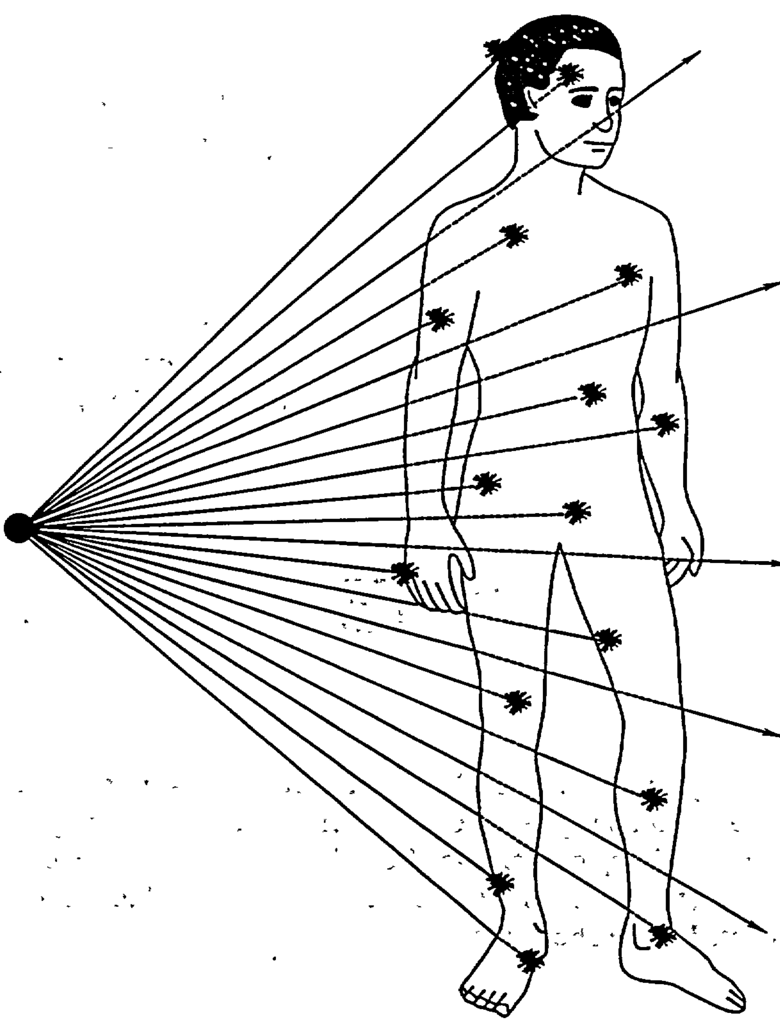
Biological Effects of Radiation



Whether the source of radiation is natural or man-made, whether it is a small dose of radiation or a large dose, there will be some biological effects. This chapter summarizes the short and long term consequences which may result from exposure to radiation.

Radiation Causes Ionizations of:

ATOMS

which may affect

MOLECULES

which may affect

CELLS

which may affect

TISSUES

which may affect

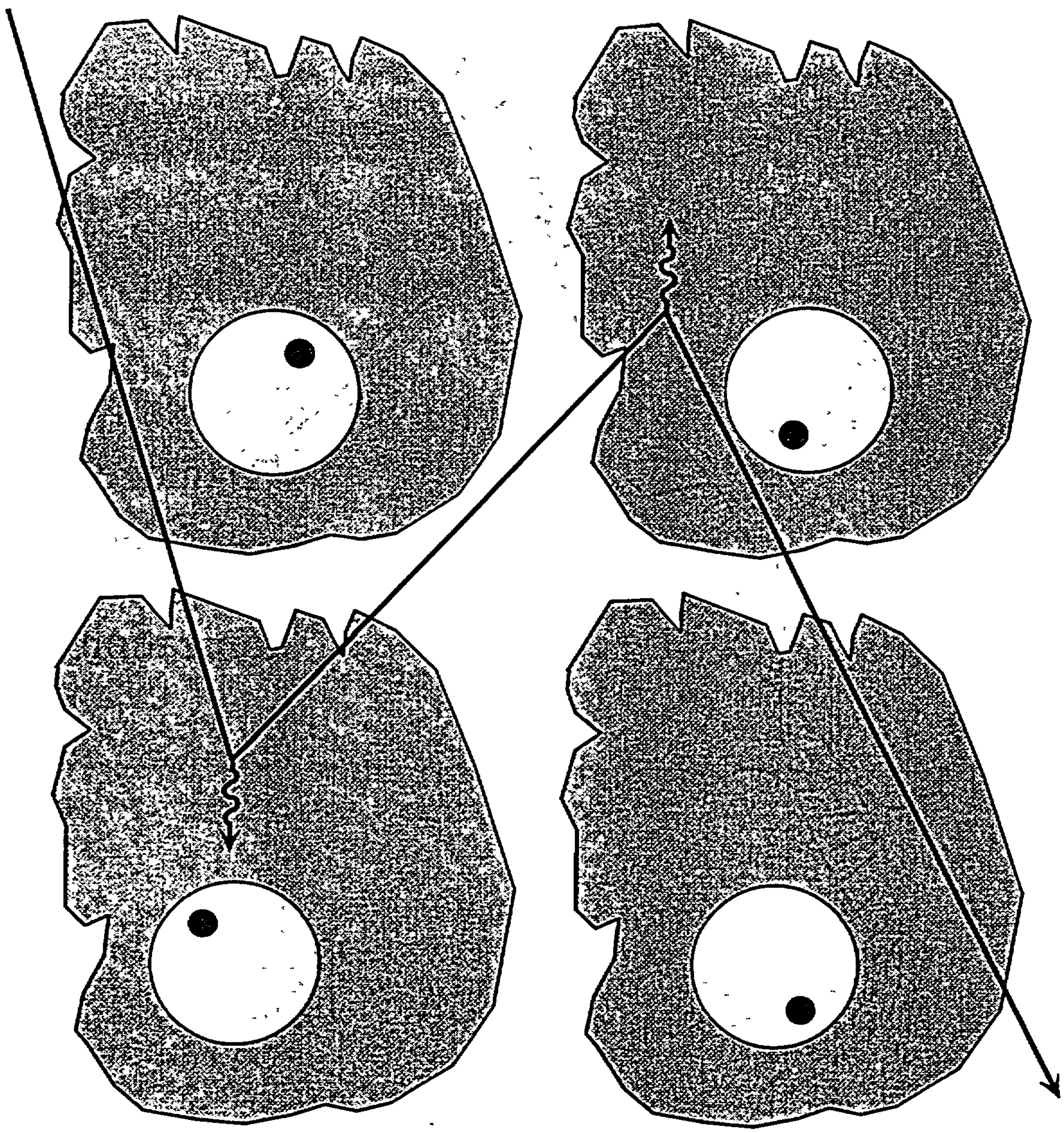
ORGANS

which may affect

THE WHOLE BODY

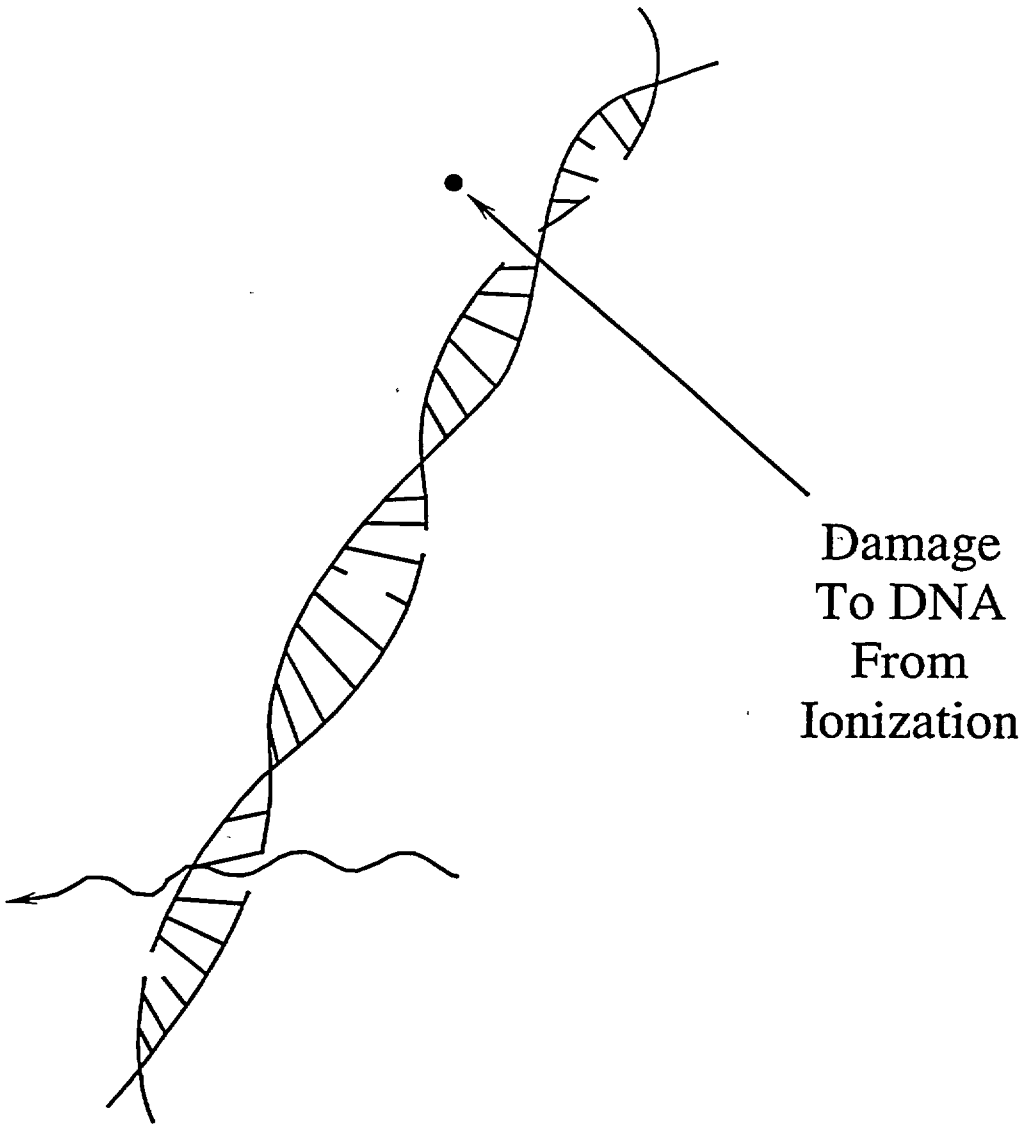
Although we tend to think of biological effects in terms of the effect of radiation on living cells, in actuality, ionizing radiation, by definition, interacts only with atoms by a process called ionization. Thus, all biological damage effects begin with the consequence of radiation interactions with the atoms forming the cells. As a result, radiation effects on humans proceed from the lowest to the highest levels as noted in the above list.

CELLULAR DAMAGE



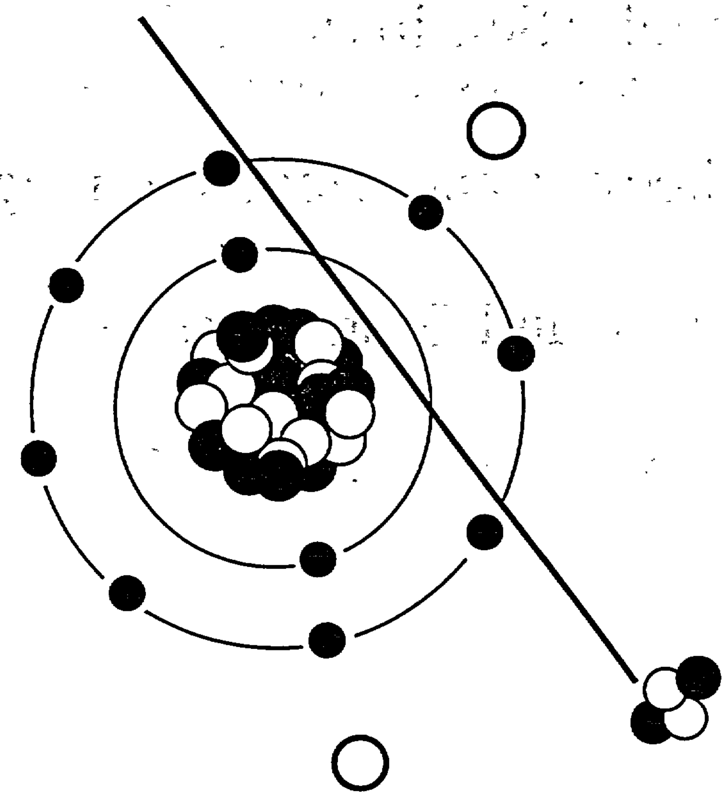
Even though all subsequent biological effects can be traced back to the interaction of radiation with atoms, there are two mechanisms by which radiation ultimately affects cells. These two mechanisms are commonly called direct and indirect effects.

