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MASTER

RISK OF PRODUCING ENERGY – AND CONSERVING IT

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If there is one question which concerns members of the general public most about generating nuclear power, it is the question of risk. Proliferation, resource availability and all the other matters which are treated in this and previous symposia, are of interest to the general public, but probably only in a limited way. As a result, I will discuss the important topic of risk to human health in this presentation.

One of the key questions in discussing the risks associated with nuclear power or any other energy system is, compared to what? That is, it is not too useful to say that there are so many man-days lost or deaths per megawatt-year, because that number will not mean much to many people. We gather most of what we know about the world in comparing things or ideas. So it is with risk. The risks we calculate mean most when they are compared to other risks.

This paper is divided into two parts. The first part is based on a study (1) done previously, comparing the risks of 11 different energy systems, including light-water nuclear power. The information presented in Ref. 1 is brought up to date as necessary.

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In addition, a crude attempt has been made to calculate some risks associated with one form of conservation. In the past few years, conservation has been held by some to be the panacea of most of our energy problems. Of course, conservation has always been going on; even a wealthy man shuts the windows in his house in wintertime. However, just as producing energy has its risks, detailed in the next section, so does conservation. Even when we conserve, there is "no free lunch." What is perhaps surprising about the results to be presented below is the magnitude of the risk of conservation compared to that of nuclear power. It is likely that coming years will see a refinement of the calculations, but this first attempt suggests that risk from at least one form of conservation can be large.

RISK OF ENERGY PRODUCTION

How can we compute the total risk of an energy system? Just as the cost of any article is made up of a number of sources, so the risk of an energy system has many origins. While it is impossible to state with certainty that the sources of risk noted in Figure 1 are the only sources, they are the major considerations in most risk studies.

Most of the risk sources in this figure seem to be of non-catastrophic origin, i.e. accidents or illnesses that occur one at a time. For example, most accidents in plant construction will likely involve only one person. This is confirmed in the report from which Figure 1 is taken (1). Even for systems like nuclear power and hydroelectricity, which receive considerable publicity about real or potential catastrophes, the proportion of catastrophic (as measured by historical statistics) to non-catastrophic risk is very small.

It might be contended that catastrophic risk is the only aspect that matters, and that all other risk should be neglected in calculations. This is a philosophical point, and it cannot be proved one way or the other. However, it seems clear that the total loss to society from building and operating energy systems is made up of all the deaths, accidents and illnesses that can be attributed to them, not just some. A person who is killed in a small accident is just as dead as someone who dies in a large one.

Does the production of energy actually increase occupational risk (as contrasted with public risk), or would this risk have existed in any case? To illustrate this seemingly obscure point, consider smelting steel for a turbine destined for a nuclear reactor. It is agreed that producing a tonne of steel has associated with it a small number of deaths and accidents. If the steel had not gone into the turbines, it might have been incorporated into lorries or tricycles. In this sense, the overall risk to society has not increased. By this reasoning, only if more steel than normal is required does the risk rise.

This approach, sometimes termed 'incremental,' has not been followed in most risk studies for a variety of reasons. First, no account is taken of public risk in the 'incremental' reasoning. As noted above, public risk of energy systems has usually drawn more attention than occupational risk. Secondly, the cost of anything, whether in terms of risk or money, is made up of what does take place, not what might have taken place. For example, consider an automobile. The steel, copper, glass, aluminum, etc., used to build it might well have been employed elsewhere, but its cost to the purchaser is based on the materials actually used. In the same way, almost all risk analysts use the 'absolute' approach, in which the total risk is computed, rather than the incremental.

Figure 1 indicates that most of the risk of any energy system will be 'statistical' rather than direct. Direct risk can be defined as that intimately connected with building and operating a system: falling off the roof while installing a solar collector, dying in a coal mine accident, and so forth. But there will be also substantial risk from transporting copper for wiring, producing fibreglass for windmill blades, and all the myriad activities that result in a complete energy system. This latter risk is indirect or 'statistical.' In other words, statistical risk as defined here is incurred by someone who cannot be identified by name.

One can make a case that 'statistical' risk is not part of total risk, since it is not directly associated with the energy system. On the other hand, a considerable portion, at least in terms of attention paid, of the risk of nuclear power and fossil-fueled systems is statistical in nature. For example, it has been estimated (2) that there will be about one death as a result of the Three Mile Island nuclear accident in 1979. This cancer death will occur over the next few decades, in an area where hundreds of thousands of cancer deaths will take place in the same period. Because this death cannot be identified explicitly, it is clearly 'statistical.' The same principle applies to many of the deaths and illnesses caused by air pollution.

Few, if any, have suggested that because these deaths are 'statistical,' they should be discarded from risk calculations. If the concept can be used for nuclear power and fossil fuels, there seems to be no reason why it should not be used to compute the risk of solar, wind-power, or any other system.

How does risk calculation proceed? As can be deduced from Figure 1, there are a variety of methods used. The length of this paper does not allow a full discussion of each type.

