Nuclear Safety Aspects Of A Westinghouse Pressurized Water Reactor

C. Eichelдinger; P. T. Chu; G.A. Rasmussen; J.R. Galando *)

I. INTRODUCTION

The three major elements toward developing an awareness of the benefits of nuclear power is to understand why nuclear power is needed, the safety consideration of nuclear power and the operating plant safety performance.

The need for nuclear power is underscored by the fact that energy is an essential ingredient of economic growth. Energy growth and GNP growth have historically exhibited a remarkable lock-step relationship. It would not be correct to say that the availability of energy causes economic growth, but economic growth certainly cannot take place unless adequate supplies of energy are available for the goods and services that make up the gross national product.

Worldwide oil and gas reserves are being rapidly depleted and based on present rates of consumption, most of these resources will be gone in the next century. It is vital that those resources be preserved since they cannot be substituted for producing such things as lubricants, aviation fuel, fertilizers and plastics. To use those energy sources which can provide abundant, safe, clean energy economically is of paramount importance in the planning of national development. Coal and uranium are such energy resources best suited for electric power generation in large installations.

The experience with nuclear plants indicates that nuclear power can produce electricity safety and with substantial savings to the users. The savings that are realized by having nuclear power to generate electricity can be utilized for other worthwhile purposes.

Today, there are 55 nuclear power plants in the United States which are available for operation. These plants now represent approximately 9 percent of the total electrical generating capacity of the United States. In the Chicago area, nuclear power is presently generating 30 percent of the electricity consumed. In the Miami area, it accounts for 20 percent and in Boston, it accounts for over 30 percent. In 1974, the nuclear power generated in the Philadelphia area accounted for 9,4 percent and eith the scheduled completion of new facilities in 1975, that percentage rise to 17 percent. In the Pittsburgh area, completion of nuclear facilities will account for more than 20 percent of electricity generated by nuclear power late this year.

II. PWR SYSTEM DESCRIPTION

The process that takes place within the nuclear reactor is known as fission which is a very stable and controllable process, more predictable than the com-

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*) Westinghouse

bustion process. It provides a clean source of heat, but it is not as well understood as the combustion process to the general public. If the combustion process is allowed to take place in an uncontrolled manner, it would cause great damage. The same would apply to the fission process. The nuclear reactor technology as practiced currently is so developed that the design provisions not only harness the fission rection, but also allow a wide safety margin under the most severe hypothetical accident.

The fission process, illustrated in Figure 1, is caused when neutrons of a fissionable material – Uranium 235 – are released and strike other uranium atoms, releasing heat. This process also generates what are known as fission products. The fission products release the radioactivity that is associated with the fission process and these fission products form the wastes that must be separated out and carefully disposed of.

Fission takes place within pellets of uranium fuel that, typically in a Westinghouse PWR, are three-fourth of an inch long and three-eights of an inch in diameter. These pellets are stacked end to end in a long special zirconium alloy tube which is completely sealed. The pellets contain typically three percent uranium 235 and 97 percent uranium 238, the latter is a more abundant isotope which cannot fission in sufficient quantity to serve as a light water fuel. These 12-foot-long tubes are clustered in fuel assemblies – 235 tubes to an assembly, and there are about 120 assembles in a 600 MWe reactor.

The fuel assemblies are surrounded by water which acts as a coolant or heat transfer medium and also as a moderator – that is, water slows up neutrons so that the fission process can take place. This water is under high pressure, so that bulk boiling does not occur. It flows through the tube side of the steam generators where the heat is transferred from the pressurized water or the primary coolant through tube walls to water in the secondary system to generate steam that drives the turbine generator. Thus the fuel and its coolant is isolated from the system that actually generates electricity. This system is called the pressurized water reactor and is shown in Figure 2.

III. SAFETY CONSIDERATIONS OF NUCLEAR POWER PLANTS

Safety is not an absolute quantity. No single endeavor is absolutely safe, under any conditions, and just about every endeavor can be hazardous under certain conditions. Ideally, a balanced safety assessment should proceed along the following lines : (1) establish an acceptable risk level to the individual and the population at large; (2) calculate likehood and consequences of various accidents and series of accidents; (3) weigh consequences and probability of occurrence; and (4) calculate the overall risk to public health and safety. The concept of safety is merely an acceptance or rejection of a given risk level.

A. ANS Classification of Plant Conditions

The probabilistic approach to nuclear plant safety is desirable in that it offers a mathematical means of dealing with a highly subjective problem. It stops short, however, of providing a completely practical guide for design. Therefore, several years ago, the American Nuclear Society developed four categories of plant conditions for pressurized water reactor in accordance with anticipated frequency of occurence and potential radiological consequences to the public. The four categories are :

Condition I – Normal Operation & Operational Transients : Condition I occurences are those which are expected frequently or regularly in the course of power operation, refueling, maintenance, or maneuvering of the plant. These conditions shall be accommodated : (a) with margin between any plant parameter and the value of that parameter which would require either automatic or manual protective action; and (b) with margin between the actual public radioactivity exposure and the allowable limits, i.e. by keeping the radioactivity releases as low as reasonably achievable.

Condition II – Transients of Moderate Frequency : Condition II occurrences are transients which may occur with moderate frequency during the life of a particular plant. These transients shall be accommodated : (a) with, at most, a shutdown of the reactor plant capable of returning to operation after corrective action; and (b) with public radioactivity exposure within 10 CFR 20 *) limits.

Condition III – Infrequent Transients : Condition III occurrences are transients which may occur very infrequently during the life of a particular plant These events shall be accomodated : (a) with the failure of only a small fraction of the fuel elements in the reactor, although sufficient fuel element damage might occur to preclude resumption of operation for a considerable outage time : and (b) with public radioactivity exposure limited to 1/10 of the 10 CFR 100 **) limits.

Condition IV – Limiting Accidents : Condition IV occurrences are accidents that are not expected to occur during the life of the plant, but are postulated because their consequences would include the potential for the release of significant amounts of radioactive material while their likehood cannot be judged to be practically zero. Condition IV accidents are the most severe events that are protected against in plant designs and represent the limiting design bases. Condition IV accidents shall not cause a release of radioacitve material that results in doses to public in excess of 10CFR100 limits.

B. Some Recent Studies on Risk Analysis

Attention to safety is the reason for the outstanding safety record and the extremely small risks which nuclear power present to the public. Two recent independent studies have been completed to quantify these public risks. One study was performed in Sweden, and another was done in the United States under the direction of Professor Norman C. Rasmussen of the Massachusetts Institute of Technology. The numerical results of these studies differ somewhat, but they both reach the same conclusion–today's nuclear power stations, even a large number of them, present a negligible risk to our society. The Rasmussen study provides a comparison of the fatality risk as shown in Figure 3, 4 and 5. The risk to the public in the United States by the operation of 100 reactors causing 100 or more early fatalities is one chance in 100,000 years.