Direct Effect



If radiation interacts with the atoms of the DNA molecule, or some other cellular component critical to the survival of the cell, it is referred to as a direct effect. Such an interaction may affect the ability of the cell to reproduce and, thus, survive. If enough atoms are affected such that the chromosomes do not replicate properly, or if there is significant alteration in the information carried by the DNA molecule, then the cell may be destroyed by "direct" interference with its life-sustaining system.

Indirect Effect



Radiolytic Decomposition of Water in a Cell

If a cell is exposed to radiation, the probability of the radiation interacting with the DNA molecule is very small since these critical components make up such a small part of the cell. However, each cell, just as is the case for the human body, is mostly water. Therefore, there is a much higher probability of radiation interacting with the water that makes up most of the cell's volume.

When radiation interacts with water, it may break the bonds that hold the water molecule together, producing fragments such as hydrogen (H) and hydroxyls (OH). These fragments may recombine or may interact with other fragments or ions to form compounds, such as water, which would not harm the cell. However, they could combine to form toxic substances, such as hydrogen peroxide (H_2O_2), which can contribute to the destruction of the cell.

Cellular Sensitivity to Radiation

(from most sensitive to least sensitive)

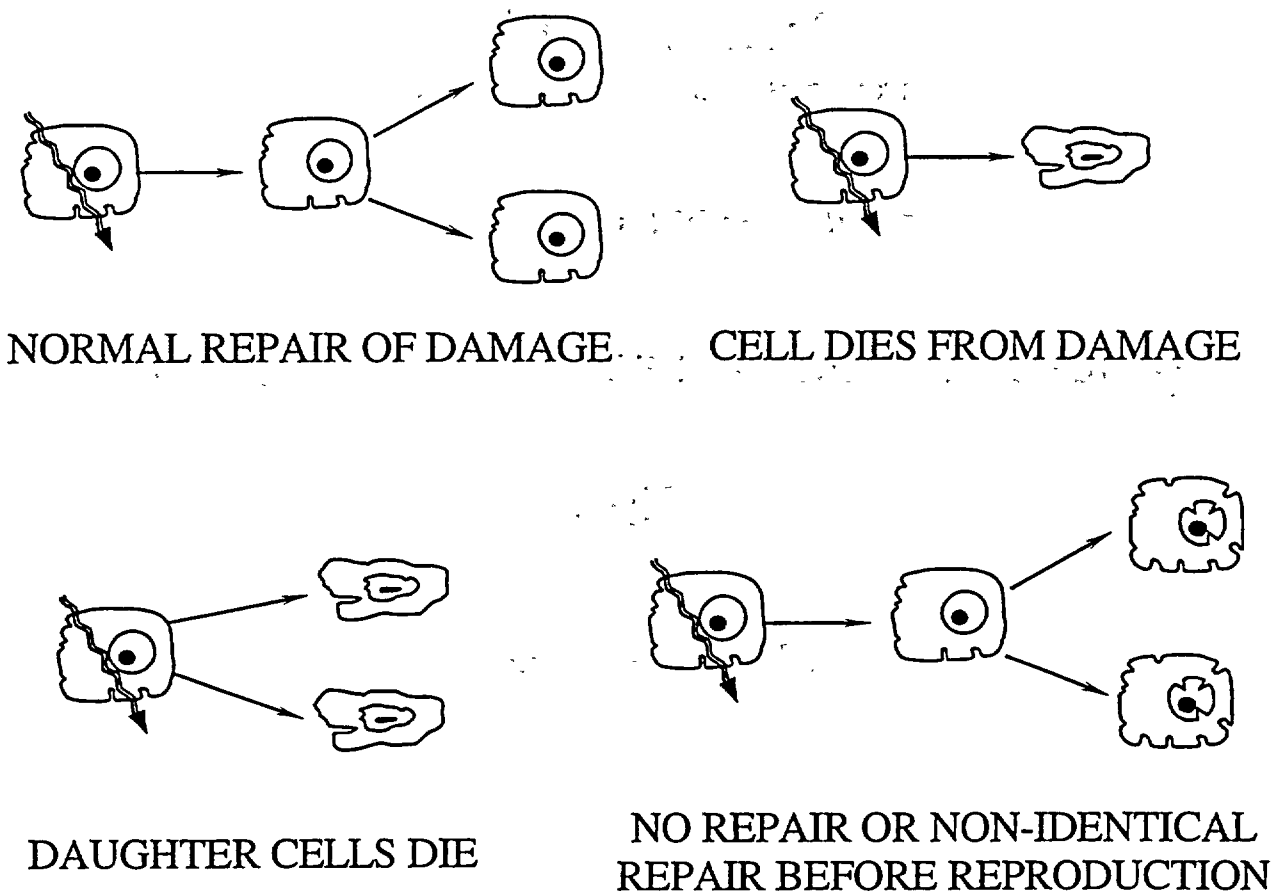
Lymphocytes and Blood Forming Cells

Reproductive and Gastrointestinal (GI) Cells

Nerve and Muscle Cells

Not all living cells are equally sensitive to radiation. Those cells which are actively reproducing are more sensitive than those which are not. This is because dividing cells require correct DNA information in order for the cell's offspring to survive. A direct interaction of radiation with an active cell could result in the death or mutation of the cell, whereas a direct interaction with the DNA of a dormant cell would have less of an effect.

As a result, living cells can be classified according to their rate of reproduction, which also indicates their relative sensitivity to radiation. This means that different cell systems have different sensitivities. Lymphocytes (white blood cells) and cells which produce blood are constantly regenerating, and are, therefore, the most sensitive. Reproductive and gastrointestinal cells are not regenerating as quickly and are less sensitive. The nerve and muscle cells are the slowest to regenerate and are the least sensitive cells.



Cells, like the human body, have a tremendous ability to repair damage. As a result, not all radiation effects are irreversible. In many instances, the cells are able to completely repair any damage and function normally.

If the damage is severe enough, the affected cell dies. In some instances, the cell is damaged but is still able to reproduce. The daughter cells, however, may be lacking in some critical life-sustaining component, and they die.

The other possible result of radiation exposure is that the cell is affected in such a way that it does not die but is simply mutated. The mutated cell reproduces and thus perpetuates the mutation. This could be the beginning of a malignant tumor.

Organ Sensitivity

(from most sensitive to least sensitive)

Blood Forming Organs

Reproductive and Gastrointestinal Tract Organs

Skin

Muscle and Brain

The sensitivity of the various organs of the human body correlate with the relative sensitivity of the cells from which they are composed. For example, since the blood forming cells were one of the most sensitive cells due to their rapid regeneration rate, the blood forming organs are one of the most sensitive organs to radiation. Muscle and nerve cells were relatively insensitive to radiation, and therefore, so are the muscles and the brain.

Sensitivity

Rate of Reproduction

Oxygen Supply

The rate of reproduction of the cells forming an organ system is not the only criterion determining overall sensitivity. The relative importance of the organ system to the well being of the body is also important.

One example of a very sensitive cell system is a malignant tumor. The outer layer of cells reproduces rapidly, and also has a good supply of blood and oxygen. Cells are most sensitive when they are reproducing, and the presence of oxygen increases sensitivity to radiation. Anoxic cells (cells with insufficient oxygen) tend to be inactive, such as the cells located in the interior of a tumor.

As the tumor is exposed to radiation, the outer layer of rapidly dividing cells is destroyed, causing it to "shrink" in size. If the tumor is given a massive dose to destroy it completely, the patient might die as well. Instead, the tumor is given a small dose each day, which gives the healthy tissue a chance to recover from any damage while gradually shrinking the highly sensitive tumor.

Another cell system that is composed of rapidly dividing cells with a good blood supply and lots of oxygen is the developing embryo. Therefore, the sensitivity of the developing embryo to radiation exposure is similar to that of the tumor, however, the consequences are dramatically different.

Whole Body Sensitivity Factors

Total Dose
Type of Cell
Type of Radiation
Age of Individual
Stage of Cell Division
Part of Body Exposed
General State of Health
Tissue Volume Exposed
Time Interval over which Dose is Received

Whole body sensitivity depends upon the most sensitive organs which, in turn, depend upon the most sensitive cells. As noted previously, the most sensitive organs are the blood forming organs and the gastrointestinal system.

The biological effects on the whole body from exposure to radiation will depend upon several factors. Some of these are listed above. For example, a person, already susceptible to infection, who receives a large dose of radiation may be affected by the radiation more than a healthy person.

Radiation Effects

High Doses (Acute)

Low Doses (Chronic)

Biological effects of radiation are typically divided into two categories. The first category consists of exposure to high doses of radiation over short periods of time producing acute or short term effects. The second category represents exposure to low doses of radiation over an extended period of time producing chronic or long term effects.

High doses tend to kill cells, while low doses tend to damage or change them. High doses can kill so many cells that tissues and organs are damaged. This in turn may cause a rapid whole body response often called the Acute Radiation Syndrome (ARS). High dose effects are discussed on pages 6-12 to 6-16.

Low doses spread out over long periods of time don't cause an immediate problem to any body organ. The effects of low doses of radiation occur at the level of the cell, and the results may not be observed for many years. Low dose effects are discussed on pages 6-17 to 6-23.

Occupation High Dose Exposures

Chernobyl
Irradiators
Inadvertent Criticalities

Non-Occupational High Dose Exposures

Chernobyl (firefighters)
Nagasaki and Hiroshima
Therapy source in Goiania, Brazil

Although we tend to associate high doses of radiation with catastrophic events such as nuclear weapons explosions, there have been documented cases of individuals dying from exposure to high doses of radiation resulting from workplace accidents and other tragic events.

Some examples of deaths which have occurred as a result of occupational (worker related) accidents are:

Inadvertent criticality (too much fissionable material in the right shape at the wrong time)
Irradiator (accidental exposure to sterilization sources, which can be more than 10 million curies)
Chernobyl (plant workers)

An example of a nonoccupational accident occurred in 1987 in Goiania, Brazil. An abandoned medical therapy source (cesium) was found and cut open by people who did not know what it was. This resulted in the deaths of several members of the public and the spread of radioactive contamination over a large area.

A recent inadvertent criticality event occurred in a fuel processing plant in Japan.

High Dose Effects

Dose (Rad)	Effect Observed
15 - 25	Blood count changes in a group of people
50	Blood count changes in an individual
100	Vomiting (threshold)
150	Death (threshold)
320 - 360	LD 50/60 with minimal care
480 - 540	LD 50/60 with supportive medical care
1,100	LD 50/60 with intensive medical care (bone marrow transplant)

Every acute exposure will not result in death. If a group of people is exposed to a whole body penetrating radiation dose, the above effects might be observed. The information for this table was extracted from NCRP Report No. 98, *Guidance on Radiation Received in Space Activities,* 1989.

In the above table, the threshold values are the doses at which the effect is first observed in the most sensitive of the individuals exposed. The LD 50/60 is the lethal dose at which 50% of those exposed to that dose will die within 60 days.