The amount of materials required for each system per unit energy output over its lifetime must be determined. The number of man-hours (or person-hours) required to produce this quantity is then estimated. Labour statistics that show the number of deaths, accidents and illnesses per man-hour are generally available.

The three sets of data are then combined for each material. For example, suppose mining X tonnes of coal requires Y man-hours. If the number of deaths per man-hour of work is Z, then the number of deaths per tonne of coal is YZ/X. The risk associated with each material is found in the same way, and these subvalues are added to determine the total risk of material acquisition.

Finished products will require intermediate and raw materials, and this should be accounted for in the calculations. For example, steel will require coal, iron ore and other industrial goods.

A similar approach may be taken in calculating construction risk. The trades electrical work, plumbing, roofing, etc. must be determined, as well as the time required per unit energy output. Then the risk per unit time (as contrasted with unit mass) can be found from industrial statistics. The data are then combined as above, and added to the material acquisition risk.

The other components of risk shown in Figure 1 are calculated in similar ways when possible, although different techniques are sometimes required. For example, transportation risk is calculated by assuming that all materials move a fixed distance by rail, and the average risk per tonne-kilometre is used to evaluate this source. The main exception is that sand and gravel are assumed to move negligible distances from where they are quarried.

A point of possible contention is how one calculates public risk for rare events like dam failures and reactor radioactivity releases. There are basically two approaches: historical and theoretical. The historical method takes what has happened over time as the basis for computations. Since there have been no theoretical calculations for the frequency of hydroelectric dam failures, the number of people killed by these accidents is divided by the total amount of hydroelectricity ever produced to yield public risk from this source.

On the other hand, nuclear power has had at least two extensive theoretical studies of public risk. In general, 'maximization' of nuclear risk, i.e. taking the highest value from these sources, was used, to avoid potential charges of pro-nuclear bias.

One may contrast historical with theoretical estimates of nuclear public risk. Generally speaking, the historical (or experimental) values of risk are lower than the theoretical ones, even when the accident at Three Mile Island is taken into account. Of course, there is no guarantee that this situation will remain unchanged in the future, but it is of interest to note that the controversial theoretical studies (2,3) have not underestimated nuclear risk, at least so far.

Given all these general considerations, and others not mentioned here owing to lack of space, what are the results of risk calculations? Some findings, from using the methodology briefly sketched above, are shown in Figure 2. This figure shows the man-days lost per unit energy for occupational risk, i.e., to these engaged in producing the energy.

What accounts for the relative rankings? Simply put, most non-conventional systems -- on the right of Figure 2 -- employ dilute energy like sunlight or wind. This energy is dilute in contrast to the concentration in a lump of coal or a nuclear fuel rod. It then requires a large number of collectors, windmills, solar panels, etc., per unit of useful energy. In turn, this array of collectors requires considerable amounts of steel, glass, copper and other materials. Producing the raw, intermediate and finished materials, fabricating and installing them generates industrial risk. This recitation may sound rather like 'the house that Jack built,' but it suggests the origin of Figure 2.

Figure 3 shows public risk, again expressed in the same units as Figure 2. Two of the conventional technologies, coal and oil, lead the list, due to emissions produced by burning fuel. Some non-conventional technologies have moderate values of public risk, primarily due to the energy back-up required to provide baseload reliability. Part of this back-up is coal and oil, with their attendant public risk.

Another component of public risk is due to the steel used in building systems. Coal is required for making most steel, and is the source of most of the oxides of sulfur produced industrially. There are emissions traccable to those technologies, such as non-conventional systems, which do not produce any air pollution directly.

Natural gas-fired electricity has the lowest public risk, followed by nuclear and ocean thermal. For nuclear power, both the risk of waste management and possible reactor catastrophes were included. Nuclear wastes risk is long-term, extending many centuries into the future. Long-term risk from any technology considered here (except nuclear) is generally not evaluated. However, a case can be made that the long-term risk from nuclear waste management will be small with adequate planning. Further study is needed to test this hypothesis.

In summary, then, nuclear risk appears to be fairly low in comparison to others for both the occupational and public side. It is bested by electricity from natural gas, but is lower than the other nine systems considered. These results are different from what we would expect on the basis of public perception. This question is one which deserves more attention than we can give it here. It seems clear that the messages of objectivity are not getting to the public as clearly as they might.

RISKS IN ENERGY CONSERVATION

As noted above, there is risk associated with using energy. Can there be risk associated with avoiding the use of energy, i.e.. conserving it?

The answer is yes. There are innumerable ways of conserving energy, from turning off lights to designing cities differently. Because of space limitations, we will focus on only one, saving energy by "tightening" houses. This type of conservation is chosen because it is one of the few for which enough data exist to allow a calculation of risk per energy saved.

When we think of saving heating energy in the home, we generally think of adding insulation to the ceiling or walls. There is risk associated with obtaining the raw materials for this insulation, fabricating and installing it. However, it proved difficult to obtain data with which one could calculate the risk, as well as information on the probable amounts of energy saved by greater insulation. As a result, consideration of this aspect of conservation will have to be deferred.

