiation.

Radioactivity is a natural and spontaneous process. It occurs when an unstable atom of an element emits or radiates the excess energy of its nucleus. This emission or radiation may take the form of particles or photons. The end result of this process is to lower the energy level of the original atom transforming it to a lower energy form of the element. This lowering of the energy level is referred to as decay. In some cases, the new form of the element is also radioactive. When this is the case, the process of decay will continue in a procession of successively lower energy levels until a stable non-radioactive form is attained. This process of attaining successively lower energy levels is sometimes referred to as the decay chain. The period of time it takes a radioactive element to reduce its energy level by one half is referred to as its half-life. In summary, then, radioactivity is the process by which excess energy is emitted from an atom's nucleus, while radiation is the emission of energy from one point to be received at another.

TYPES OF RADIATION

There are basically three types of radiation which are of concern in the nuclear waste disposal debate. These are Alpha, Beta, and Gamma radiation. Alpha radiation, which is the type emitted by plutonium, consists of two neutrons and two protons. Actually, Alpha particles are the nuclei of helium atoms. Of the three types of radiation commonly associated with nuclear energy, Alpha particles are the least penetrating. In fact, Alpha particles can be stopped by the thinnest barriers and are not capable of penetrating human skin under normal circumstances. As a result, they do not present the problems which are associated with Beta and Gamma radiation.

The second form of radiation associated with nuclear energy is Beta radiation. Unlike Alpha particles, Beta particles are composed of high-speed electrons and are, therefore, much more penetrating. They need relatively heavy shielding, such as a heavy wood barrier, or narrow gauge steel. Still, they do not present an unwarranted hazard; and as long as materials which are Beta emitters are properly shielded, they can be handled with relatively little risk.

The third form of radiation with which nuclear energy is commonly associated is Gamma radiation. Gamma radiation consists of photons and is similar to the x-ray in its composition. The most penetrating of the three forms, Gamma radiation presents serious hazards and must be shielded by thick lead barriers or other materials of similar density. It is Gamma radiation which is most frequently associated with short term health effects.

NORMAL EXPOSURE TO RADIATION

All three of the forms of radiation associated with nuclear energy are also found in nature. In fact, during the normal course of a year, everyone is exposed to certain levels of them. The most useful measure of this exposure is in terms of "rems" or "millirems." The millirem is 1/1000 of a rem. This unit of measurement takes into account the biological effects of the various forms of radiation, including Alpha, Beta, and Gamma radiation. Generally, the dosages are expressed in millirems per year, which is abbreviated as mrem/year.

The natural or "background" radiation to which an individual is exposed each year varies to some degree. This is partly attributable to the variation in radiation between different regions of the country. For example, those living in proximity to geysers are exposed to certain amount of radon gas, which is found in steam issuing from the earth. We all are exposed to about four mrems/year due to atomic fallout. X-rays or other radiological techniques can quickly raise an individual's annual radiation inventory. As a rule, however, the normal exposure resulting from background radiation ranges from 115 to 215 mrem/year.

DOSE EFFECTS OF RADIATION

The effects of radiation are assumed to have what is termed a dose relationship. By this it is meant that the higher the degree of exposure, the more severe the effect will be. While there is no evidence to indicate that the exposure to relatively low levels of radiation will have any effect on an individual, for reasons of safety, it is assumed that there is no level at which some effect will not occur. This assumed proportional relationship between exposure levels and biological effects is called the "linear hypothesis" of radiation effects. Under this hypothesis, for example, if 100,000 mrem of radiation exposure were to produce 10 incidences of observed radiation effects, then 10,000 mrem would produce one observed radiation effect and so forth.

Given the assumption of the linear hypothesis, it is useful to look at the biological effect of radiation in terms of level of exposure. Basically the effects of radiation may be divided into two categories. These categories derive their name from the nature of the effect. The first category is termed "genetic effect." Genetic effects of radiation come from the damaging of genes by exposure to radiation. They are suffered by the exposed individual's offspring rather than by the individual himself. Included in genetic effects are mutations, birth defects, and stillbirths. Considerable understanding of the genetic effects of radiation has been gained through studies of the survivors of the Hiroshima and Nagasaki atom bombs. These studies are continuing today to try to determine the long range impact of exposure to radiation on successive generations.

The second category of radiation effects is termed "somatic effect." These effects directly impact the health of the individual exposed. They include such things as an increased risk of cancer and, at very high levels, shortening of life.