It is sometimes difficult to understand why some people die while others survive after being exposed to the same radiation dose. The main reasons are the health of the individuals at the time of the exposure and their ability to combat the incidental effects of radiation exposure, such as the increased susceptibility to infections.

Other High Dose Effects

Skin Burns
Hair Loss
Sterility
Cataracts

Besides death, there are several other possible effects of a high radiation dose.

Effects on the skin include erythema (reddening like sunburn), dry desquamation (peeling), and moist desquamation (blistering). Skin effects are more likely to occur with exposure to low energy gamma, X-ray, or beta radiation. Most of the energy of the radiation is deposited in the skin surface. The dose required for erythema to occur is relatively high, in excess of 300 rad. Blistering requires a dose in excess of 1,200 rad.

Hair loss, also called epilation, is similar to skin effects and can occur after acute doses of about 500 rad.

Sterility can be temporary or permanent in males, depending upon the dose. In females, it is usually permanent, but it requires a higher dose. To produce permanent sterility, a dose in excess of 400 rad is required to the reproductive organs.

Cataracts (a clouding of the lens of the eye) appear to have a threshold of about 200 rad. Neutrons are especially effective in producing cataracts, because the eye has a high water content, which is particularly effective in stopping neutrons.

Acute Radiation Syndrome (ARS)

Hematopoietic
Gastrointestinal
Central Nervous System

If enough important tissues and organs are damaged, one of the Acute Radiation Syndromes could result.

The initial signs and symptoms of the acute radiation syndrome are nausea, vomiting, fatigue, and loss of appetite. Below about 150 rad, these symptoms, which are no different from those produced by a common viral infection, may be the only outward indication of radiation exposure.

As the dose increases above 150 rad, one of the three radiation syndromes begins to manifest itself, depending upon the level of the dose. These syndromes are:

Syndrome	Organs Affected	Sensitivity
Hematopoietic	Blood forming organs	Most sensitive
Gastrointestinal	Gastrointestinal system	Very sensitive
Central Nervous System	Brain and muscles	Least sensitive

Summary of Biological Response to High Doses of Radiation

< 5 rad	-	No immediate observable effects
~ 5 rad to 50 rad	-	Slight blood changes may be detected by medical evaluations
~ 50 rad to 150 rad	-	Slight blood changes will be noted and symptoms of nausea, fatigue, vomiting, etc. likely
~ 150 rad to 1,100 rad	-	Severe blood changes will be noted and symptoms appear immediately. Approximately 2 weeks later, some of those exposed may die. At about 300 - 500 rad, up to one half of the people exposed will die within 60 days without intensive medical attention. Death is due to the destruction of the blood forming organs. Without white blood cells, infection is likely. At the lower end of the dose range, isolation, antibiotics, and transfusions may provide the bone marrow time to generate new blood cells and full recovery is possible. At the upper end of the dose range, a bone marrow transplant may be required to produce new blood cells.
~ 1,100 rad to 2,000 rad	-	The probability of death increases to 100% within one to two weeks. The initial symptoms appear immediately. A few days later, things get very bad, very quickly since the gastrointestinal system is destroyed. Once the GI system ceases to function, nothing can be done, and medical care is for comfort only.
> 2,000 rad	-	Death is a certainty. At doses above 5,000 rad, the central nervous system (brain and muscles) can no longer control the body functions, including breathing blood circulation. Everything happens very quickly. Nothing can be done, and medical care is for comfort only.

As noted, there is nothing that can be done if the dose is high enough to destroy the gastrointestinal or central nervous system. That is why bone marrow transplants don't always work.

In summary, radiation can affect cells. High doses of radiation affect many cells, which can result in tissue/organ damage, which ultimately yields one of the Acute Radiation Syndromes. Even normally radio-resistant cells, such as those in the brain, cannot withstand the cell killing capability of very high radiation doses. The next few pages will discuss the biological effects of low doses of radiation.

Annual Exposure to Average U.S. Citizen

Exposure Source	Average Annual Effective Dose Equivalent (millirems)
Natural:	
Radon	200
Other	100
Occupational	0.90
Nuclear Fuel Cycle	0.05
Consumer Products:	
Tobacco	?*
Other	5 - 13
Environmental Sources	0.06
Medical:	
Diagnostic X-rays	39
Nuclear Medicine	14
Approximate Total	360

* The whole body dose equivalent from tobacco products is difficult to determine. However, the dose to a portion of the lungs is estimated to be 16,000 millirems/year.

Everyone in the world is exposed continuously to radiation. The average radiation dose received by the United States population is given in the table above. This data was extracted from material contained in NCRP Report No. 93, *Ionizing Radiation Exposure of the Population of the United States*, 1987.

Radiation workers are far more likely to receive low doses of radiation spread out over a long period of time rather than an acute dose as discussed previously. The principal effect of low doses of radiation (below about 10 rad) received over extended periods of time is non-lethal mutations, with the greatest concern being the induction of cancer.

The next few pages will discuss the biological effects of low doses of radiation.

Categories of Effects of Exposure to Low Doses of Radiation

Genetic
Somatic
In-Utero

There are three general categories of effects resulting from exposure to low doses of radiation. These are:

- Genetic - The effect is suffered by the offspring of the individual exposed.
- Somatic - The effect is primarily suffered by the individual exposed. Since cancer is the primary result, it is sometimes called the Carcinogenic Effect.
- In-Utero - Some mistakenly consider this to be a genetic consequence of radiation exposure, because the effect, suffered by a developing embryo/fetus, is seen after birth. However, this is actually a special case of the somatic effect, since the embryo/fetus is the one exposed to the radiation.

Genetic Effects

Mutation of the reproductive cells passed on to the offspring of the exposed individual

The Genetic Effect involves the mutation of very specific cells, namely the sperm or egg cells. Mutations of these reproductive cells are passed to the offspring of the individual exposed.

Radiation is an example of a physical mutagenic agent. There are also many chemical agents as well as biological agents (such as viruses) that cause mutations.

One very important fact to remember is that radiation increases the spontaneous mutation rate, but does not produce any new mutations. Therefore, despite all of the hideous creatures supposedly produced by radiation in the science fiction literature and cinema, no such transformations have been observed in humans. One possible reason why genetic effects from low dose exposures have not been observed in human studies is that mutations in the reproductive cells may produce such significant changes in the fertilized egg that the result is a nonviable organism which is spontaneously resorbed or aborted during the earliest stages of fertilization.

Although not all mutations would be lethal or even harmful, it is prudent to assume that all mutations are bad, and thus, by USNRC regulation (10 CFR Part 20), radiation exposure SHALL be held to the absolute minimum or As Low As Reasonably Achievable (ALARA). This is particularly important since it is believed that risk is directly proportional to dose, without any threshold.

Somatic Effects

Effect is suffered by the individual exposed
Primary consequence is cancer

Somatic effects (carcinogenic) are, from an occupational risk perspective, the most significant since the individual exposed (usually the radiation worker) suffers the consequences (typically cancer). As noted in the USNRC Regulatory Guide 8.29, this is also the NRC's greatest concern.

Radiation is an example of a physical carcinogenic, while cigarettes are an example of a chemical cancer causing agent. Viruses are examples of biological carcinogenic agents.

Unlike genetic effects of radiation, radiation induced cancer is well documented. Many studies have been completed which directly link the induction of cancer and exposure to radiation. Some of the population studied and their associated cancers are:

Lung cancer - uranium miners
Bone cancer - radium dial painters
Thyroid cancer - therapy patients
Breast cancer - therapy patients
Skin cancer - radiologists
Leukemia - bomb survivors, in-utero exposures, radiologists, therapy patients

In-Utero Effects

Effects of radiation on embryo/fetus

Intrauterine Death
Growth Retardation
Developmental Abnormalities
Childhood Cancers

The in-utero effect involves the production of malformations in developing embryos.

Radiation is a physical teratogenic agent. There are many chemical agents (such as thalidomide) and many biological agents (such as the viruses which cause German measles) that can also produce malformations while the baby is still in the embryonic or fetal stage of development.

The effects from in-utero exposure can be considered a subset of the general category of somatic effects. The malformation produced do not indicate a genetic effect since it is the embryo that is exposed, not the reproductive cells of the parents.

The actual effects of exposure in-utero that will be observed will depend upon the stage of fetal development at the time of the exposure:

Weeks Post Conception	Effect
0 - 1 (preimplantation)	Intrauterine death
2 - 7 (organogenesis)	Developmental abnormalities/growth retardation/cancer
8 - 40 (fetal stage)	Same as above with lower risk plus possible functional abnormalities

Radiation Risk:

With any exposure to radiation, there is some risk

The approximate risks for the three principal effects of exposure to low levels of radiation are:

Effect	Excess Cases per 10,000 exposed per rad
Genetic	2 to 4
Somatic (cancer)	4 to 20
In-Utero (cancer)	4 to 12
In-Utero (all effects)	20 to 200

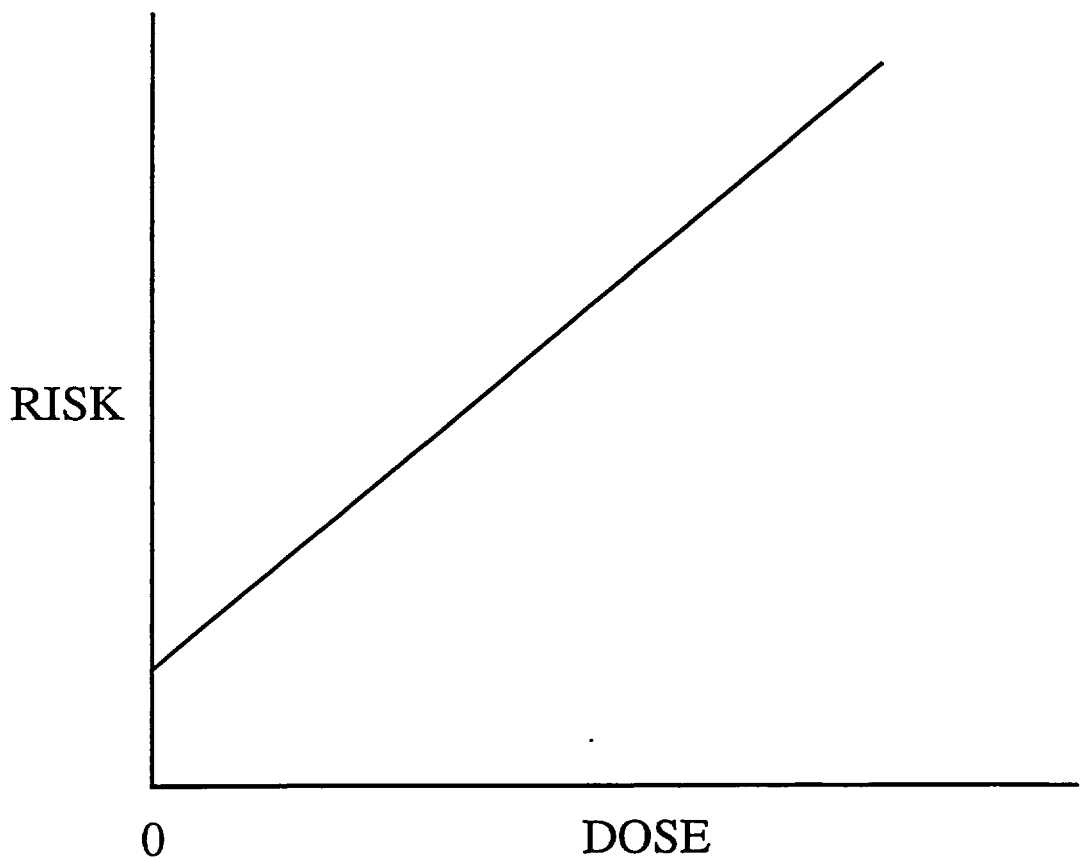
Genetic - Risks from 1 rem of radiation exposure to the reproductive organs are approximately 50 to 1,000 times less than the spontaneous risk for various anomalies.