For an individual living near a nuclear plant the chance of being a fatality in a reactor accident is one in 75 million per year. By comparison, a person is 10.000 times likely to drown, and even 150 times more likely to be killed by

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lightning. The study further noted that the probability of an accident occuring which resulted in 1,000 or more early fatalities was about one in a million years, or about the same probability of a meteor striking a U.S. population center and causing 1,000 fatalities. Thus, these independent risk studies clearly demonstrate that the risks associated with nuclear power are very small.

IV.WESTINGHOUSE SAFETY DESIGN PHILOSOPHY

The reason why nuclear risk is so low is a result of the dedicated and detailed engineering effort that is directed toward nuclear safety. Some of the key elements that contribute significantly toward the safety of nuclear plants are :

○ "Defense in Depth" Philosophy of Design

○ Multiple Barrier Against Release of Radioactivity to the Environment

○ Multiple Review by Many Parties

○ Openness

○ High Quality Material and Workmanship

A. Defense in Depth

The design philosophy which we employ has been described as "defense in depth". Nuclear power plants are designed so as not only to be safe during normal operation but also to safely account for the possibility, however remote, of large and, for all practical purpose, incredible accidents as well.

A simplified overview of the three levels of defense-in-depth is summarized in Table 1. The first level addresses prevention of accidents through the design of the plant, including quality assurance, redundancy, testing, and inspection so that plants will operate reliably.

TABLE I DEFENSE IN DEPTH

○ 1st Level : Prevent Accidents Through Plant Design

- High Quality Standards
- Redundancy
- Testing
- Inspection

○ 2nd Level : Anticipate Failures or Operating Errors

- Provide Protection Devices and Systems
- Conservative Design Practices
- Built–In Safety Margins
- Redundancy in Detection and Actuation Devices

○ 3rd Level : Postulate Occurrence of Extremely Unlikely Circumstances

- Hypothetical Accidents–Design Basis
- Incorporate Safety Features and Equipment to Safety Control Situation

Despite the care taken at the first level, it is prudently anticipated that some failures or operating errors will occur during the life of a plant which can have the potential for safety problems. Accordingly, a second level or protection devices and systems are provided. These devices and Systems assure that these incidents will be prevented or arrested in a safe manner by alarm and finally shutdown. Here again, conservative design practices, built-in safety margins, and redundancy in both the detection and actuation equipment are incorporated into the plant.

The third level of safety, which supplements the first two, is designed to add even further margin by postulating for design purpose the occurrence of extremely unlikely circumstances. We taken a severe hypothetical accident far beyond that which anyone expects to occur and which only could occur in the event of failures in both the first and second levels of defense. This design basis accident then is studied in detail, with an arbitrary compounding of combinations and sequences of events to make more demanding the safeguards performance objectives. From an analysis of these postulated events, we design and incorporate into the plant the third level of features and equipment to safely control the situation and protect the public health and safety.

Table II, Reactor Coolant Pipe – Defense in Depth, outlines a typical system example of how the concept of levels is implemented.

TABLE II REACTOR COOLANT PIPE – DEFENSE IN DEPTH

○ 1st Level :

- Non-Corrosion Material
- Meets ASME Codes
- Hydrostatic Testing Before Operation
- Radiographic Inspection Before Operation
- In–Service Inspection Program

○ 2nd Level :

- Leakage Detection Systems
- System Monitoring Devices – Pressure, Temperature and Alarm Indicators

○ 3rd Level :

- Postulate Largest Pipe Break
- Provide Safeguards
  - Emergency Core Cooling System
  - Containment

Since the beginning of the power reactor industry, the loss of reactor coolant has been established as one of the design basis accidents. The development of reliable effective core cooling systems, detailed analytical models, and associated experimental verification programs has been a fundamental part of the Westinghouse design and development effort.

The rupture of reactor coolant system pipe (Loss of Coolant Accident (LOCA), if it can happen at all, is estimated to have a frequency no highher than 10^{-4} per reactor plant year. With the injection of coolant by the Emergency Core Cooling System (ECCS), the fuel rods remain cooled and intact, and the fission products are retained by the fuel clad.

The fission products released to the containment from the coolant discharge is very small and is retained in the containment structure. The public impact from such an event is negligible compared to back-ground activity.

The ECCS design incorporates redundancy and its chance of failure is estimated to be less than 10^{-3} per demand. The combined probability of LOCA and ECCS failure is then less than 10^{-7} per reactor year. In this theoretical event, the fuel would melt causing release of volatile fission products (noble gases and iodines) to the containment. The containment safeguards would automatically actuate to control containment pressure and scavenge iodine from the vapor volume. If it is assumed the fuel meltdown results in containment breach, essentially only noble gases would be available for release to the environment.

The containment safeguards systems are also redundantly designed and their failure probability is also estimated to be less than 10^{-3} per demand. The combined probability of LOCA, ECCS failure, and containment safeguards systems failure is thus estimated at less than 10^{-10} per reactor year assuming independent events. In this theoretical event the release of volatile fission product upon containment breach would include an estimated 25 percent of the iodine fission products as well as the noble gases.

The Westinghouse ECCS evaluation model used to analyze plant performance during the hypothetical loss of coolant accident (LOCA) and for ECCS performance evaluations was accepted by the NRC in April, 1975. The NRC reported that the Westinghouse ECCS model was in complete conformance with 10 CFR 50, Appendix K (Final Acceptance Criteria for ECCS) requirements. The Westinghouse model is the first vendor ECCS model that has been accepted by the U.S. NRC for reference in licensing applications as an approved ECCS evaluation model.

To summarize, Westinghouse has :

○ developed the required computer codes and models to analyze the reactor and NSSS performance during a loss-of-coolant accident;

○ conducted the experimental verification programs which were incorporated in its ECCS evaluation model,

○ a system designed to provide emergency core cooling, and

○ an NRC approved and acceptable ECCS model that can be referenced in licencing applications and satisfies the NRC Final Acceptance Criteria.

One of the misunderstandings about the safety of nuclear power plants is the idea that these third level systems and defenses are the primary or sole reason why we claim the plants are safe and that we really expect the things to happen which the third level is designed to guard against. The accidents which are postulated at the third level, including the design basis loss of coolant accident, are remote and can only result if the first level of defense and the second level of defense fail. Thus, the accident postulated for the third level of defense is never expected to occur.

B. Multiple Barrier

Another factor which contributes to the safety of nuclear power plants are four distinct barriers which prevent the release of radioactive material to the environment as schematically shown in Figure 6.