But accompanying many, if not most, installations of insulation is extra weatherstripping, caulking around windows and doors, etc. As Hadley (4) points out, these techniques decrease the air infiltration (or leakage) into and out of a house, but mere insulation does not. If the rate of infiltration is decreased by weatherstripping, etc., we may find a higher level of natural and manmade pollution in houses. One such naturally occurring pollutant is radon gas. Radon gas is released from the earth and from certain building materials like stone. Because the radon gas is radioactive, it can, in principle, cause lung cancer. Thus increasing conservation measures in homes, yielding increased levels of radon, can cause increased risk.

All of the above is quite general, and has been discussed in the literature previously. What we would like to do is to transform these generalities into the risk per unit energy saved for this type of conservation, so it can be compared to the analogous value for nuclear power or other energy forms.

Before beginning the calculation, we note that it proved difficult to get data on the number of man-hours required to install a given amount of weatherstripping. If this quantity were known, we would calculate the associated risk by using industrial accident statistics. As a result, in what follows we are considering only public risk of home heating conservation, not the occupational risk. We are then underestimating this risk until appropriate data are available.

A caution which should be noted is that there are many uncertainties in the data, ranging from variations in radon levels in different parts of the same house, to definitions of what is an "energy-efficient" house, to the health effects of radon. What follows can only be termed a first cut at the calculations, a first cut that is likely to be improved in the future.

The initial step is to relate the air infiltration rate to the radon dose, expressed in working levels or working level months. The air infiltration rate can be roughly defined as the "turn-over" of air in a house. It is usually measured in air changes per hour (ach). If a house has an air change rate of 1 ach, it does not mean that every last atom in the air has been changed in an hour, but that the number of oxygen, nitrogen, and other atoms which enter the house in an hour is about the same as the number which was in the house at the beginning of that time.

A working level is defined as the potential alpha energy from the short-lived daughters of radon which will produce 1.3×10^5 million electron volts of energy in one liter of air. Taken from studies on the health effects of radon on miners, the exact definition is not of great consequence here. It is useful, however, as a measure of the amount of energy produced by radon and its radioactive products in the air.

As a crude approximation, the working levels vary inversely as the air infiltration rate. That is, if we multiply the exposure in working levels times the air infiltration rate, the resulting graph, as a function of infiltration rate, should be a straight line if this hypothesis is correct. Some results are shown in Figure 4. We can see that the experimental data do not follow one straight line closely, but considering the many sources of error in the data one may assume a fit fairly close to the straight line.

On the other hand, the U.S. Environmental Protection Agency (5) states that *"decreasing the air exchange rate by a factor of two more than doubles the indoor concentration of radon decay products, because the equilibrium ratio of radon decay products to radon also increases with decreasing ventilation."* This assertion would produce a curve similar to those of Phillips (6) and Cliff (7) in Figure 4.

The next step in the calculation is to determine air infiltration rates for both average and "energy efficient" houses. Here the data become quite murky, because every house is different in this respect, and the definition of what is or is not an energy efficient house is not clear.

However, in spite of these problems some data can be supplied. Myers (8) assumes a value of 1 ach for normal houses, basing this on British data. He notes that Canadian values might be as low as 0.3, although he does not give data on this. Cliff (9) uses a value of 0.7 for typical houses. Swedjemark (10) uses 0.6 0.7 for Swedish houses. McNall (11) uses a value of 0.5 1.5 for houses built before 1973 74. Hurwitz (12) assumes a value of 1 for typical homes. Hollowell (13) uses a value of 2 for "older" homes in New York State.

It can be seen from the above that there are considerable differences in the values found for normal homes. Added to the complication is the fact that newer homes may be less leaky than old ones (10). However, it seems logical to use a value of 1 ach for typical European and North American homes. To allow for variation, a factor of perhaps 1.3 could be chosen as a spread. This spread is fairly large, but may be reduced as further data are gathered.

What are the air infiltration rates for "energy efficient" homes? The problem of consistency is perhaps even greater than for normal houses, since energy efficient homes differ so strongly in design and construction. However, again there are available data which can be used. Fleischer (14) finds that winter radon levels in energy efficient homes are about five times that in ordinary homes. If the product of the air infiltration rate and radon exposure is roughly constant and ordinary homes have an ach = 1, as surmised above, this implies ach = 0.2 for energy efficient houses.

Phillips (6) suggests that these houses have an ach = 0.1-0.2. Hurwitz (12) suggests 0.1, based on Hollowell (13). In another paper by Hollowell (15), he suggests an ach of less than 0.3. Hadley (4) assumes a value of 0.3-0.5, but without giving data. Berk (16) shows values ranging from 0.1 to 0.4 for four U.S. houses, with an average of 0.22. Besant (17) says that the value can be as low as 0.05 for some houses, noting that 0.2 is a practical lower limit in cold weather. Cohen (18) assumes a value of below 0.3.

Again, it is difficult to choose from this wide array, but the evidence seems to point to a value of around 0.2 ach for energy-efficient houses, to within a factor of about 1.5.