Somatic - For radiation induced cancers, the risk estimate is small compared to the normal incidence of about 1 in 4 chances of developing any type of cancer. However, not all cancers are associated with exposure to radiation. The risk of dying from radiation induced cancer is about one half the risk of getting the cancer.

In-Utero - Spontaneous risks of fetal abnormalities are about 5 to 30 times greater than the risk of exposure to 1 rem of radiation. However, the risk of childhood cancer from exposure in-utero is about the same as the risk to adults exposed to radiation. By far, medical practice is the largest source of in-utero radiation exposure.

Because of overall in-utero sensitivity, the NRC, in 10 CFR Part 20, requires that for the declared pregnant woman, the radiation dose to the embryo/fetus be maintained less than or equal to 0.5 rem during the entire gestation period. This limit is one-tenth of the annual dose permitted to adult radiation workers. This limit applies to the worker who has voluntarily declared her pregnancy in writing. For the undeclared pregnant woman, the normal occupational limits for the adult worker apply (as well as ALARA).

Linear No-Threshold Risk Model



General consensus among experts is that some radiation risks are related to radiation dose by a linear, no-threshold model. This model is accepted by the NRC since it appears to be the most conservative.

LINEAR - An increase in dose results in a proportional increase in risk
NO-THRESHOLD - Any dose, no matter how small, produces some risk

The risk does not start at 0 because there is some risk of cancer, even with no occupational exposure. The slope of the line just means that a person that receives 5 rems in a year incurs 10 times as much risk as a person that receives 0.5 rems in a year.

Exposure to radiation is not a guarantee of harm. However, because of the liner, no-threshold model, more exposure means more risk, and there is no dose of radiation so small that it will not have some effect.

Radioactive Waste Management

This section will discuss the sources, handling, and ultimate disposal of radioactive wastes (sometimes referred to as radwaste) generated by nuclear power plant operation.

Solid, liquid, and gaseous materials from nuclear operations that are radioactive or become radioactive (contaminated) and for which there is no further use

Radioactive waste is material that is radioactive that is no longer needed at the plant and can be disposed of. The following are some examples of the sources of radioactive waste.

After a fuel assembly has been used in the reactor core to generate power, there is a large inventory of fission products held inside the cladding of the fuel. Since the processing of spent fuel is not done for commercial power plants, the fuel must be disposed of in some safe fashion.

The activation products that are carried by the reactor coolant system are collected by the filters and demineralizers in the cleanup systems. When the filters and demineralizer resins are full, they must be disposed of as radioactive waste.

A paper towel or rag used to wipe up radioactive water must be disposed of as radioactive waste.

A contaminated piece of equipment that is no longer useable must be disposed of as radioactive waste.

High Level Radioactive Waste

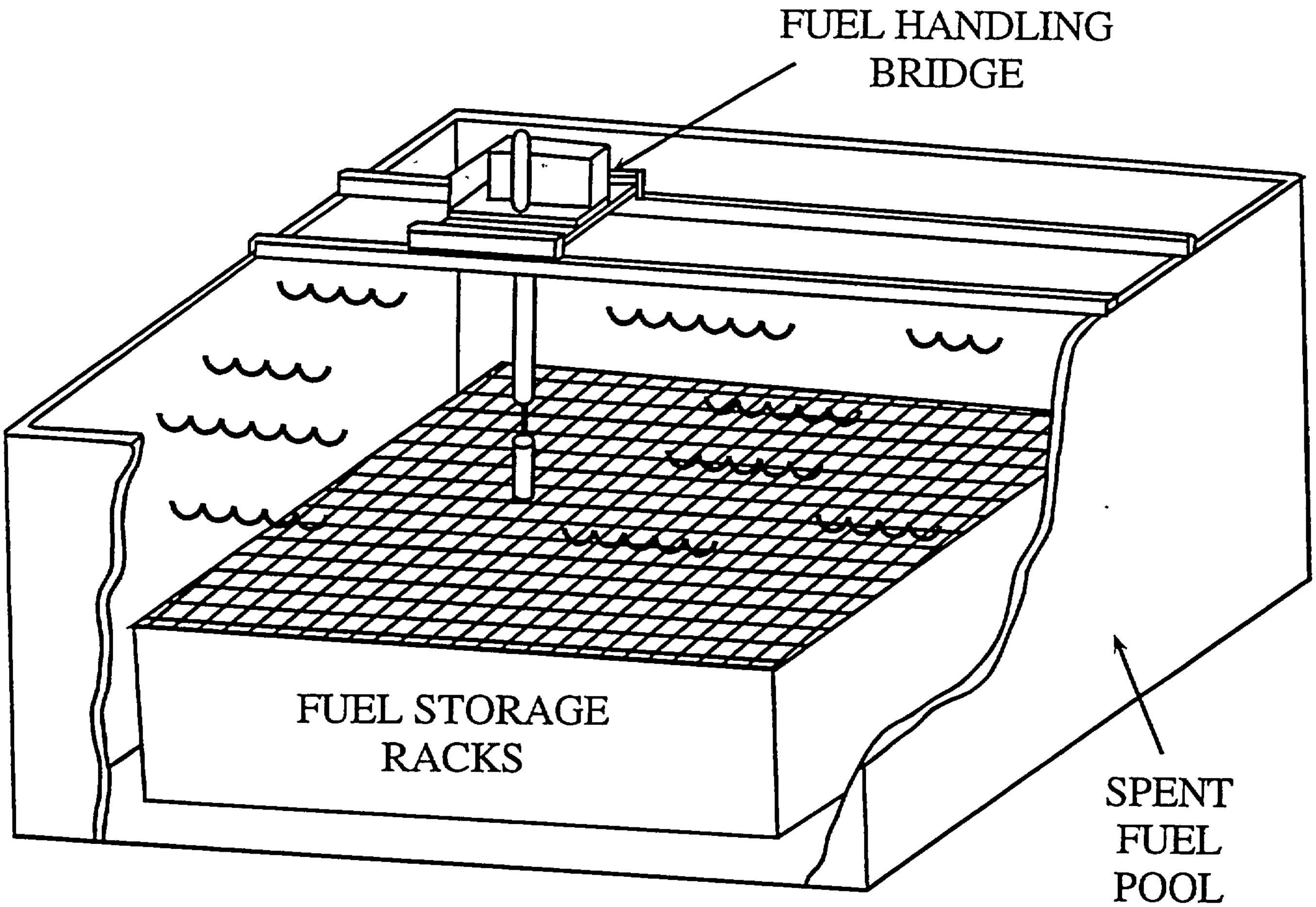
Low Level Radioactive Waste

There are two general classifications of radioactive waste. These are:

High Level Radioactive Waste
and
Low Level Radioactive Waste

Disposal of high level radioactive waste is the responsibility of the Department of Energy. The licensing of high level waste disposal facilities is the responsibility of the USNRC, as specified in 10 CFR Part 60, "*Disposal of High-Level Radioactive Waste in Geologic Repositories.*"

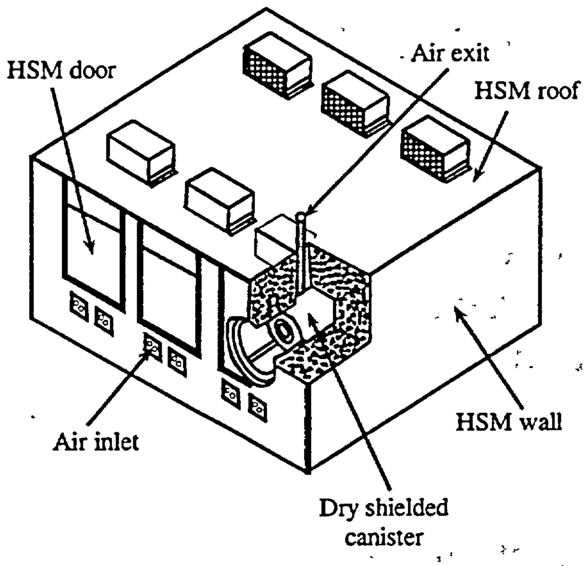
Disposal of low level radioactive waste is also subject to licensing by the USNRC. The regulations for these disposal facilities are in 10 CFR Part 61, "*Licensing Requirements for Land Disposal of Radioactive Waste.*"

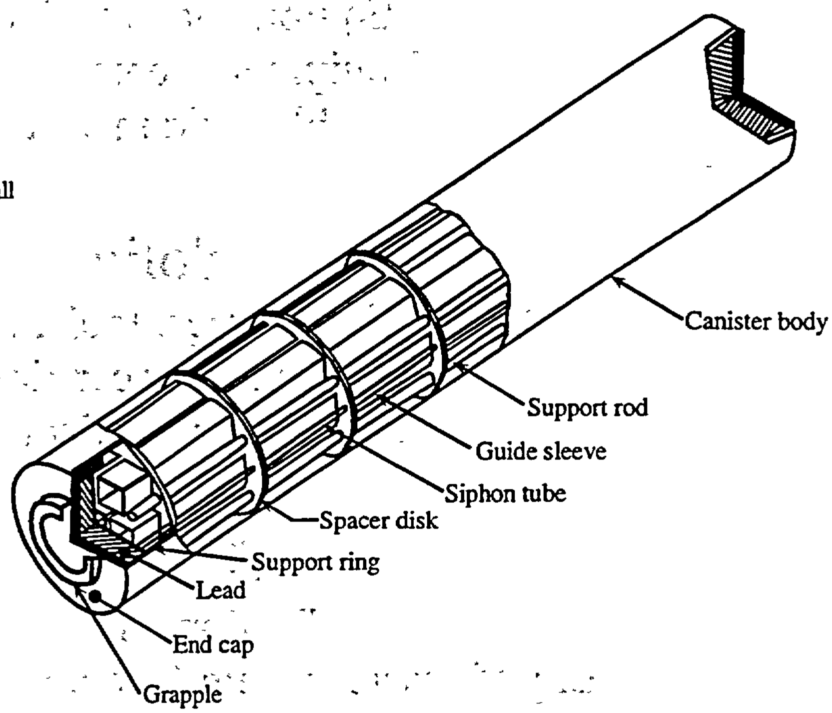


Spent fuel is classified as high level radioactive waste. This is due to the buildup of very highly radioactive fission products as the fuel is used in the reactor.

When the spent fuel is removed from the reactor to be replaced with new fuel, it must be stored for a period of time in the spent fuel pool. The spent fuel must be kept under water due to the heat being generated by the decay of the fission products and to limit the radiation levels in the area of the spent fuel pool. The spent fuel pools are usually located onsite. However, due to the amount of fuel some power plants must store, there are some offsite storage pools.

Presently, there are no disposal facilities for commercial high level radioactive waste.





After several years, the heat generated by the decay of the fission products decreases sufficiently to allow the storage of the spent fuel in an air-cooled, dry, above ground storage facility. These facilities must be designed to remove the heat from the spent fuel and be designed to limit the radiation in the areas around the facilities.

The illustration above is a horizontal storage module (HSM) with shielded canister. The fuel would be inside the canister, which would then be placed inside the HSM. This is just one of several designs of dry fuel storage, some horizontal and some vertical.

Low Level Radioactive Waste:

Liquid:

Equipment leakoff points
Equipment vents and drains
Floor drain system

Solid:

Contaminated rags, tools, clothing, etc.
Spent filter cartridges
Spent demineralizer resins

Gaseous:

Equipment vents
Liquid waste system (evaporator gas stripper)

All radioactive waste that is not high level radioactive waste is low level radioactive waste. The principal sources of low level radwaste are the reactor coolant (water) and the components and equipment that come in contact with the coolant. The major constituents of low level radwaste are activation products (crud) and a very small percentage of fission products (if any leak out of the fuel rods).