These multiple barriers are inherent design features of pressurized water reactor power plants in the United States. Each barrier forms a successive back-up system to guard against any release of radioactive fission products and each is designed, constructed, and maintained using high quality materials and sound, proven engineering principles.

The first barrier consists of the nuclear fuel itself. The radioactive fission products produced in the fuel must diffuse through it to escape.
The fuel pellets are of high density and are an effective diffusion barrier to lock in the radioactive products.

The fuel pellets are sealed in metal tubes called fuel cladding. The cladding contains and confines almost all of the radioactive fission products which manage to escape from the fuel. This provides the second barrier against radioactive release.

The reactor coolant system constitutes the third barrier to prevent the release of fission products which might have escaped from the fuel cladding. Finally, the leak-tight reactor containment serves as the fourth barrier, to prevent the release of radioactive fission products to the outside environment. The containment has systems to reduce the pressure and remove heat in case of a severe reactor accident and is a very massive structure which would be extremely difficult to penetrate,. Beyond this barrier is the site boundary distance as a further measure of protection.

A summary of the four barriers between fission products and the environment is given in Table III.

TABLE III MULTIPLE BARRIERS

○ Fission Products Trapped in Fuel Pellets

○ Fuel PelletsEncased in Sealed Metal Tubes

○ Fuel Tubes Enclosed Inside Reactor Coolant System

○ Reactor Coolant System Inside Containment

C. Multiple Reviews

Another factor contributing to the safety and environmental acceptability of nuclear power plants is the multiple and independent reviews by various government agencies as well as internal design reviews conducted by the nuclear system vendors. like Westinghouse, the utilities and the architect-engineers.
The major safety review of nuclear plants in the U.S. is conducted by the Nuclear Regulatory Commission (NRC) which controls the issuance of construction permits and operating licences. Before a construction permit is issued, the utility must make application and furnish the regulatory agency with a safety analysis report and an environmental report. The review an process as shown in Figure 7 is lengthy and could last nearly a year. Figures 8 and 9 illustrate the environmental considerations given to gaseous and liquid effluents in the Environmental Reports. Further, the Advisory Committee on Reactor Safeguards make an additional review and then the law requires that a public hearing be held. This hearing is conducted by the Atomic Safety and Licensing Board. Only after all these parties have been satisfied, and state and lo-

cal permits obtained, can a construction permit be issued. In order to obtain an operating license, essentially the same review process is conducted.

Table IV summarizes the major parties involved in this review process as practiced in the U.S.

TABLE IV. MULTIPLE REVIEWS BY MANY PARTIES

- Nuclear Regulatory Commission
- Advisory Committee on Reactor Safeguards
- Atomic Safety and Licensing Boards
- Environmental Protection Agency
- Department of Interior – U.S. Geological Survey
- Federal Power Commission
- State and Local Agencies
- Internal Design Reviews
    - Vendors
    - Utilities
    - Architect – Engineers

D. Openness

Table V illustrates several factors which reflect the openness in which the industry operates and from which benefits are derived which contribute toward safety. Accessibility of important information concerning plant safety is made available to interested parties in the licensing review process and at public hearings. Additionally, in the nuclear industry almost everything is reported. Abnormal occurrences or events, equipment failures, and construction problems associated with important plant safety features or systems are continually being brought to the attention to the NRC either through required reporting procedures or by the NRC inspection staff. If the potential exists that other facilities may be affected and that the occurence has a significant effect on safety, the NRC will notify all licencees requesting that appropriate action be taken to assure that a similar situation does not exist or will not occur at their facility. The result of this open exchange of information on plant experience is of great benefit to the industry leading to further improvements in nuclear plant reliability and safety;

TABLE V OPENNESS

- Public Access to Information and Participation in Licensing Review Process
- Public Intervention or Limited Appearance Hearings
- Utilities Report all Abnormal Occurences
- NRC Publishes Occurrence Reports for Industry Information/Action
- NRC Places Communications, Meeting Minutes, Reports . . . etc. in Public Document Room

V. OPERATING PLANT EXPERIENCE

The discussion thus far has dealt extensively with safety considerations and design philosophy of pressurized water reactors. The true test, however, is in the actual operation of nuclear plants. The operating plant safety performance can best be described by looking at three specific areas; the reliability of nuclear units, the few abnormal occurrences reportable to U.S. Congress and the environmental considerations of normal plant operation.

A. Nuclear Plant Reliability

Recently, the reliability of nuclear units has received public criticism. However, relative to fossil units of comparable size, the performance of nuclear units has been competitive with those units. Shown in Figure 10 is a comparison of cumulative capacity factors *) for large fossil and nuclear units in the United States as reported by the Edison Electric Institute and by the NRC.

Also shown are capacity factors for Westinghouse nuclear units of comparable size. As indicated , nuclear unit performance, and especially that of Westinghouse units, have equalled for surpassed fossil fired stations, including the case where only coal-fired stations are considered.

Realted to the reliability issue is the matter of "abnormal occurrences" at nuclear plants as reported by the nuclear Regulatory Commission. For instance, in 1974 there were 1,424 abnormal occurrences reported at operating plants, but only four were described as being directly significant and none of these had any effect upon the public. For the most part these abnormal occurrences are variations from plant operating technical specifications and should not be interpreted to mean that accidents are regularly occurring at nuclear plants.

The U.S. Congress now defines an abnormal occurrence as an unscheduled incident or event which the NRC determines is significant from the standpoint of public health or safety. The NRC has further interpreted this to mean those events involving an actual loss or significant reduction in the degree of protection against radioactive materials. The bulk of the abnormal occurrences under the old definition are now reported as "reportable occurrences." During the first half of 1975, no incidents of events occured at the 53 licensed operating nuclear power plants which had an actual impact on or consequence to the health and safety of the public. However, although an adequate margin of safety was always present, some events did occur which involved a temporary reduction in the level of protection. There have been three single one reccurring and three genetric significant events, which were considered to be abnormal occurrences, and are reviewed in Table VI. The occurrence of these events has shown that the reliance on the defense-in depth concept is sound for the protection of public health and safety.

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*) $$\text{Capacity Factors} = \frac{\text{Net Electrical Power Generated (MWH)}}{\text{Maximum Dependable x Total Hours Since of Commercial Operation}}$$

TABLE VI. OCCURRENCES AT NUCLEAR POWER PLANTS
First Half of 1975.