While data on the effects of radiation at doses below 1000 mrem are inadequate to make any real assessment of their nature, the linear hypothesis is still applied; therefore, it is assumed that there will be some sort of effect. In fact, at levels of up to 9000 mrem, no observable effect exists. It is not until levels of exposure range considerably above this level that effect can even be detected in a laboratory, and there are no clinically observable effects at levels under 50,000 mrem. Between 50,000 and 100,000 mrem, there are observable effects, but they are primarily transient in nature, or genetic. The lifespan of the exposed individual is not appreciably shortened. Between 100,000 and 250,000 mrems, there is a relatively low rate of mortality. However, there is a high rate of acute radiation sickness. Radiation sickness includes such symptons as vomiting, diarrhea, loss of hair, hemorrhaging, and fever. Individuals who do not encounter complications usually recover from the somatic symptoms within three months after exposure. However, there can be subsequent genetic effects including sterility. At dose levels of 450,000 mrems and above, 50% of the exposed population dies within thirty days. The balance of the exposed population will survive but will likely experience some sort of permanent impairment. At levels of exposure above 1,000,000 mrems, the exposed population will die within thirty days.

As can be seen, it takes an extraordinarily high dose of radiation to have serious effects on the health of the exposed population. While one cannot take this to mean that there is no inherent danger in exposure to lower levels of radiation, it does mean that allegations that exposure to radiation, no matter what the dose, will be fatal are simply untrue. Further, as long as adequate safeguards are employed, there is not reason for an individual to be exposed to dosages anywhere near those known to have harmful effects. The fact that there is a potential for biological effects associated with radiation is just that -- a potential. Knowing that the potential hazard exists allows us to take precautions to prevent that potential from becoming a reality.

PLUTONIUM: MYTHS AND REALITY

One of the most common arguments against the ability of society to cope with the problem of nuclear waste disposal is the allegation that we cannot effectively insure safe disposal of plutonium. It is further contended that plutonium is the most toxic substance known to mankind and that its existence in large quantities presents virtual assurance of the destruction of civilization. While many individuals believe that these arguments are true, there appears to be little evidence to support them.

Perhaps the most significant single fact with regards to the relative safety of plutonium is that as of April 1976, the most recent date for which data was available for the purposes of this study, there were no known deaths attributable to plutonium. While this does not mean that with the growth of the absolute amount of plutonium in existence there will not be some corresponding increase in the potential for plutonium-related deaths, it does mean that at least up to the present, the plutonium already in existence has been safety dealt with. It would, therefore, follow that, based on our current level of experience, it would appear that the management of plutonium wastes is within the capability of society.

There are fairly rational reasons to believe that the management of plutonium will be possible over and above the historic data supporting the contention. First, there is the nature of plutonium itself. As has been said, opponents of nuclear energy commonly refer to plutonium as "the most toxic substance known to mankind." One fallacy of this comparison is that it fails to differentiate between chemical toxicity and radio toxicity. Plutonium is not nearly as toxic as many other fairly common substances. For example, lead arsenate is 11.5 times as toxic as plutonium, and potassium cyanide is 1.6 times as toxic. Further, whereas poisons such as potassium cyanide or lead arsenate act in a matter of minutes or hours, it would take fifteen years for a lethal dose of ingested plutonium to kill someone. It should be noted that certain biological toxins such as botulism and anthrax spores are literally tens of thousands of times as toxic as plutonium in the chemical sense. Again, this is not to suggest that plutonium presents no hazard to health but rather to put its potential hazard in perspective. Whereas its chemical toxicity is relatively low, the radio toxicity of plutonium is quite high. However, the hazard presented to human beings exists only under certain circumstances.

First, plutonium is an Alpha emitter. This means that the form of radiation it produces cannot pentrate human skin. Therefore, the plutonium must be somehow introduced into the body. Here again, there is no hazard unless certain conditions exist. It must either enter the lungs or be in a soluable form which can enter the blood stream. If it enters the lungs, it may stay there for a prolonged period of time and eventually induce lung cancer. This will not happen in all cases, and, even if the permissible lung burden is exceeded, it will take from 15 to 45 years for the individual to develop the disease. As has been said, the other means by which plutonium can cause adverse health effects in humans requires that the substance be in a soluble form when it enters the body so that it can be absorbed into the bloodstream. Plutonium, normally, is non-soluable, so the number of instances in which plutonium could enter the bloodstream are limited. Upon entering the bloodstream, soluable plutonium will travel to the bone and liver tissues where it can also cause forms of cancer due to prolonged alpha bombardment.

What is important about the biological effects of plutonium in terms of its potential hazard is that it must actually enter the body, and at that, it must be in particular forms if it is to be of any danger. Outside the body, because of the inability of alpha particles to penetrate even very thin barriers, it presents essentially no danger. It must either be inhaled or in some way introduced into the bloodstream to have an effect. This, to say the least, is difficult and is something against which precautions can be taken.