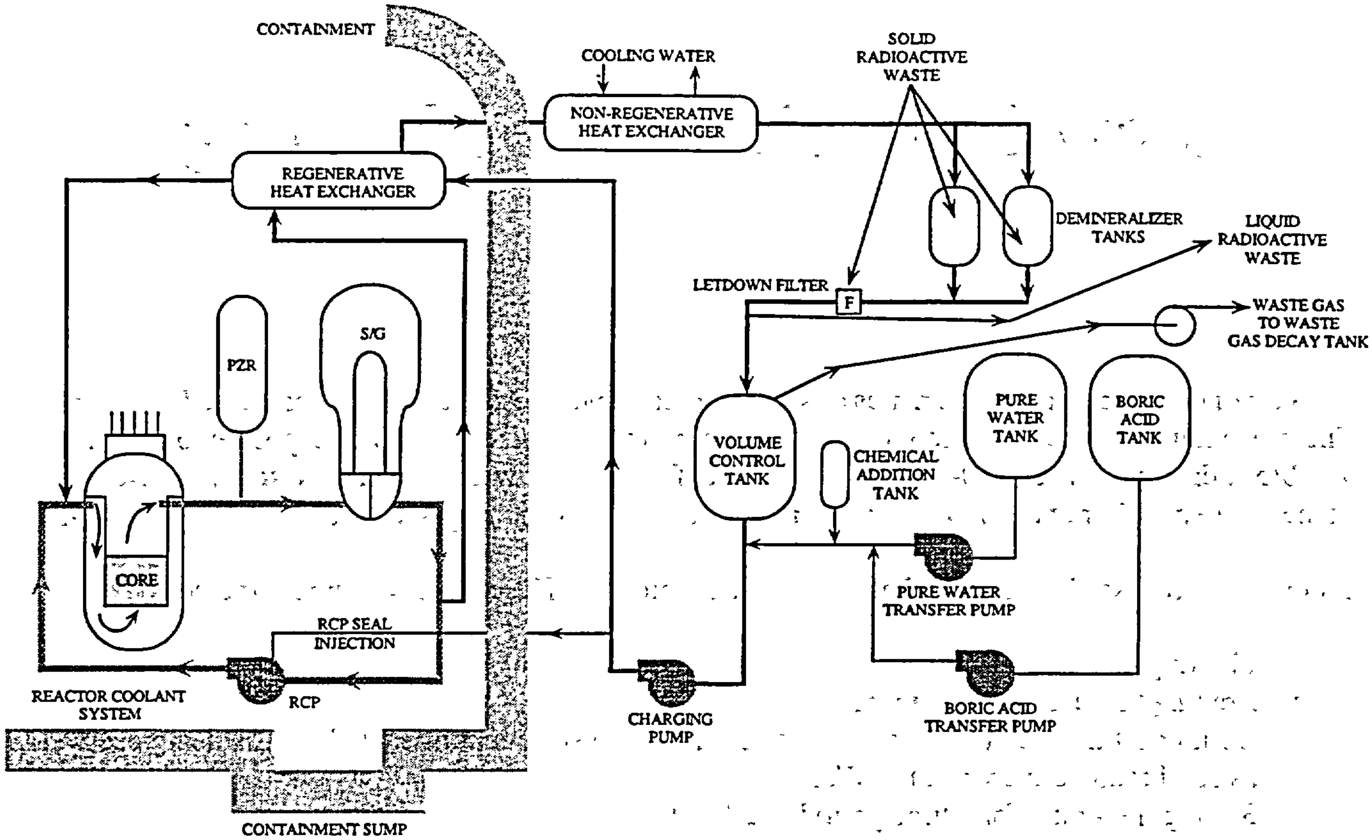
Low level radioactive wastes can be in the form of solids, liquids, or gases. The list above gives some examples of the sources of each form of low level radwaste.

Low level radioactive waste is also classified based upon the concentration and type of radionuclides involved (10 CFR Part 61).

Class A waste is usually segregated from other waste at the disposal site. It must meet the minimum requirements.

In addition to minimum requirements, Class B waste must meet more rigorous requirements on waste form to ensure stability after disposal.

Class C waste must meet all of the Class B requirements and requires additional measures at the disposal facility to protect against inadvertent intrusion.



The chemical and volume control system (CVCS) on a pressurized water reactor is used to remove the activation products and fission products from the reactor coolant. It will be used to show some of the sources of solid, liquid, and gaseous radioactive wastes.

As the reactor coolant flows through the chemical and volume control system, it passes through demineralizers and filters. The demineralizer resins and filter cartridges become contaminated due to the impurities they remove from the coolant. After use, the resins and cartridges will be disposed of as solid radioactive waste. In the volume control tank, the reactor coolant is sprayed into a hydrogen gas bubble. As the water is sprayed, gases are stripped out of solution. These gases can then be vented to the waste gas system to be processed as gaseous radioactive waste. If water needs to be removed from the reactor coolant system, there is a flow path that can be lined up to divert the reactor coolant flow from the chemical and volume control system to the liquid radwaste system for processing.

The chemical and volume control system is only one example of how radioactive waste is generated by the operation of a power plant system. Wastes are also generated due to the cleanup of areas (rags, clothing, etc.), the replacement of equipment (used parts, contaminated tools, etc.), and by improper housekeeping (contaminated clothing from stepping in a puddle, etc.).

Low Level Radwaste Handling

Because of the different characteristics of solids, liquids, and gases, each must be processed differently. The waste must also be processed in such a manner as to minimize the risk of exposure to the public. The block diagram on page 10-9 shows the layout of a simple radwaste handling system. A discussion of the dose a member of the public can receive from releases from the plant can be found on page 10-11.

Liquids are processed to remove the radioactive impurities. These processes might include:

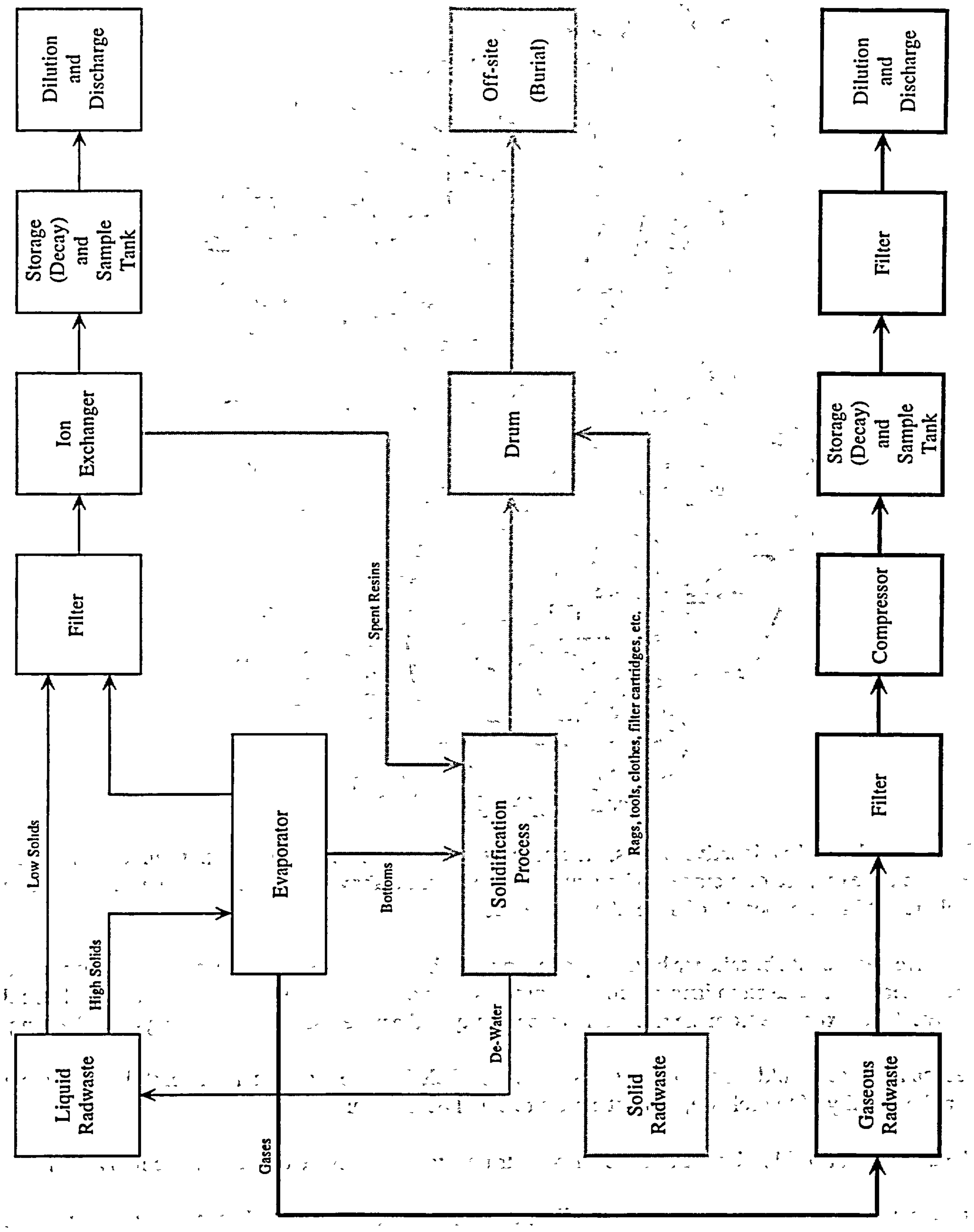
- Filtering,
- Routing through demineralizers,
- Boiling off the water (evaporation) and leaving the solid impurities (which are then processed as solid radioactive waste), and/or
- Storing the liquid for a time period to allow the radioactive material to decay.

After processing, the water will be sampled. If samples show the water meets the required standards, the water can be placed in the storage tanks for use in the plant or be released to the environment. If the samples show the water does not meet the standards, it will be reprocessed.

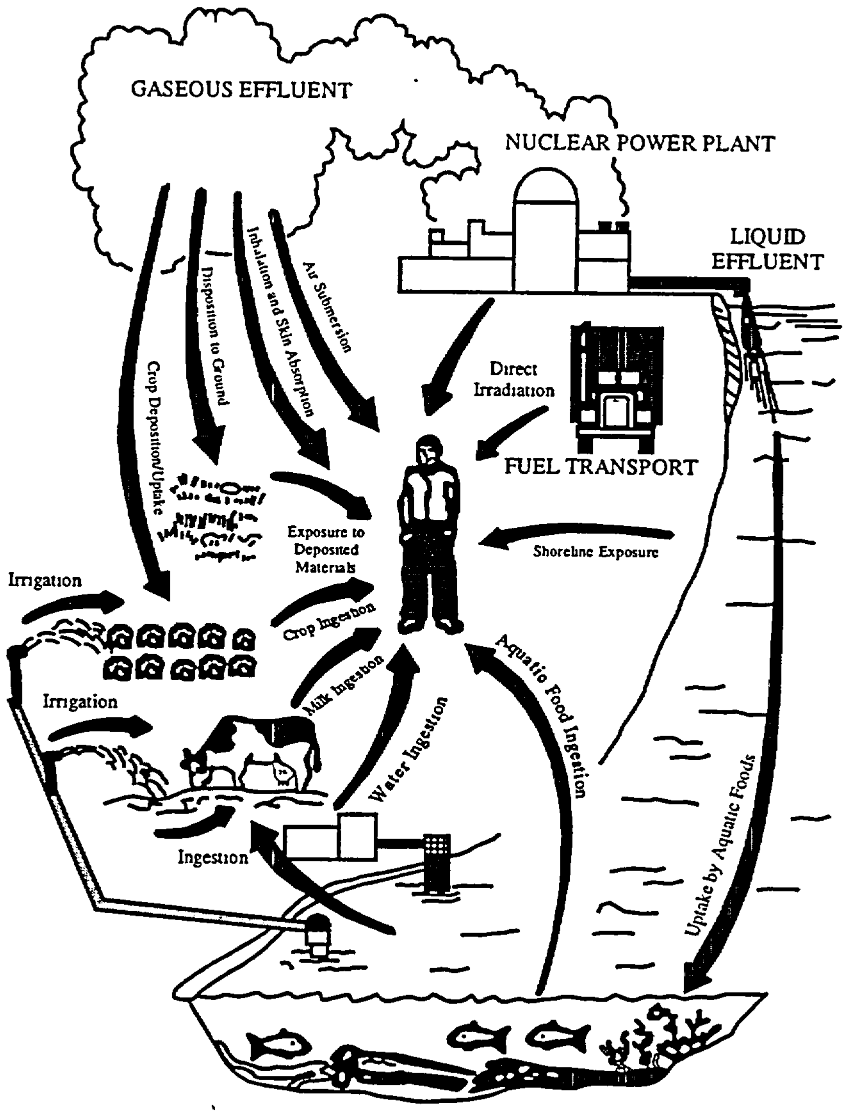
Some materials, such as the evaporator bottoms (solids that remain after the water is evaporated off), will be mixed with some material to form a solid (such as concrete). This is also sometimes done with spent demineralizer resins. After mixing with a hardener, the material is processed as solid radioactive waste.