Event Type	Event	Facility
Single	Steam Generator Tube Failure	Point Beach 1
Single	Fire in Electrical Cable Trays	Browns Ferry 1 & 2
Single	Loss of Main Coolant Pump Seals	H.B. Robinson 2
Recurring	Improper Control Rod Withdrawals-Maintenance	Dresden 2 Quad Cities 1
Generic	Cracks in Pipes at Boiling Water Reactors	Dresden 2, Quad Cities 1 & 2. Millstone, Monticello, and Peach Bottom 3
Generic	Fuel Channel 1 Box Wear at Boiling Water Reactors	Duane Arnold, Cooper, Peach Bottom 2 & 3 Browns Ferry 1 & 2 Brunswick 2, Hatch 1, Fitzpatrick, and Vermont Yankee
Generic	Steam Generator Feedwater Flow Instability at Pressurized Water Reactor	Surry 1, Turkey Point, Indian Point 2, and Calvert Cliffs 1

B. Environmental Considerations

The actual risks to members of the public from the operation of nuclear power plants is so very low as to be considered negligible. The radioactive emissions from a nuclear plant are again very low in terms of biological risks. In fact, in terms of radiation impact, coal and oil fired plants may lead to radiation exposure to the general population at levels similar to or greater than nuclear power plants.

A brief look at the estimated population doses from the operation of nuclear power plants as compared to exposure limits established by international guidelines will allow us to appreciate the conservative design of nuclear power plants.

Routine releases from nuclear power plants are now estimated to deliver about 0.003 millirem per year to the average U.S. population. This is less than 20 millionths of the maximum dose of 170 millirem per year to a member of the critical segment of the general public which has been specified by two longstanding international groups of experts : the International Commission on Radiological Protection and the National Council on Radiation Protection and Measurement. The whole body dose limit of 5 – 10 millirem per year from reactor effluents to the most exposed individual is only 1 – 2 percent of internationally approved guidelines for radiation protection. If nuclear power plants continue to be built with no technological improvements, the anticipated radiation level to which the average American would be exposed in the year 2000, assuming that about a thousand nuclear power plants, are in operation, is only one-fifth of a millirem – less than 1/600 of the "natural" exposure levels.

To place nuclear power plant radiation in better perspective, consider the intrinsic natural background radiation in the U.S. due to cosmic rays, natural radioactive elements presently existing in the air and water environment as well as in the elements of the human body. The average natural background radiation level in the U.S. is about 130 millirem per year. Man-Made radiation such as from medical and dental X–rays expose us by an additional increment. The incremental average nationwide exposure has been reduced from about 54 millirem in 1964 to 36 millirem in 1970, but is still far, far greater than the average exposure of 0.003 millirem from nuclear power plants. Table IV shown below is a comparison between the exposure received from nuclear power plant and all other sources not related to nuclear power.

TABLE VII SOME TYPICAL RADIATION DOSES

Annual Average Radiation Dose	**Annual Dosage (mrem/yr)**
Building Construction Materials	57
Water, food, air (U.S. average)	30
Air travel (600 miles/yr)	4
Black & white television (3 hrs/day)	<0.1
Color television (3 hrs/day)	0.1 – 0.6
Chest X–ray (1 per year)	150
Dental X–ray (1 per year)	20
U.S. Average Dose	150 – 200 mrem/yr
Typical nuclear power plant at site boundary	1 – 2 mrem/yr

This further illustrates the point that the additional dose to an individual from the operation of a nuclear power facility is only a small fraction of his total yearly dose from all sources.

Listed in Table VIII below are the radioactivity concentrations of various liquids which individuals consume or are exposed to as compared to the concentration from nuclear plants discharges.

TABLE VIII LIQUID RADIOACTIVITY LEVELS

	Pico Curies*/Liter
Maximum Allowable Nuclear Plant Discharge	20
River Water	10–100
4% Beer	130
Ocean Water	350
Milk	1400
Salad Oil	4900

*1 pico-curie = 10^{-12} curies

In summary, emissions from nuclear plants are negligible for all practical purposes. Of much greater concern should be the 20.000 deaths per year in the U.S. estimated to be caused by air polution from all sources.

VI.CONCLUSION

In summary, the following points should be considered :

1. Nuclear power plants offer an abundant supply of economic energy.
2. The risks associated with nuclear power plants are much less than the risks accepted in our everyday lives.
3. Plants designed with the emphasis on safety including the defense-in-depth concept provides assurance of continued low risk.
4. The outstanding safety and reliability record of all light water reactors, but especially pressurized water reactors, provides proof of the nuclear safety.

The Westinghouse pressurized water reactor is a safe, economical, reliable and environmentally preferable method of meeting the world energy needs. The same conservative design philosophy is strictly followed by Westinghouse regardless of where the plant is located throughout the world.