THE GENERATION AND NATURE OF NUCLEAR WASTES

Nuclear wastes are generated as a consequence of the normal operations of a reactor. As Uranium 235 atoms are split or fissioned by bombardment with neutrons in a chain reaction, energy is produced. This energy, which is primarily in the form of heat is ultimately used to produce electricity. A by-product of this process is the creation of two fragments of the original atom which are called "fission fragments." These fission fragments can be any of some 35 elements. Some of the fission fragments will be stable elements, and others will be radioactive. Frequently, the radioactive elements constituting fission fragments are isotopes of stable elements such as iodine or bromine.

Over time, as the chain reaction continues, more and more of these fission fragments are created. Eventually, they begin to interfere with the fissioning of the Uranium 235. After about a year, they generally build up to the point where one third of the fuel must be replaced. Even though the fission fragments are preventing the fuel from sustaining a sufficient level of criticality to maintain an adequate chain reaction, there still is considerable fissionable material (Uranium 235 and Plutonium) left in the fuel elements. It is possible to reclaim these from the used or spent fuel and the common practice is to do so.

Fissionable materials such as the U 235 and Pu 239 are retrieved from spent fuel through reprocessing. It has been estimated that the use of reprocessing will save approximately 2.5% of the overall cost of power production in a standard 1000 megawatt (Mwe) nuclear plant. This would amount to around $1.4 million per year. It also will serve to conserve Uranium and thereby reduce the amount which must be mined by around 10% per year.

Basically, reprocessing is accomplished through use of solvents to extract Uranium and Plutonium 239 from spent fuel rods. These rods are the most common form of reactor fuel. They consist of sealed metal tubes ½ inch in diameter and 12 feet long. Inside the tubes, there are pellets of Uranium Oxide which are 1 inch long. When the tubes are removed for reprocessing, they are first chopped into small segments and the pellets are taken out. These pellets are then placed in a solution of strong acids (nitric acid) and dissolved. After dissoultion, chemicals are added which act to separate fissionable materials. The remaining solution contains roughly 99% of the fission products (remnants of the fission fragments). This by-product of reprocessing constitutes what is commonly thought of as High-Level Wastes (HWL).

Initially, the wastes contained in the solution generate a tremendous amount of heat through their natural process of radioactive decay. The heat is so intense that it would boil away the solution in which the materials are suspended if it were not subjected to cooling. As a result, the wastes must be stored on an interim basis in holding tanks where they are allowed to decay to a point where the heat generated by the wastes will not be a problem. The normal holding period is around five years.

The interim storage facilities are called boiling waste tanks. These tanks are approximately 60 feet in diameter and 29 feet high. Actually, two tanks and a concrete vault are involved, so the term "tank" is actually a misnomer. There is an inner tank which is made of 304L type stainless steel, measuring 54 feet in diameter and 20 feet high. Along the bottom, and the last eight feet of the walls, the steel is one-half inch thick. This tank contains apparatus for cooling the wastes, so that the temperatures remain within tolerable limits, and also contain an agitator. The agitator continuously scours the lower corners and the bottom of the tank to insure that the wastes remain suspended in the solution. The outer tank, as has been said, is 60 feet by 29 feet. It is also constructed of 304L type stainless steel. There is a pump connected to the tank so that its integrity can be checked. Both of these tanks are encased in a concrete vault four feet thick and buried ten feet underground.

In addition to the tanks and concrete vault, the system is backed up by several ponds which can furnish for cooling the wastes in the eventuality that the cooling system should break down during an emergency. A second tank is provided. The purpose of the second tank is to have a facility available should the integrity of either the main tank or the concrete vault be breached. Examples of tanks such as these may be found at the storage facilities at Barnwell, South Carolina. While there can be no such thing as a completely safe storage facility, the boiling waste tanks come as close as may reasonably be expected. Any one of the barriers, the two tanks and vault, could prevent discharge of hazardous wastes into the surrounding environment under any but the most extreme circumstances. The second tank provides more than adequate backup should the integrity of the facility be breached. Further, the relatively short time during which wastes would be stored in this form tend to mitigate against the advent of a serious leak or breach of the integrity of the system.