Gaseous wastes are filtered, compressed to take up less space, and then allowed to decay for some time period. After the required time has passed, the gases will be sampled. If the required limits are met, the gases will be released to the atmosphere, or sometimes the gases will be reused in specific areas of the plant.

Solid wastes are packaged as required and shipped to a burial site for disposal (transportation of radioactive material is discussed in Chapter 11).



Radioactive Waste Handling System



Gaseous and liquid radioactive wastes, after processing, may be released to the environment. This can result in the exposure of members of the public. The diagram above shows some of the pathways that could result in the exposure of a member of the public.

Liquid releases could be taken in by the aquatic growth, which could then be consumed by an individual. The water could be used to irrigate crops, or processed as drinking water. Also, the individual could receive direct exposure from the release if in the vicinity of the water, such as swimming or sunbathing.

Gaseous releases could result in exposures by being inhaled by the individual. Also, if the individual is in the vicinity of the release, a direct exposure could be the result.

The transport of solid radwaste and fuel also contribute to the exposure of the average individual.

The amount of exposure received due to all of these processes is very small, when compared to the average yearly dose received (see Chapter 8). Also, there are limits placed on the amount of exposure a member of the public can receive from a nuclear power plant.

10 CFR Part 20 Dose Standards

2 millirems in any hour from external sources
in an unrestricted area

100 millirems in a calendar year
(sum of external and internal radiation)
in a controlled or unrestricted area

10 CFR Part 50 Design Objectives

Liquids

3 millirems/year to the whole body
10 millirems/year to any organ

Gases

5 millirems/year to the whole body
15 millirems/year to the skin

Solids and Iodine

15 millirems/year to any organ

As discussed in Chapter 9, 10 CFR Part 20 states that the licensee must control radioactive material such that no member of the public in an unrestricted area receives a dose of 2 millirems in any hour from external sources or 100 millirems in a calendar year from external and internal sources in a controlled or unrestricted area. This control of radioactive material would also include the release of radioactive material to the environment, air, or water.

In addition to the limits of 10 CFR Part 20, the NRC has issued numerical design objectives for each reactor unit for exposure from radioactive material releases into water and air. These design objectives are published in 10 CFR Part 50 and are considerably lower than the limits published in 10 CFR Part 20.

Regional Low-Level Waste Compacts

<u>Northwest</u>
Alaska
Hawaii
Idaho
Montana
Oregon
Utah
Wyoming
Washington is the current host state

<u>Southwestern</u>
Arizona
North Dakota
South Dakota
California is the selected host state

<u>Rocky Mountain</u>
Colorado
Nevada
New Mexico

<u>Midwest</u>
Indiana
Iowa
Minnesota
Missouri
Ohio
Wisconsin

<u>Central</u>
Arkansas
Kansas
Louisiana
Oklahoma
Nebraska is the selected host state

<u>Central Midwest</u>
Kentucky
Illinois is the selected host state

<u>Appalachian</u>
Delaware
Maryland
West Virginia
Pennsylvania is the selected host state

<u>Northeast</u>
Connecticut and New Jersey are both selected as host states

<u>Southeast</u>
Alabama
Florida
Georgia
Mississippi
Tennessee
Virginia
North Carolina is the selected host state

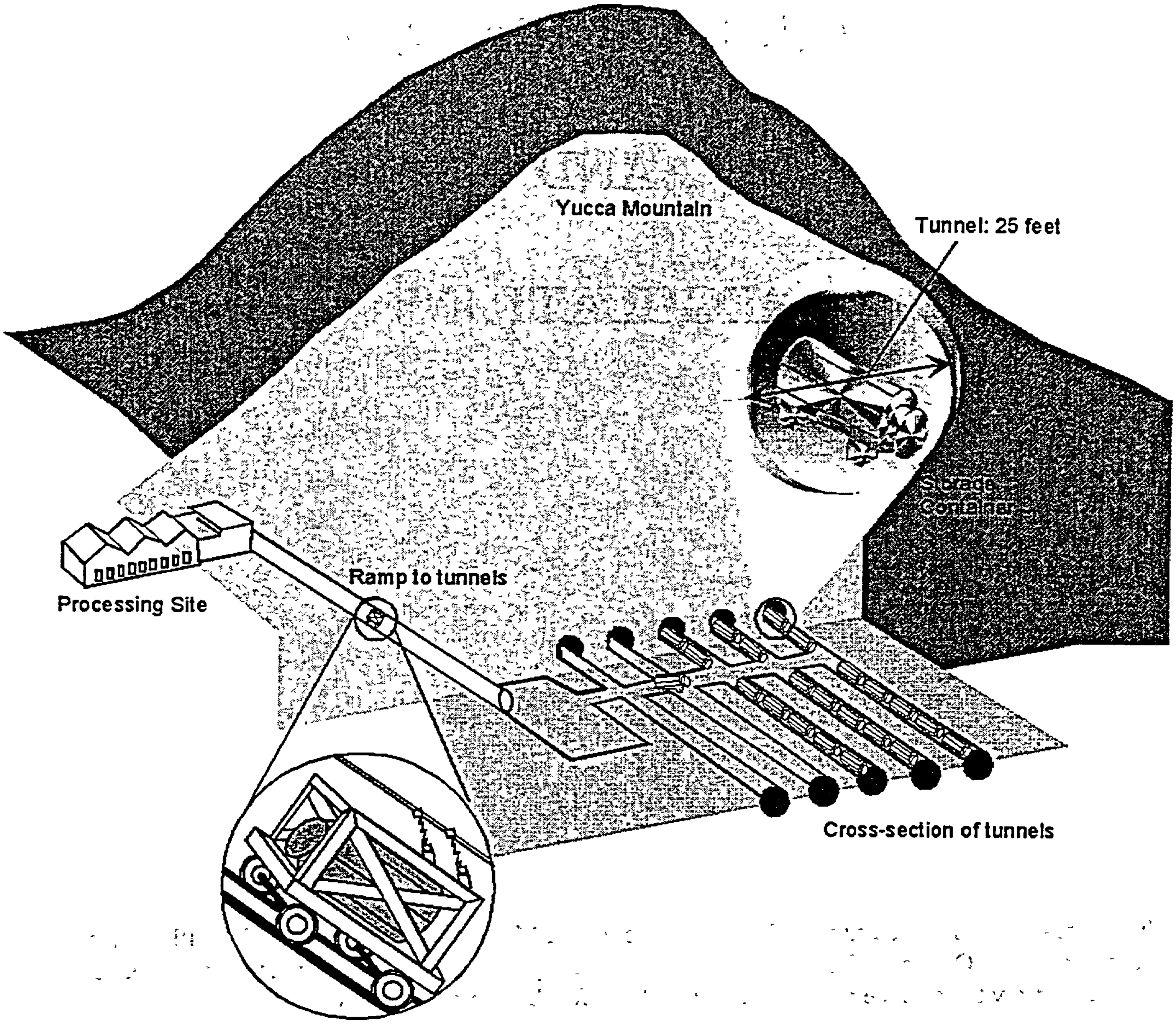
<u>Proposed</u>
Maine
Vermont
Texas

<u>Unaffiliated</u>
District of Columbia
Massachusetts
Michigan
New Hampshire
New York
Puerto Rico
Rhode Island
South Carolina

In addition to proper handling, the proper disposal of radioactive waste will help to minimize the dose received by members of the public. Currently, low level radioactive waste is all that is accepted for disposal at burial sites. There are three disposal sites which are presently operating. Barnwell, South Carolina can accept all low-level waste except from North Carolina. Hanford, Washington can accept waste from the Northwest and Rocky Mountain compacts. Clive, Utah is only authorized to accept Class A, low-activity, high-volume waste.

The Nuclear Waste Policy Act of 1980 gives States the responsibilities for management and disposal of most civilian low-level radwaste. Disposal is regulated by a State entering into an agreement with the NRC (Agreement State).

The Act also divided the US into regional low level waste compacts. Each compact has a host State which will contain the low-level waste disposal site. Some compacts have more than one host State. Some disposal sites are being reviewed at this time.



Even though there is not presently a high-level waste repository accepting spent fuel for disposal, the Nuclear Waste Policy Act of 1982, as amended, directed the Department of Energy to site, design, construct, and operate a high-level waste repository.

YUCCA MOUNTAIN

AND

REGULATIONS

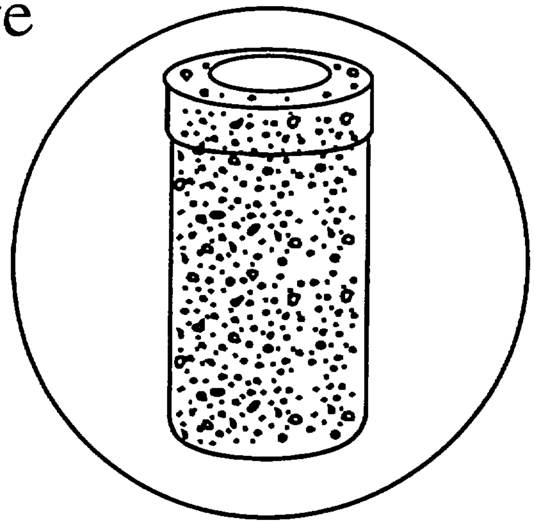
The proposed site for the high level repository is Yucca Mountain, Nevada. The site will resemble a mining complex. On the surface will be the waste handling facilities (offices, repair shops, etc.). About 1000 feet below the surface will be the disposal site for the containerized waste.

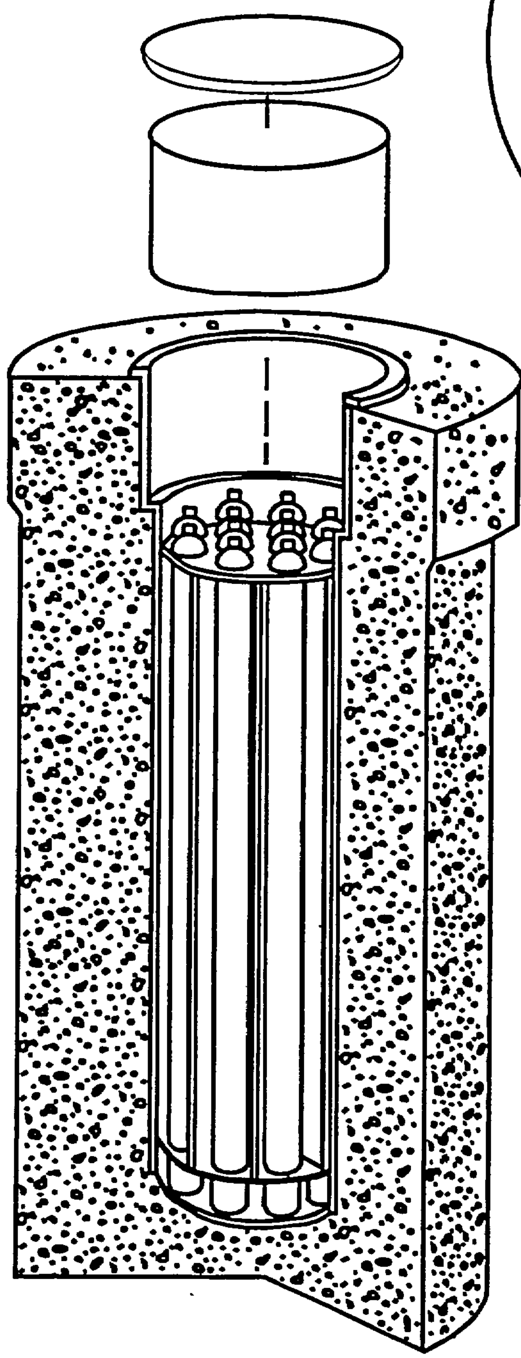
The EPA has published its final regulations for the site. They can be found in 40 CFR Part 197, "Environmental Radiation Protection Standards for Yucca Mountain." The regulations limit the dose to the public to 15 mrem/year from the facility. The regulations also impose an additional groundwater protection dose limit of 4 mrem/year from beta and photon emitting radionuclides.