To summarize the conclusions so far, a typical house may have an ach = 1. with a range of 0.8-1.3; an energy-efficient house may have an ach = 0.2, with a range of 0.13-0.3.

The next step is to estimate the working levels corresponding to those values. Myers (8) assumes a value of 0.14 WLM/year for an ach = 1, and

0.53 WLM/year for an ach = 0.2. Other authors have different values relating picocuries (pCi)/liter of radon, air changes per hour, and WLM, but they tend to have higher values of radon concentration for a given ach than Myers. Examples are Hurwitz (12), Berk (19), Guimond (20), and O'Riordan (21). In the interests of being conservative, i.e., not exaggerating the risk, we will adopt Myers' value for an ach = 1, and assume that the product of ach x WLM/year is constant. Using the values of others quoted in this paragraph would produce higher calculated risk.

With these assumptions, the value for a typical house is 0.14 WLM/year, with a range of (0.14/1.3)-(0.14/0.8) = 0.11-0.18 WLM/year. The value for an energy efficient house is 0.14/0.2 = 0.7, with a range of (0.14/0.3)-(0.14/0.13) = 0.46-1.1. The range includes the value of Myers (8) of 0.53 at ach = 0.2.

The next step is to determine the number of fatal lung cancer cases per WLM/year. Myers (8) assumes 100-500 per 10^6 persons per WLM. It seems reasonable to take 300 as a best average. This assumption is reinforced by Cohen's (18) value of 200-450 for the same conditions. In turn, Cohen's values are taken from the 1977 UNSCEAR report.

We are now in a position to calculate the number of lung cancers produced in going from a typical house to an energy efficient one. The changes in WLM/year from the latter to the former is 0.7-0.14 = 0.56. This implies 300 x 0.56 = 170 extra cancers per 10^6 persons. Since the ranges for WLM/year are 0.11–0.18 and 0.46–1.1, the extreme values of changes are (0.46–0.18)–(1.1–0.11) = 0.28–1.0 WLM/year. Using the dose-effect range of Myers, this is (100–500) (0.28–1.0) = 28–500 annual extra cancers per 10^6 persons.

As mentioned above, the object of this section is to calculate the risk per unit energy saved. It proved difficult to find estimates of what the energy saved corresponding to a given change in air infiltration might be. One of the few is due to Myers (8), who estimates that going from ach = 1 to 0.2 corresponds to an annual energy change, per person, of 0.6 to 0.12 kilowatt-year. The difference is then 0.6 0.12 = 0.48 kWyr per person. This value applies to Canadian weather, and probably would apply to the northern United States. Myers notes that the risk per unit energy saved would be twice as great if the basic energy use in typical houses were half as much as he assumed.

We are now in a position to perform the final calculations. The average or "best-value" risk per megawatt-year is 170/(10^3 x 0.48) = 0.35 deaths. The range is (28–500)/(10^3 x 0.48) = 0.06–1.0 deaths. By way of comparison, the public risk from generating nuclear power is also shown in Figure 5. Values from the latter are taken from Ref. 1.

Figure 5 shows that the risk per unit energy for one form of conservation is much greater than that of nuclear power. This is in spite of the fact that the risk of the latter is probably overestimated in Ref. 1, where the values were obtained. In addition, the left-hand bar in Figure 5 includes all public risk of nuclear power, including waste management, transportation, etc. Nuclear public risk from reactor operation alone is estimated in Ref. 1 to be 0.03–0.23 deaths per 1000 megawatt-years.

There are a few additional comments which can be made about the results of Figure 5. First, to repeat what was stated before, many of the approximations made in the calculations are crude. However, the relative position of conservation risk versus nuclear probably would remain the same even if the approximations were more refined. Second, the risk per unit energy for conservation is lowest when one goes from a typical house to one slightly more sealed. As one seals the house more and more, the risk for each small increment of energy saved rises substantially. This is another restatement of the law of diminishing returns. Third, as partially noted above, there are sources of risk for conservation other than those which are mentioned here. For example, Berk (16) notes that formaldehyde used in insulation can have a strong health effect The occupational risk in installing weatherstripping and caulking may be great. These and other matters are left to another day. Fourth, the dose-effect relationship used in assessing the risk is the so-called linear hypothesis. Many scientists believe that it exaggerates the risk at low doses, and that a lower value would be more reasonable. If this lower value were chosen, the risk for nuclear power in Figure 5 would also decrease, and the relative positions of the two bars probably would not change substantially. Fifth, it is possible that air exchangers may be used in some energy-efficient houses. This can reduce the radon level and thus the risk. Sixth, in no way is it implied that conservation should not be used. All forms of energy production and conservation - have associated risks, and this is just one factor society has to take into account.

SUMMARY

The idea that society can have a "free lunch" in the form of a risk-free energy system is rapidly fading away. All energy systems have some risk to human health, and for some it can be substantial. Nuclear power seems to have both a low occupational and public risk compared to other forms. In addition to this, we have presented some original research, calculating some of the risk associated with sealing up houses to keep heat in. When the effect of the accumulated radon is included, the risk per unit energy saved for this form of conservation can be great. Indeed, it appears to be much greater than the public risk of nuclear power.