SOLIDIFICATION: AN OVERVIEW

Once High-Level Wastes have decayed to the point where they may be subjected to further processing, it is currently thought that the best procedure is to solidify them. The process of solidification takes place in two steps. The first is calcination, i.e., the conversion of the liquid wastes into calcine. Calcines result from the heating of liquid inorganic materials to temperatures in the range of 300-900 degrees centigrade. When subjected to these temperatures, water and oxides of nitrogen are driven off. What remains is a dry oxide in the form of granules. An immediate advantage of the process is that it sharply reduces the amount of space required for storage, as wastes in this form occupy only one-eighth the space required to store liquid wastes with a similar content of fission products. Further, being solid, they are not prone to leakage and are far more stable.

Calcination is not a new process. Since the initiation of development of the process in 1955, considerable experience has been acquired through government-sponsored projects. In 1963, the Atomic Energy Commission began operating a pilot project plant at the Idaho Nuclear Engineering Laboratory. This facility uses a fluidized bed calcination process and has been successfully converting liquid wastes into calcines for fourteen years. More than 2.6 million gallons of liquid wastes have been converted into calcines since the plant was constructed. New technological advances in the calcination, and also make possible the linking of calcination and the next step in waste solidification: Vitrification.

The major advantage of taking the additional step from calcination to vitrification lies in the nature of vitrified wastes. Essentially, the process of vitrification fuses the wastes into a form of glass similar in chemical composition by pyrex. Because the vitrified wastes are in the form of a piece of glass, the process is also referred to as glassification. It has the property of effectively immobilizing each atom of High-Level Waste in a fixed position. Also it can be produced in large enough sizes to avoid the higher potential for dispersibility inherent in powder calcines. In fact, the potential dispersibility of vitrified wastes are estimated to be as much as 1000 times less than that of wastes which have only been calcinated.

SINGLE STEP VITRIFICATION

Until recently, vitrification processes were aimed at the conversion of wastes which already had been calcinated. The normal procedure was for the liquid wastes to go through three separate steps. First, the liquid wastes would be stored on an interim basis; then they would be converted to a calcine; and finally they would be vitrified (converted to glass). While there have been no serious mishaps directly attributable to the three-step process, it is obvious that reducing the number of stages would lead to a greater overall margin of safety. For this reason, development has taken place aimed at combining the second two steps of waste processing so that wastes will be calcinated and vitrified in a single procedure. Another advantage to the new approach to vitrification is that it is accomplished in a cannister. This eliminates a great deal of handling, and thereby reduces risk by a significant margin.

The process itself is fairly simple. Liquid wastes are introduced through a nozzle into a furnace, which is heated to 700 degrees centigrade. The chamber is essentially cylindrical, allowing the wastes to fall through. As they do so, the volatile materials and liquid are burned off. By the time the wastes have reached the bottom of the chamber, they are in the form of a calcine. The sides of the bottom of the furnace chamber are sloped so that the falling wastes, now calcinated, feed down through a diverter. At the same time, frit is being fed into the diverter through a separate channel. Frit is a mixture of various oxides of silicon, boron, and phosphorous it is the material used to make glass. The glass-making frit and calcinated wastes mix as they fall through the diverter, and the mix is fed into a storage cannister. The cannister and mixture are then heated to 1100 degrees centigrade. When it solidifies, the mixture of frit and calcinated wastes has been converted into a solid mass of glass, similar to pyrex in its composition. Each of the atoms of waste is bound as an integral part of the glass within the cannister.

Pilot-scale single step vitrification has been accomplished and has demonstrated that this approach to waste solidification is well within the grasp of current levels of technology. Experience with the pilot facility has also demonstrated that this procedure does, in fact, work as intended and that wastes treated in this fashion are far easier to handle than either calcines or liquids.

FEASIBILITY OF VITRIFICATION AS A LONG-TERM STORAGE TECHNIQUE

While vitrification appears, on the surface, to be among the most promising avenues for long-term waste storage, there are many questions which come to mind when its use is discussed. One of the most frequently voiced concerns comes from the fact that the wastes will be fused into columns of glass. Many individuals associate the term "glass" with the forms of it we encounter in our daily lives. It is, therefore, natural that concern would exist over the durability of such a material over the course of centuries. The form of glass, it should be remembered, is chemically similar to pyrex, the form of glass used for cookware and for most laboratory equipment. As a result, it is far harder and more resistant to heat than other forms. Further, the size and shape of the blocks of waste will be such that they will be much more resistant to fracture than one might imagine. Preliminary data from tests conducted, using one-sixth models of the cannisters, indicated that negligible amounts of HLW would be released even at impacts of up to eighty miles per hour. Needless to say, once the cannisters are placed in situ, there is even less danger of fracture. Tests have been conducted on the effect of the radiation from High-Level Wastes on the glass in which they will be fused. To speed up the time frame, two cannisters were filled with simulated waste containing large amounts of cerium-144. As of the present, no adverse effects have been noted. Additionally, there have been more recent experiments to deal with this question. To obtain rapid simulation of the effects which might occur over the long term, curium-244 was included in the test procedure. This particular radiation source will produce the equivalent of 10,000 years' radiation damage in just five years. It is, therefore, extremely useful in attempts to gain some understanding of the size of the problem which might be left to future generations. As of the present, no adverse radiation effects have been noted. Based on the various tests of the qualities of vitrified wastes, they appear to present a stable and highly desirable medium for long-term storage.