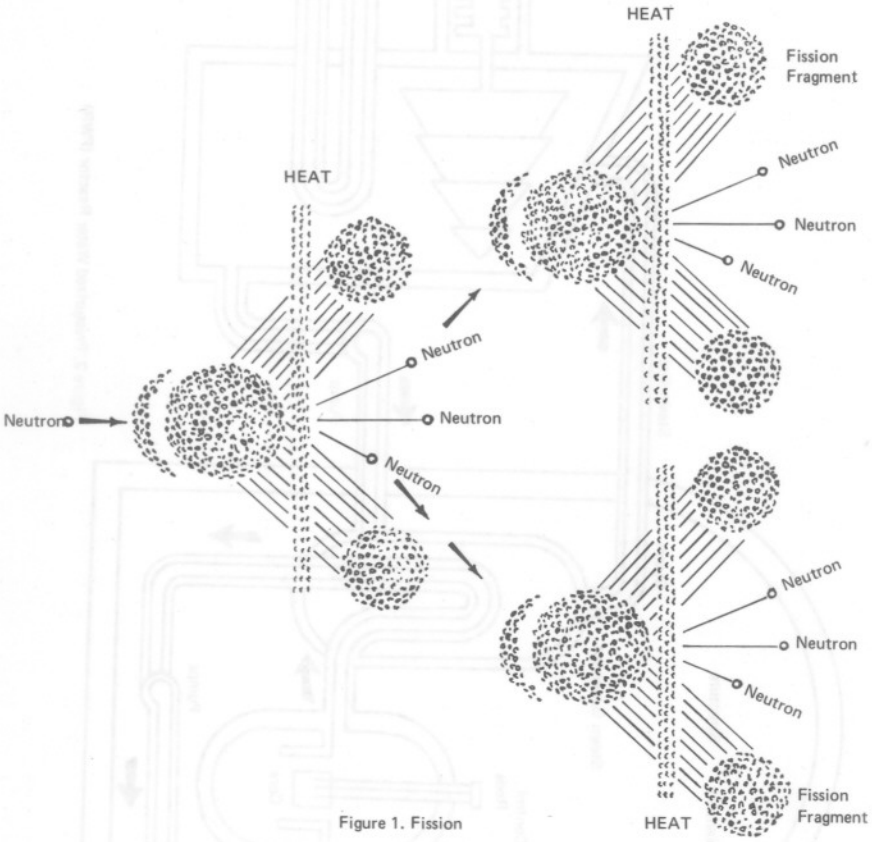

Figure 1. Fission

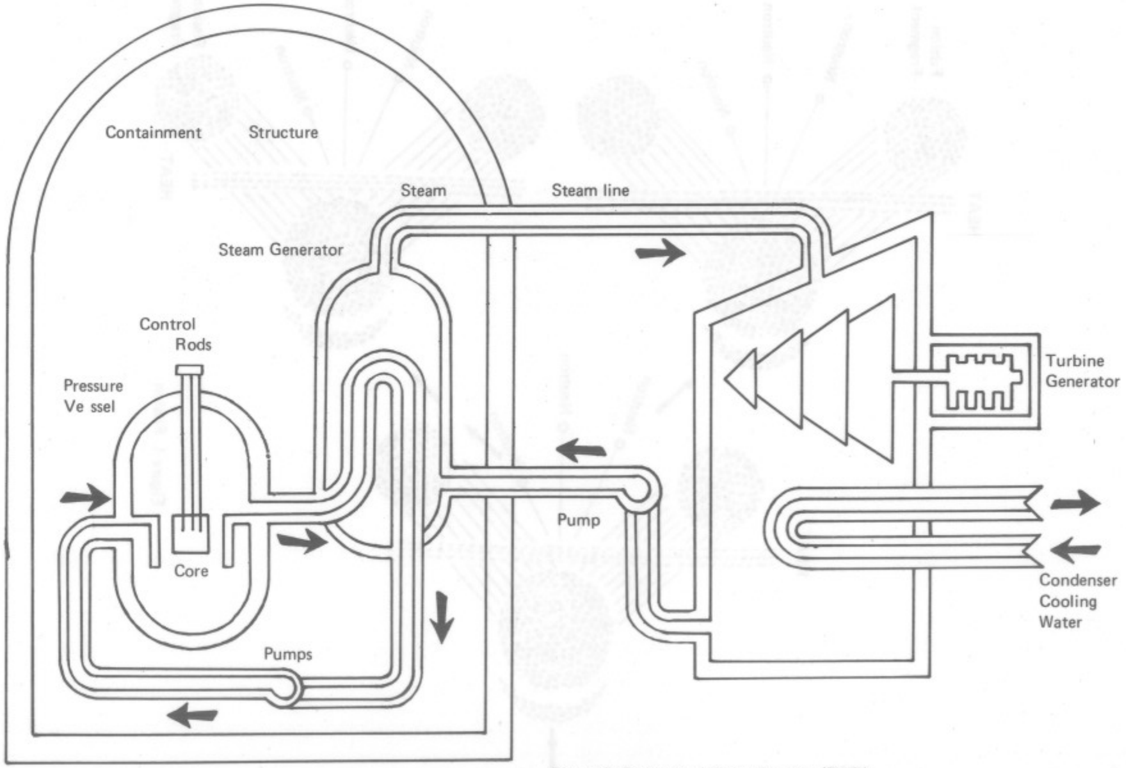

Figure 2. Pressurized Water Reactor (PWR)