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FIGURE CAPTIONS

Figure 1. Sources of risk in energy systems. All systems require raw materials, although some non-conventional systems, like solar and wind, do not require fuel in the ordinary sense. The components must be fabricated, and then the plant reactor, windmill, coal-fired generator must be constructed. The raw materials, intermediate and final materials must be transported to their destinations. There are also risks from operation, any waste disposal, and public health risks from pollution and accidents. These sources constitute most of the risks associated with energy systems.

Figure 2. Occupational man-days lost per megawatt-year net output. The top of the bars and the dotted lines indicate the upper and lower part of the range, respectively. Bars to the right of the vertical dotted lines indicate technologies less applicable to Canada. Note the logarithmic scale. Deaths are assumed to contribute 6000 man-days lost per fatality, and are combined with accidents and illness on that basis. Solid and dashed jagged lines on bars indicate maximum and minimum values, respectively, when no back-up (or low-risk back-up) energy is assumed.

Figure 3. Public man-days lost per megawatt-year net output (see explanation in caption to Figure 2). Coal ranks highest, because of air pollution effects. Natural gas and nuclear rank lowest, in spite of the publicity given their potential public risk. However, many of the non-conventional energy systems to the right of the graph have non-negligible public risk. The explanation for this is given in the text.

Figure 4. Constancy of product of air infiltration rate times radon dose rate. If the two quantities varied inversely with each other, their product as a function of air infiltration rate would be constant. Experimental data show this is not the case. However, the experimental data are scattered enough to allow the assumption of constancy as a crude approximation.

Figure 5. Relative public risk per unit energy of nuclear power and house sealing (conservation). The first bar refers to producing energy and the second to saving it. The bar for nuclear power has a maximum and a minimum (dotted). That for house sealing has a best value (solid line) and an upper and lower range (dotted lines).

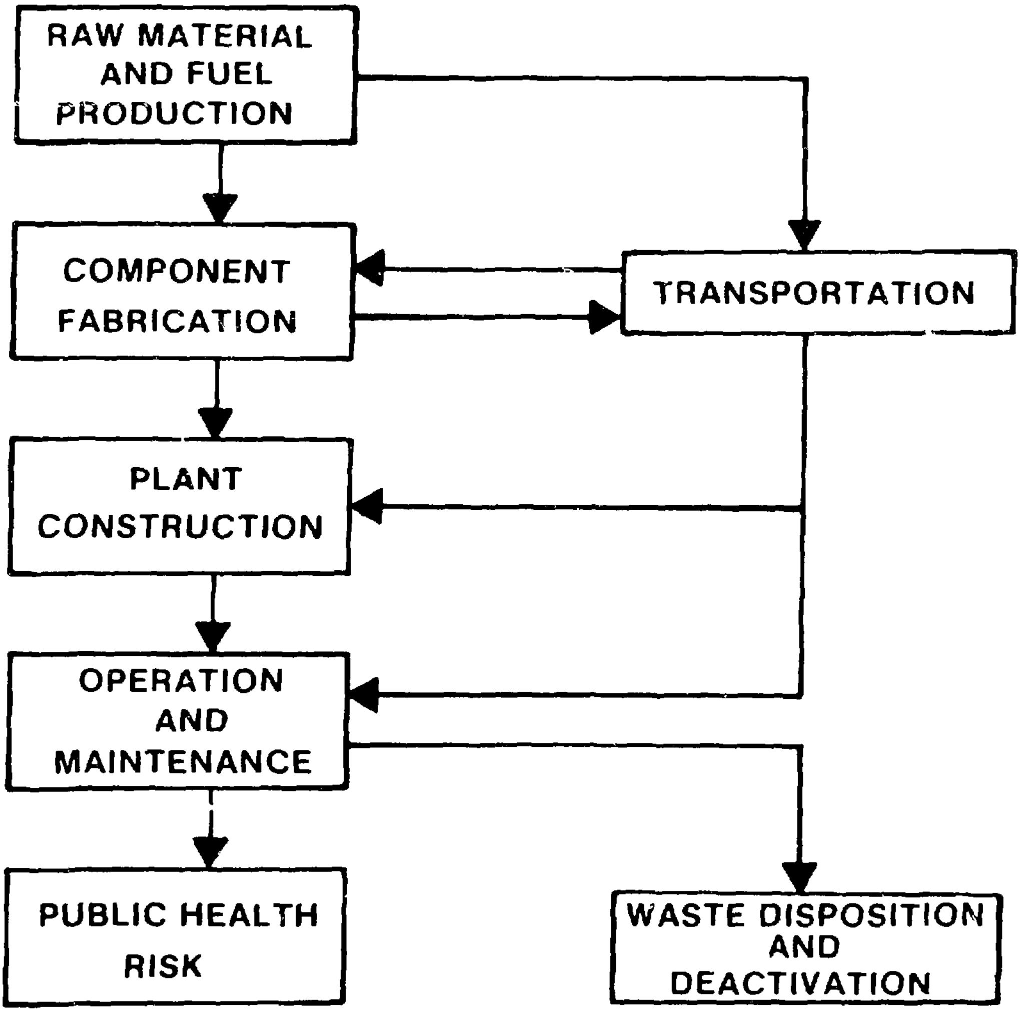
RAW MATERIAL AND FUEL PRODUCTION
COMPONENT FABRICATION
TRANSPORTATION
PLANT CONSTRUCTION
OPERATION AND MAINTENANCE
PUBLIC HEALTH RISK
WASTE DISPOSITION AND DEACTIVATION