The NRC proposed regulation (10 CFR Part 63, "Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada") has been revised to reflect the EPA regulations. The original dose limit proposed by the NRC was 25 mrem/year. However, to come into compliance with the EPA regulation, it was changed and has been sent to the Commission for approval.

Previously, it was mentioned that 10 CFR Part 60 dealt with the disposal of high level wastes. This regulation will continue to apply to all other high level facilities except for Yucca Mountain. As for 10 CFR Part 63, it will only apply to a repository at Yucca Mountain.

Sealed Storage Cask





Cask Dimensions

Height:	22 ft
Diameter:	12 ft
Weight:	200 tons (empty)
	220 tons (loaded)

The container would be a large storage cask that would hold the high-level radioactive waste.

Transportation of Radioactive Material

This section will discuss the NRC dose standards and the methods used to protect individuals from the harmful effects of radiation and contamination.

UN Classification

Class 1	Explosives
Class 2	Gases
Class 3	Flammable Liquids
Class 4	Flammable Solids
Class 5	Oxidizers and Organic Peroxides
Class 6	Poisonous and Etiological Materials
Class 7	*Radioactive Materials*
Class 8	Corrosives
Class 9	Miscellaneous Hazardous Materials

All hazardous materials which could potentially be transported are assigned to one of the nine United Nations Classes. In general, the hazardous materials listed pose an immediate threat to health and safety. However, for radioactive material, the threat is potentially the non-immediate risk of cancer, although in large enough quantities, radiation can pose an immediate threat.

Groups Promulgating Rules Governing Transport of Radioactive Materials

Department of Transportation
Nuclear Regulatory Commission
Department of Energy
Postal Services
State Agencies

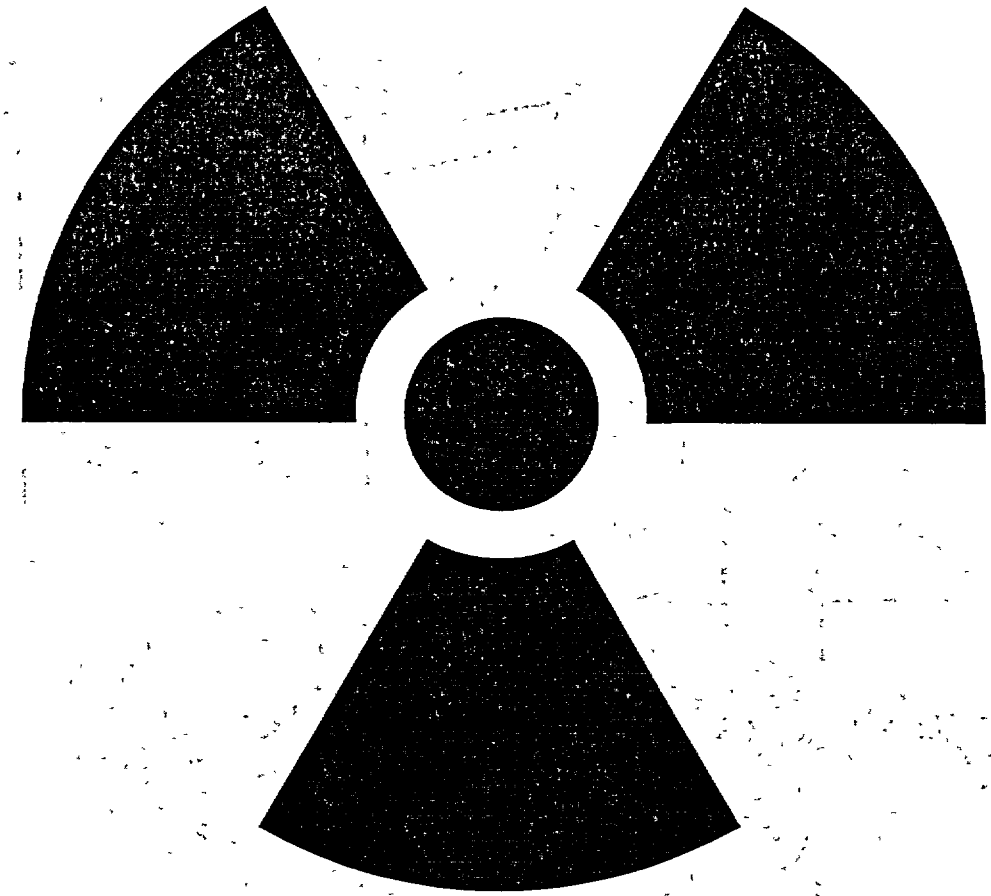
Regulations to control the transport of radioactive materials were initiated about 1935 by the Postal Service. Over the years, the Interstate Commerce Commission (ICC) became involved. Currently, there are at least five groups which promulgate rules governing the transport of radioactive material. These are the DOT, NRC, Postal Service, DOE, and the States.

Of these agencies, the DOT and NRC are the primary ones issuing regulations based upon the standards developed by the International Atomic Energy Agency (IAEA).

The NRC and DOT share responsibility for the control of radioactive material transport based upon a Memorandum of Understanding (MOU).

In general, DOT regulations (49 CFR) are more detailed. They cover all aspects of transportation, including packaging, shipper and carrier responsibilities, documentation, and all levels of radioactive material from exempt quantities to very high levels.

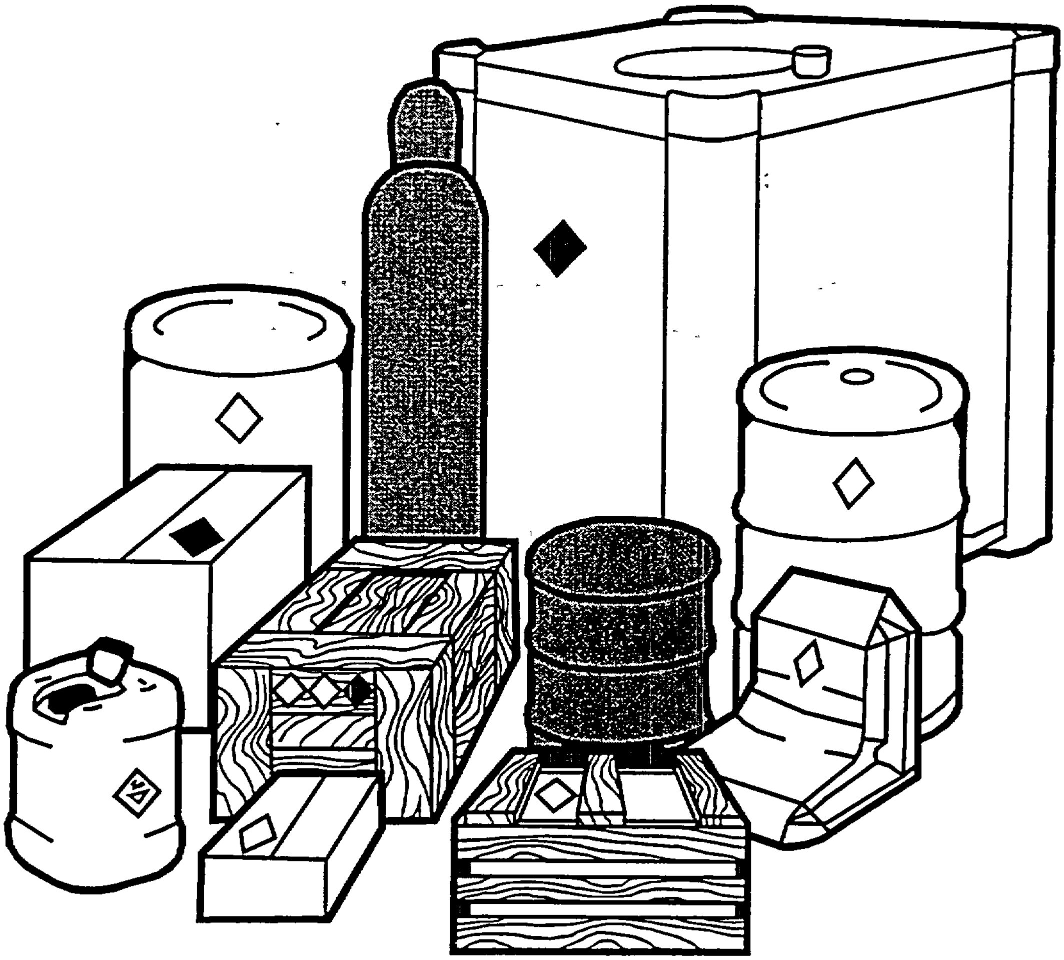
The NRC regulations (10 CFR 71) are primarily concerned with special packaging requirements for higher level quantities. NRC regulation 10 CFR 71.5 requires NRC licensees transporting radioactive material to comply with DOT regulations when NRC regulations do not apply.



For transportation purposes, radioactive material is defined as any material which has a specific activity greater than 0.002 microcuries per gram. This definition does not specify a quantity, only a concentration. As an example, pure cobalt-60 has a specific activity of 1,000 curies per gram, which is about 500 billion times greater than the definition. However, uranium-238 has a specific activity of only 0.3 microcuries per gram, which is only 150 times greater than the definition.

Although both exceed the definition of radioactive material in their pure form, either of these materials could be uniformly mixed with enough substance, such as dirt, which would cause the concentration to fall below the definition. In the case of uranium-238, if one gram were mixed with about 150 grams of dirt (about 1/3 of a pound), the concentration could be classified as non-radioactive.

Remember, however, that the definition of radioactive material above only applies for transportation.



Since transport accidents cannot be prevented, the regulations are primarily designed to:

- Insure safety in routine handling situations for minimally hazardous material and
- Insure integrity under all circumstances for highly dangerous materials.

These goals are accomplished by focusing on the package and its ability to:

- Contain the material (prevent leaks),
- Prevent unusual occurrences (such as criticality), and
- Reduce external radiation to safe levels (provide shielding).

Packages

Strong Tight Container
Type A Packages
Type B Packages

The three basic types of packages are strong tight containers, whose characteristics are not specified by regulation, followed by Type A containers, and finally Type B containers, both of which have very specific requirements in the regulations.

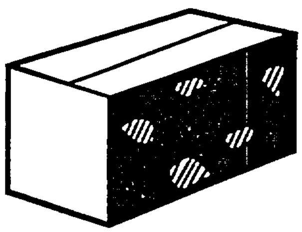
A strong tight container is designed to survive normal transportation handling. In essence, if the material makes it from point X to point Y without being released, the package was a strong tight container.

A Type A container, on the other hand, is designed to survive normal transportation handling and minor accidents.

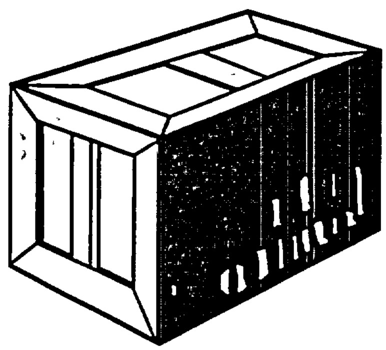
Type B containers must be able to survive severe accidents.