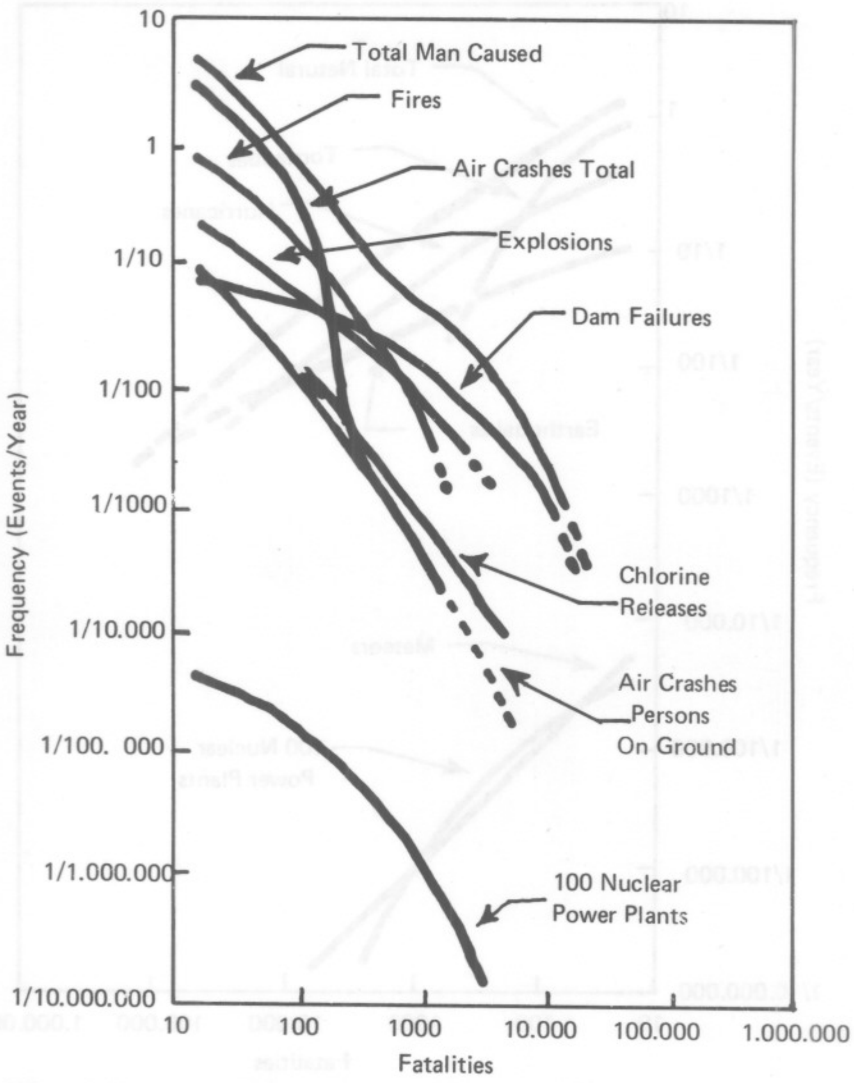

Figure 3. Frequency of Fatalities Due to Man-Caused Events

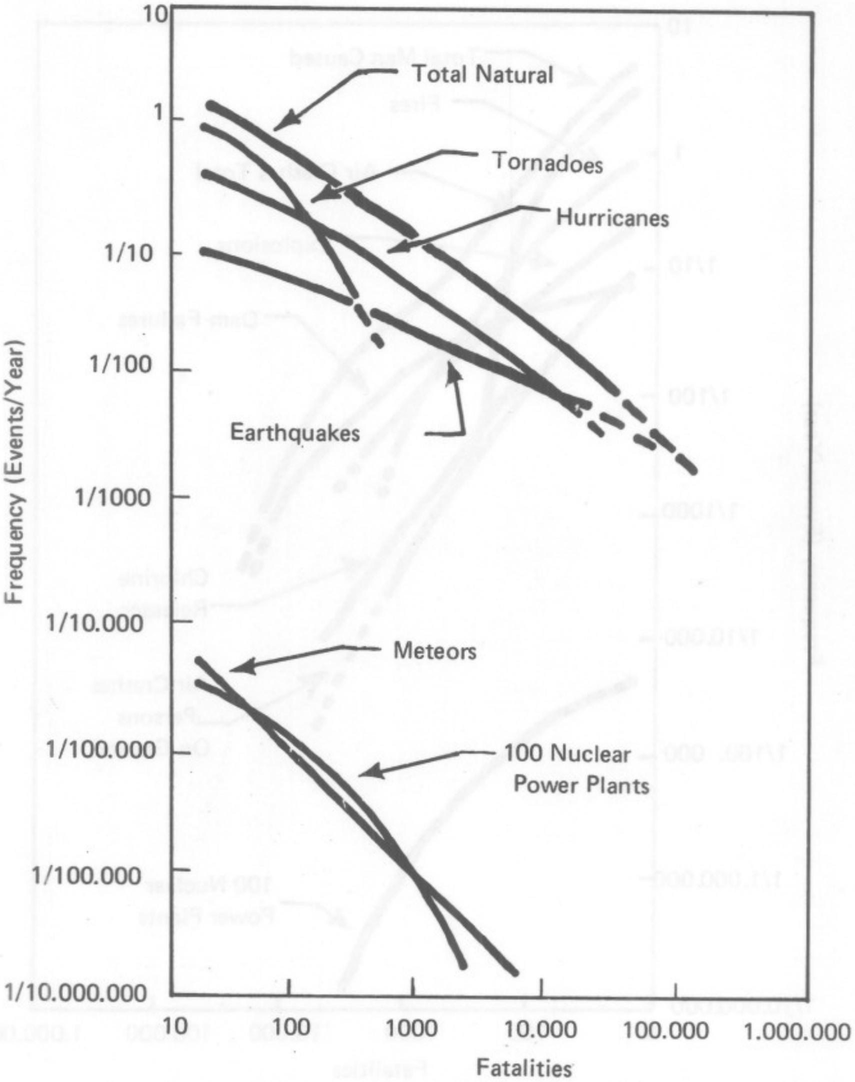

Figure 4. Frequency of Fatalities Due to Natural Events

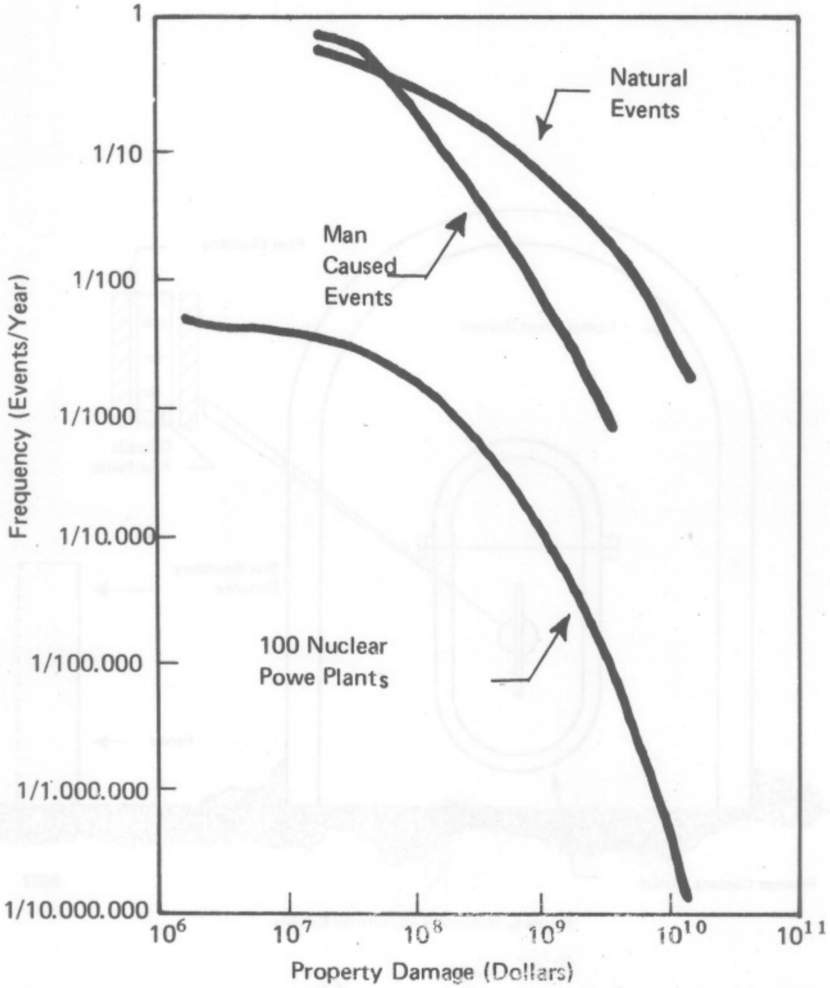

Figure 5. Frequency of Property Damage Due to Natural and Man Caused Events

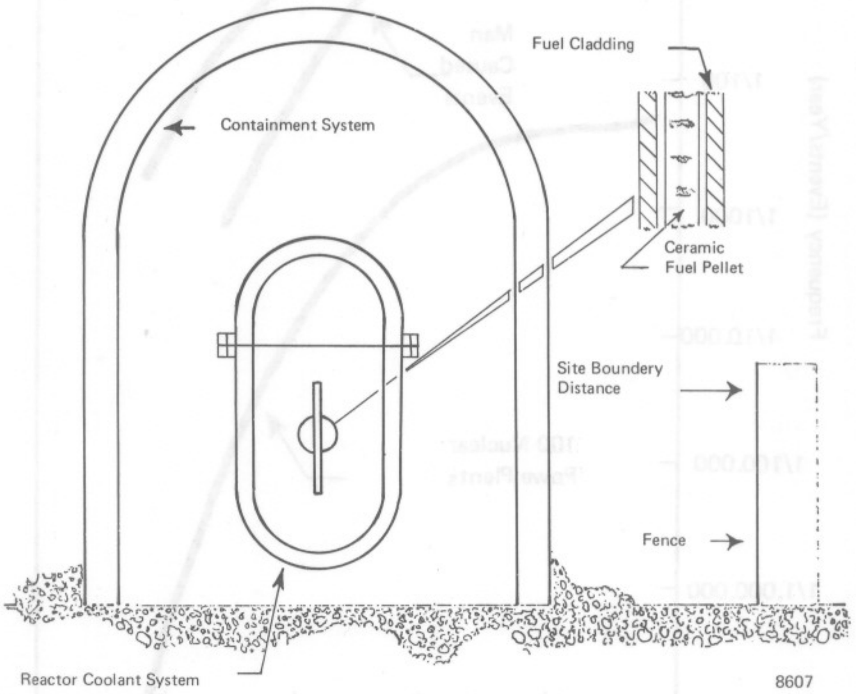

Figure 6. Multiple Radioactivity Barriers.