Figure 1

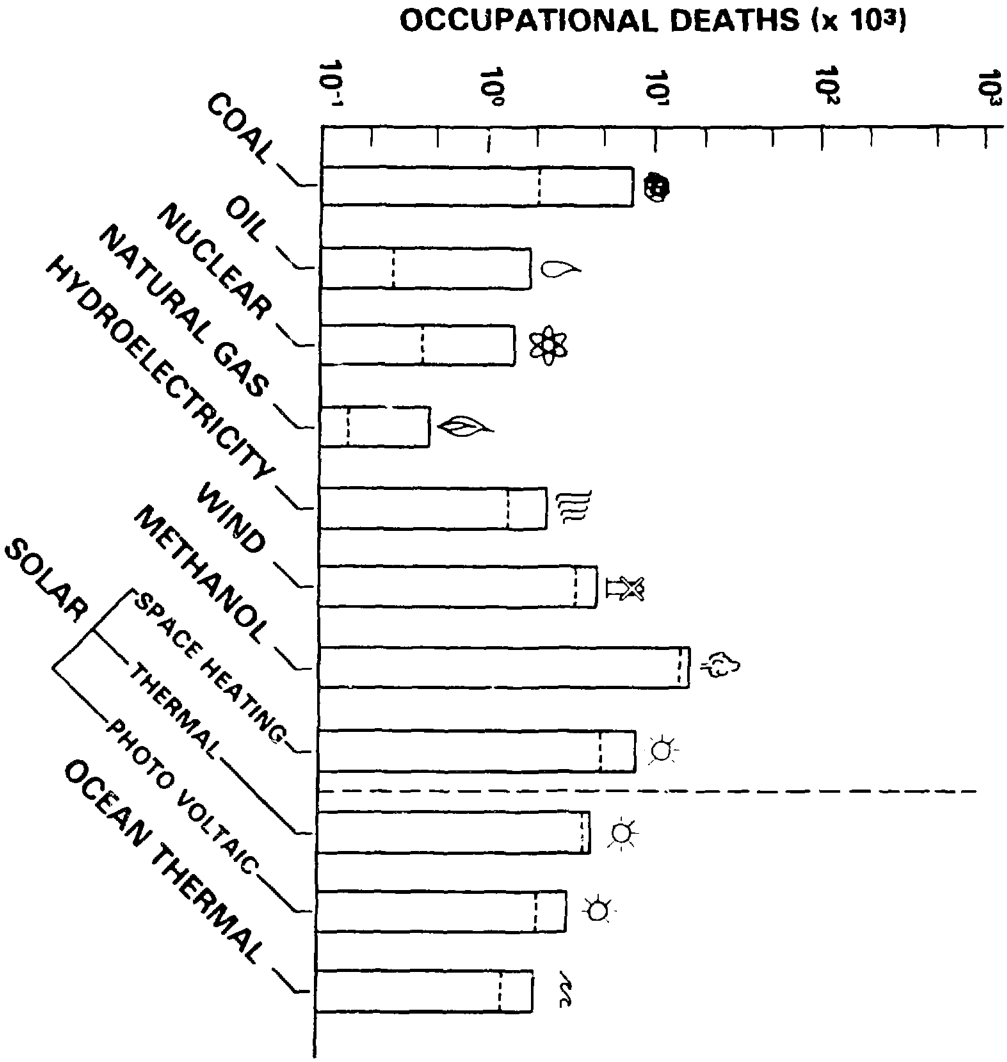

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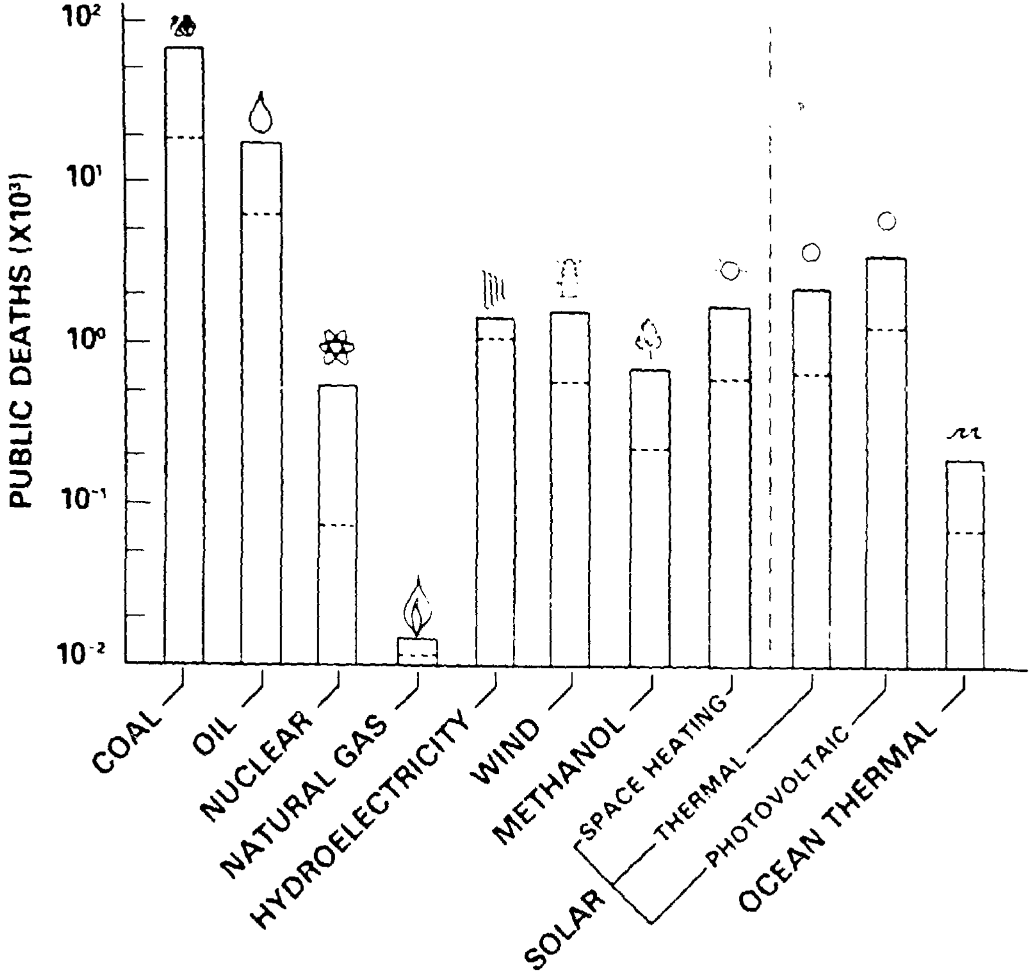
Figure 2

PUBLIC DEATHS (X10³)
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OCEAN THERMAL