STORING VITRIFIED WASTES

Once wastes have been solidified, the question then becomes what to do with them. While there have been a number of suggestions in this regard, the most promising appears to be storage in what are called stable geologic formations. This phrase is most frequently used in reference to salt domes. The reason salt domes are particularly attractive is that they generally are impervious to groundwater, and the risk of contamination of water supplies is minimized. Also, the use of salt domes would be in keeping with the concept of the "serial barriers."

The concept of serial barriers refers to the use of multiple safeguards against leakage of wastes. For example, under the safeguards envisioned for the storage of vitrified wastes, there would be several intrinsic safeguards against the wastes entering the environment. First, there is the distance between the waste repository and the nearest human habitation. This would be a minimum of ten miles, and in many instances it would be even further. Secondly, there would be the distance the salt domes lay under the ground; this could easily be one mile. The third intrinsic safeguard would lie in the nature of geologic formation itself. Since the salt domes chosen would be located toward the center of the plate on which they were located, there would be very little chance that the domes would ever be subjected to severe enough natural disturbances to allow wastes to enter the environment. Fourth, there is the stainless steel cannister which would be constructed of half-inch 304L type stainless steel. This cannister would have to be corroded away by water seepage in some fashion, and it is particularly resistant to such corrosion. It should be remembered that the type of formation used in this scenario would have no water table nearby and is essentially impervious to water anyway. Fifth, there is the nature of the vitrified waste itself. In glassified form, these wastes are particularly difficult to wear down or dissolve. Further they have an extremely low leaching rate. Therefore, if one assumes that the salt dome has been breached by a water source somehow and that the steel cannister has been corroded away, the wastes themselves must now be worn down by the water. Finally, the wastes must somehow be carried at least one mile to the surface through the soil column above. It should be noted that the soil tends to act as an excellent filter and, therefore, would probably remove most of the radioactive materials before they reached the surface. Having accomplished all of the above, the wastes would still have to somehow find their way into an aquifer in order to be carried into the surrounding environment. Needless to say, the amount of wastes which penetrated all of the various intrinsic barriers would be so small as to hold no real danger for the environment.

CONCLUSION

In summary, it would appear that the process of one-step vitrification in cannister, coupled with storage in stable geological formations presents a promising method for the safe disposal of wastes from our reprocessing of nuclear fuel. It should be noted that it takes three metric tons of uranium ore processed through the nuclear fuel cycle to produce enough wastes to fill one of the standard steel storage cannisters. Another way of looking at the waste volume is that for each metric ton of uranium used, approximately 1140 liters of liquid waste are produced which then are reduced to 70 liters of vitrified waste. It takes 210 liters of this waste to fill one of the standard steel cannisters. By the end of the year 2000, it is estimated that excluding military wastes, which actually represent the bulk of the wastes, the total commercial wastes generated will amount to 29,000,000 gallons. This volume would be easily stored in 20 standard boiling waste storage tanks. It should be noted, however, that due to Nuclear Regulatory Commission regulations, that amount would never be in existence at any one point in time. The NRC requires that wastes be solidified in some form after five years.

The disposal of nuclear wastes is a very real problem with which society will have to deal. There is no doubt that the radiation hazards associated with High-Level Wastes exist. It is not true, however, that the solution of the problem is beyond the levels of technology existing in our society.

The fact is that we have been dealing with the problem of nuclear waste disposal for over thirty years and have been successful on an interim basis. While there have been some problems associated with leakages from tanks containing World War II waste products in liquid form, it should be remembered that when those wastes were stored, the technology for dealing with them did not exist. Today it does.

As our nation's energy crisis worsens, we will soon be faced with many hard choices. Regardless of what steps are taken to add to our energy resources, it is likely that some adjustment in our rates and methods of energy consumption will take place. The severity of these adjustments may be minimized if we develop nuclear power to its full potential. Since the major objection to the development of nuclear power appears to be the fear that High-Level Wastes will poison the environment, it may be that the use of vitrification will serve to allay those fears and allow the development to take place.

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