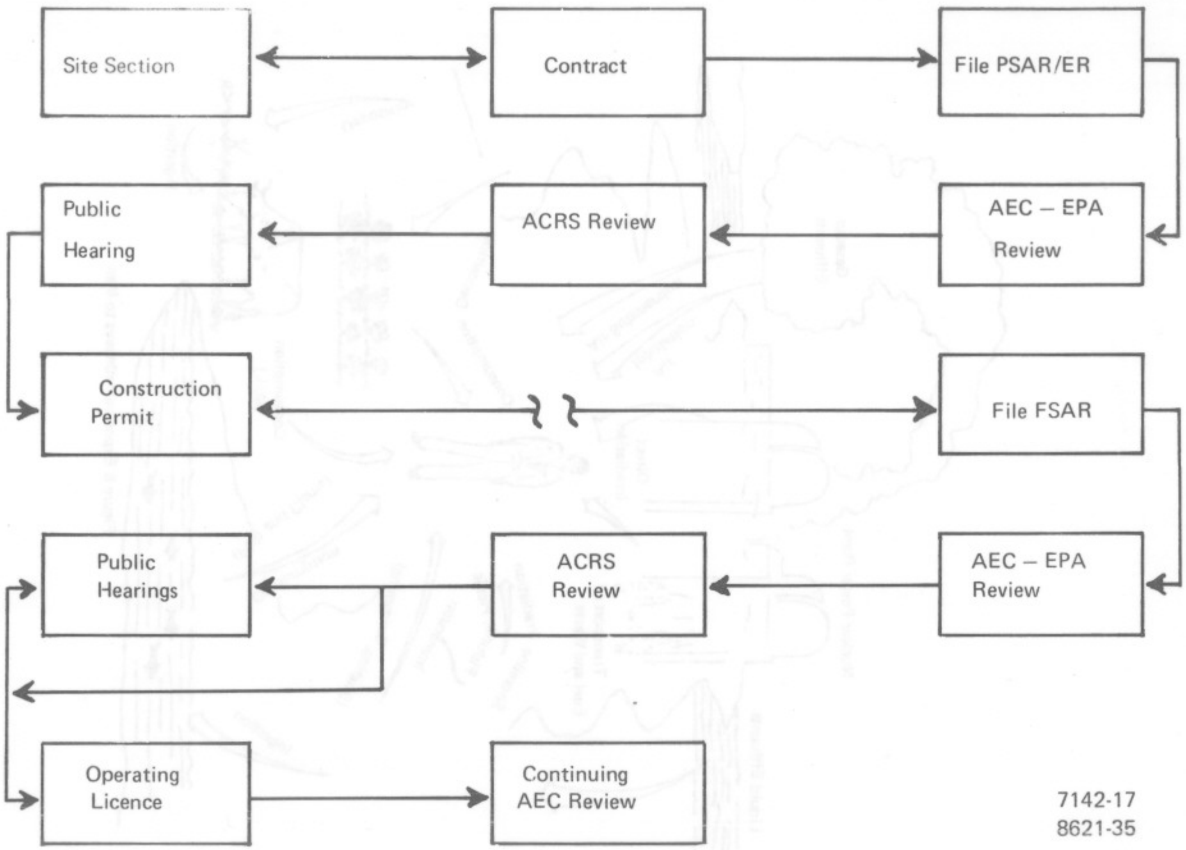

Figure 7. Significant Steps in the Licensing Process

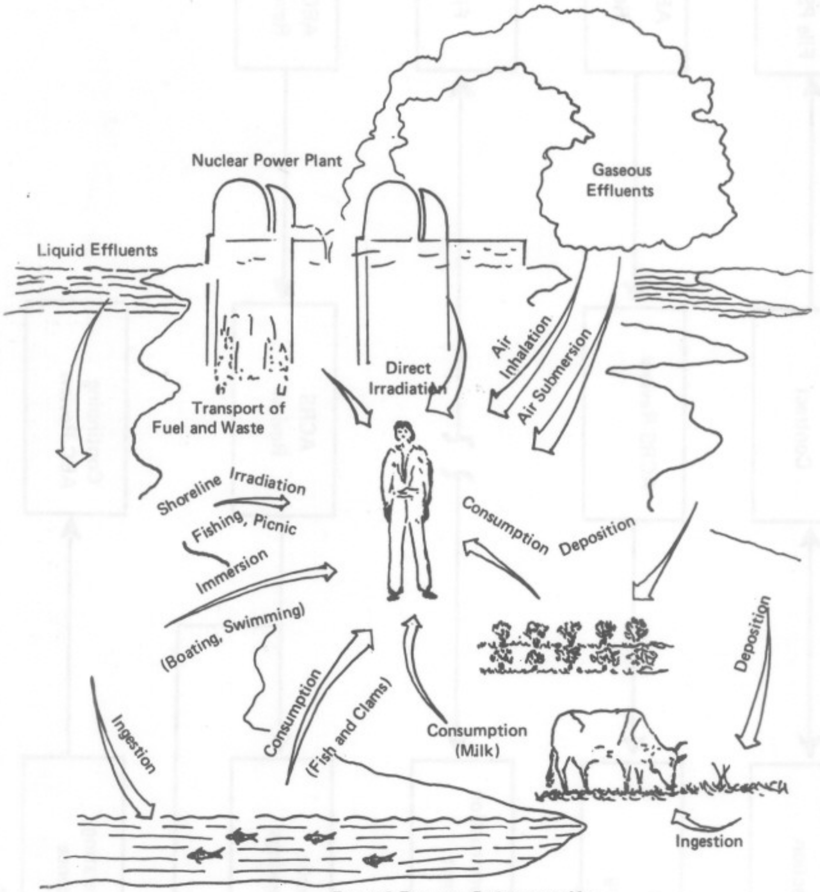

Figure 8 Exposure Pathways to Man

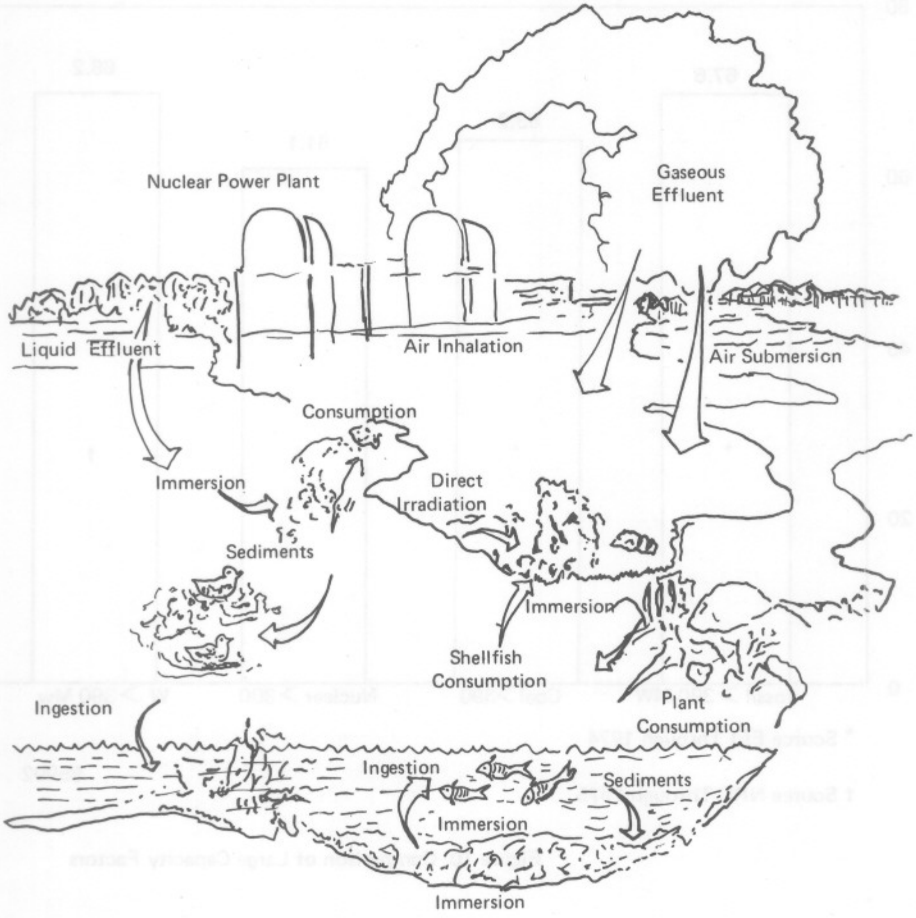

Figure 9. Exposure Pathways to Biota other than Man

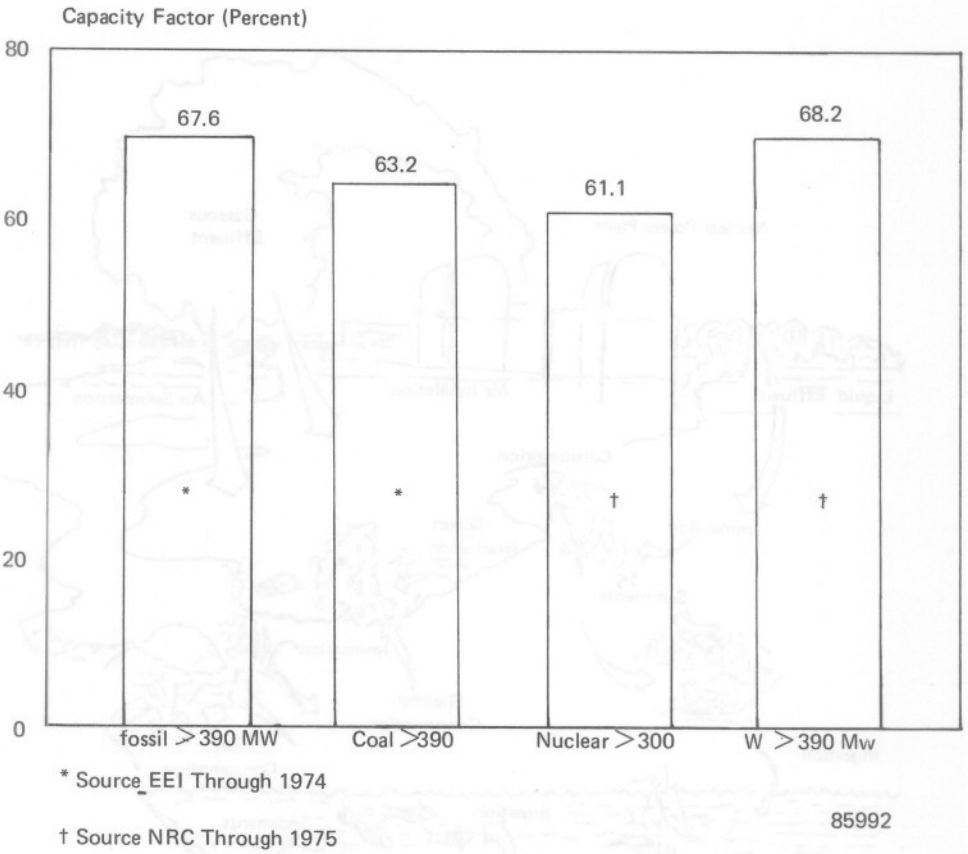

Figure 10. Comparison of Large Capacity Factors

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1. From Safety Consideration is there a limits to the number of reactors per station ?
2. Can inservice inspections be done while the reactor is still hot ?

JAWABAN :

G.E. Co.

1. The principle limitation is defined by the As Low As Practicable regulation of the NRC in 10 CFR 50 Appendix I, Radioaktive Material in Light Water Cooled Nuclear Power Reactor Effluents. Earlier versions of Appendix I set a 5 mrem/year total-site limit on liquid releases for either whole-body or single-organ exposures (i.e. the total radioactive releases from a site could not exceed the single-reactor guides no matter how many reactors were located on the side or how much power was produced there). However, now the NRC has adopted a per-reactor formulation, (i.e. for liquids – 3 mrem/year for whole-body and 10 mrem/year for single organ). We estimate this implies a limitation of four or five large reactors (1200 MWe) per site.
2. In service inspection is defined by the ASME Boiler and Pressure Vessel Code, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components; This code does not require inspections to be done while the reactor is still hot. Also we do not believe that the current state-of-the-art in non-destructive examination techniques (ultrasonic, magnetic particle, dyne penetrant, etc.) lends itself to application hot-temperature and radiation.

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