Figure 3

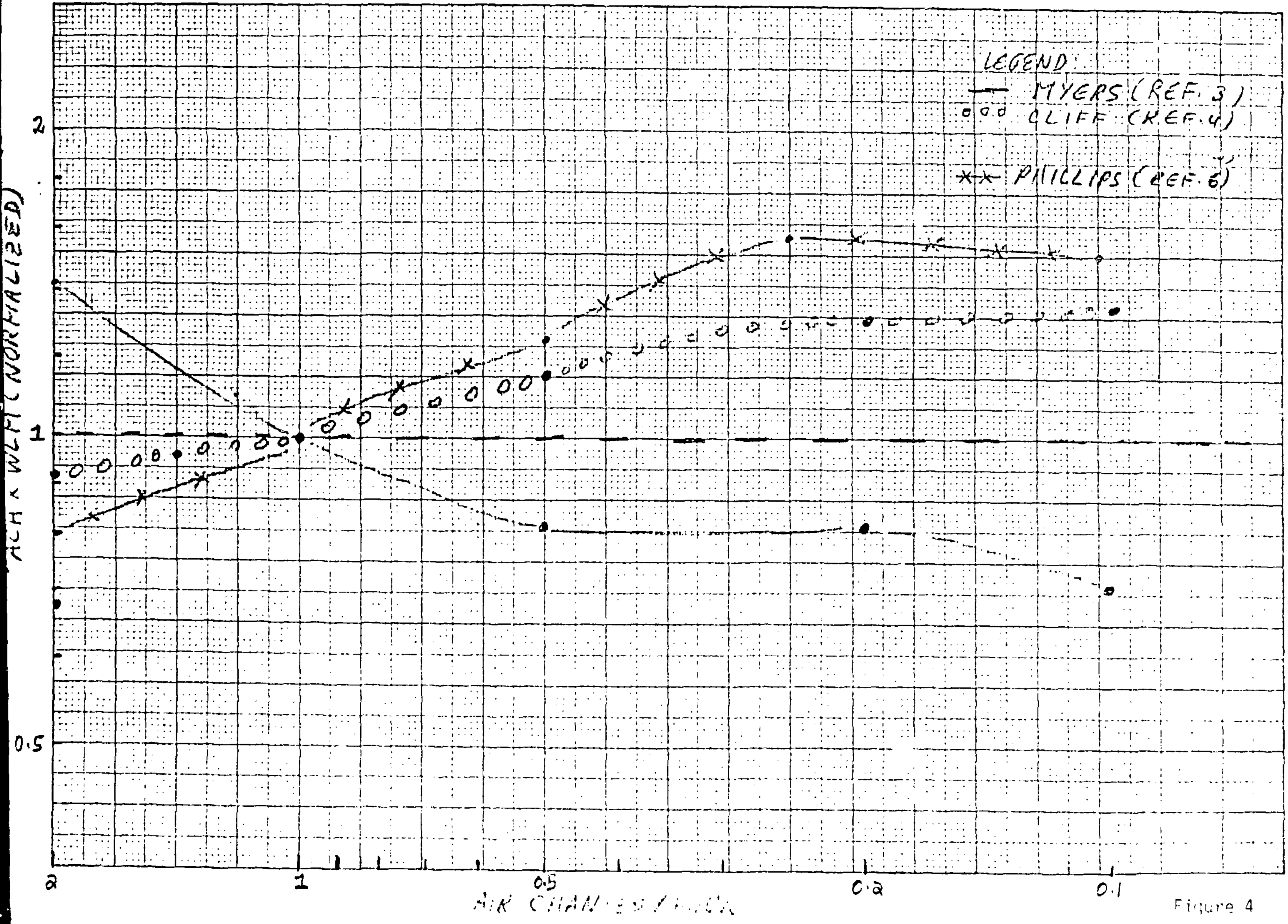
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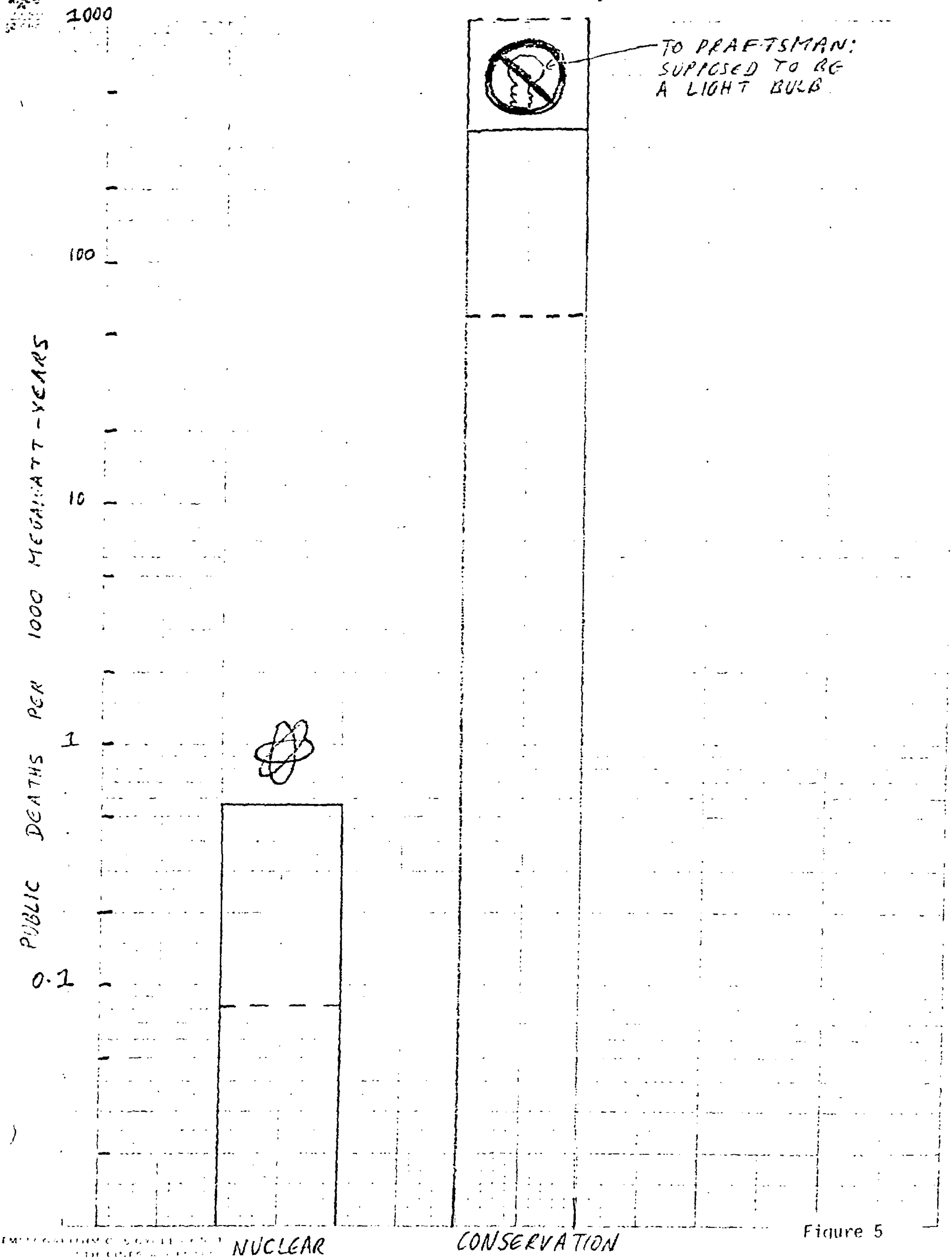
Figure 4

FIGURE



TO DRAFTSMAN: SUPPOSED TO BE A LIGHT BULB

Figure 5