Fissile materials, which could be involved in a criticality accident, also have additional requirements.

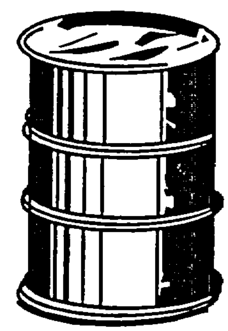
Type A



FIBERBOARD BOX



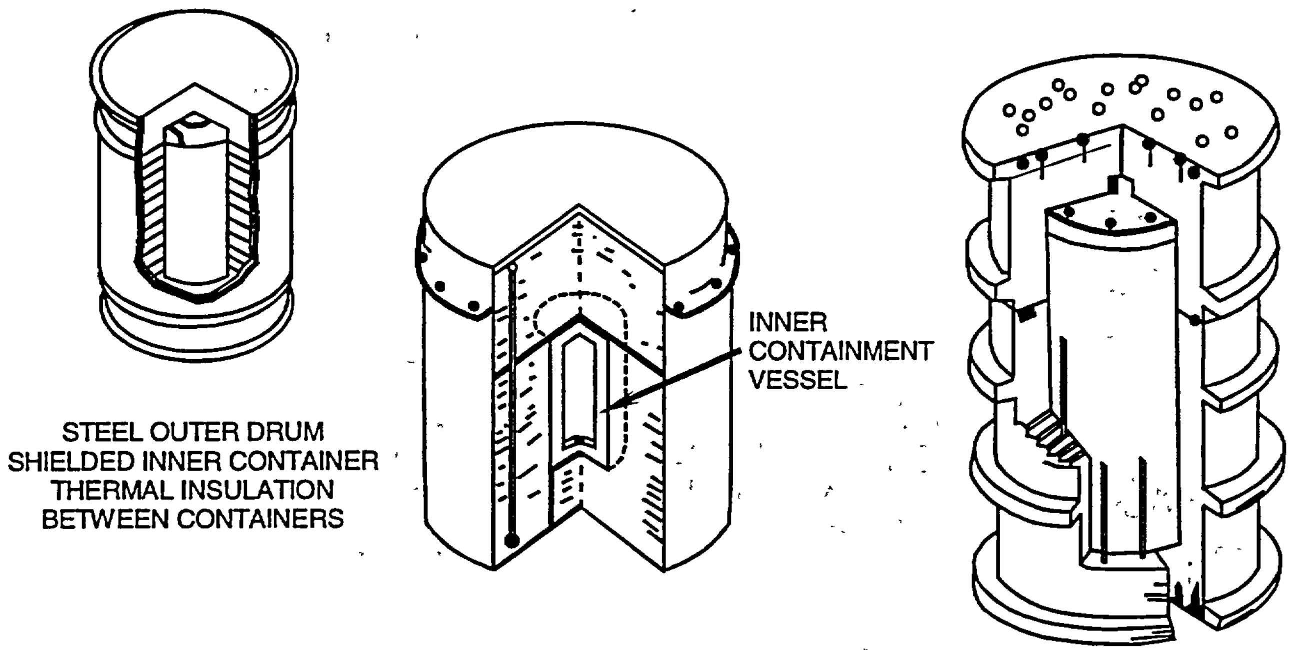
WOODEN BOX



STEEL DRUM

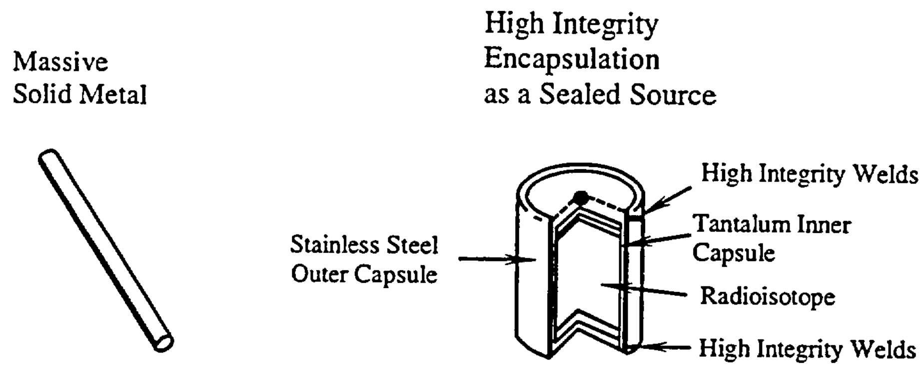
Type A packaging is based on performance requirements which means it must withstand or survive certain tests. The shape of the package or material from which it is constructed is irrelevant. A Type A package may be a cardboard box, a wooden crate, or a metal drum. The shipper must have documentation which shows that the specific design being used has passed the required tests.

Type B

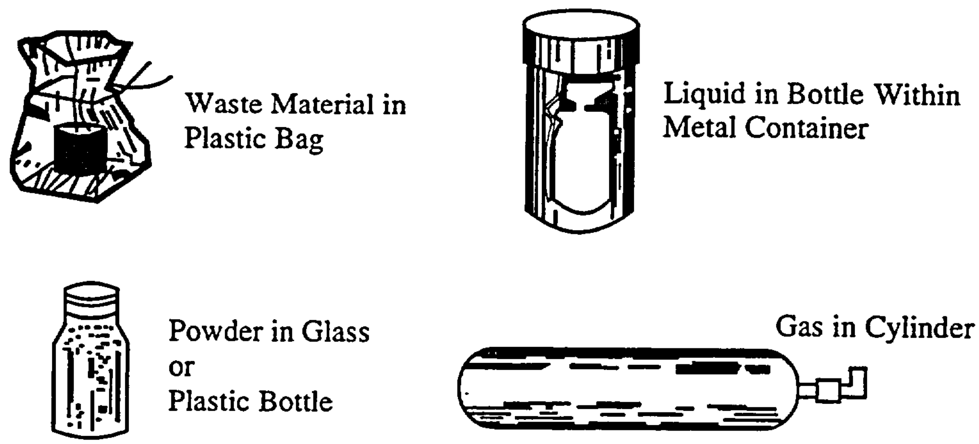


A Type B package may be a metal drum or a huge, massive shielded transport container. Like Type A packages, Type B packages must pass certain tests. However, the Type B tests are considerably more rigorous than those required for Type A packages. Most Type B packages have been issued a Certificate of Compliance by the NRC.

Special Form



Normal Form



The system created to ensure safe transport of radioactive materials is based on the assignment of a number to each radionuclide, depending upon its form (i.e., its relative hazard if released from the package during transport). The number, or "A" value, represents the limit, in curies, permitted to be transported in a Type A package. There are two distinct categories established for this system.

Special form (A_1) radionuclides are usually encapsulated sources which would only pose an external radiation hazard, not a contamination hazard, if the package was ruptured.

Normal form (A_2) radionuclides are usually not securely encapsulated and could yield significant contamination if the package was ruptured. These materials could pose an internal hazard to people at the scene of an accident. Normal form materials are typically liquids and powders.

Since the "A" values provide the limit for the amount in a package, A_2 values cannot be greater than A_1 values, since A_2 values represent material in normal form, which makes it more "hazardous." However, for some nuclides, the hazard may be the same in either form so that A1 can be equal to A2. In any case, neither A_1 nor A2 can be greater than 1000 curies.

Sample "A" Values (curies)

Material	Special Form A_1 Values	Normal Form A_2 Values	Ratio A_1/A_2
Plutonium-239	2	0.002	1,000
Strontium-90	10	0.4	25
Cobalt-60	7	7	1

When A_1 equals A_2, the hazard is considered the same, whether the material is in normal or special form. This tends to be the case for gamma emitters. For alpha emitters, the normal form (unencapsulated) is considered to be 1,000 times more hazardous as the special form (sealed), so that the A_1 values are about 1,000 times lower. Beta emitters fall between the two.

Quantity of Radioactive Material will determine Classification

Non-Radioactive
Limited
Type A
Type B
Highway Route Controlled

The manner in which radioactive material is handled for transport depends upon the amount of material and its relative hazard:

Non-Radioactive -	If the amount of material is less than 0.002 microcuries per gram, it is not considered radioactive for transportation purposes
Limited Quantity -	If the amount is greater than 0.002 microcuries per gram but does not exceed one thousandth of the A_1 or A_2 value (depending on the form), then the material is considered a limited quantity and needs only a strong tight container, which should survive routine handling.
Type A Quantity -	If the amount is less than or equal to the A_1 or A_2 value (depending on the form) but greater than one thousandth of the value, then the material requires a Type A package, which should survive minor accidents.
Type B Quantity -	If the amount is greater than the A_1 or A_2 value (depending on the form) but less than or equal to 3000 times these values, then the material requires a Type B package, which should survive a serious accident.
Highway Route Controlled Quantity -	If the amount is greater than 3000 times the A1 or A2 value (depending on the form) but less than 27,000 curies, then the material is a highway route controlled quantity, which requires a Type B package, and the carrier must have special training. State officials must be notified if the material is radioactive waste.

UNITED STATES
POSTAL SERVICE®

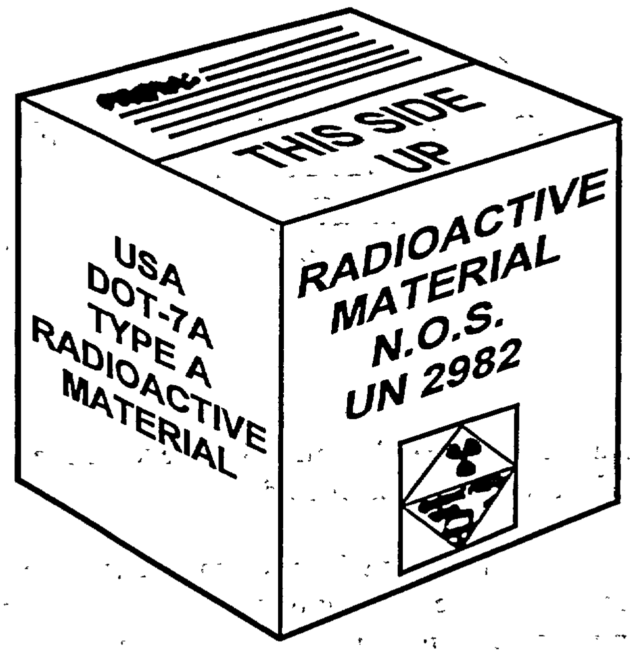
The postal service has slightly different limits. They will only accept packages containing limited quantities, i.e., with amounts small enough such that they require only a strong tight package. Quantities requiring Type A and Type B packages are not acceptable to the postal service. To provide an additional safety margin, the postal service defines limited quantities differently from DOT. The USPS limits are lower, exactly one tenth of the DOT limits. In addition, the postal service has separate limits for liquids and gases.

Low Specific Activity Material

A special classification, low specific activity, is given to any radioactive material which is uniformly dispersed throughout a substance to such an extent that it poses little hazard even if released in an accident. To be classified as low specific activity, the concentration must be greater than 0.002 microcuries per gram (otherwise it would not be radioactive) but less than specified concentration limits, which are based on the "A" values.

Although the concentrations permitted are low (300 microcuries per gram or less), the total amount of material may be quite high, depending upon how much total mass there is. Therefore, although the definition of low specific activity considers only the concentration, not the total quantity, the type of package required for the low specific activity material (either strong tight container or Type A) will depend upon the total quantity of activity (curies) rather than the concentration (microcuries/gram).

Markings



Markings are designed to provide an explanation of the contents of a package by using standard terms and codes.

Labeling

Labels are used to visually indicate the type of hazard and the level of hazard contained in a package. Labels rely principally on symbols to indicate the hazard.

Although the package required for transporting radioactive material is based on the activity INSIDE the package, the label required on the package is based on the radiation hazard OUTSIDE the package. Radioactive material is the only hazardous material which has three possible labels, depending on the relative radiation levels external to the package. Also, labels for radioactive material are the only ones which require the shipper to write some information on the label. The information is a number called the Transport Index (TI), which, in reality, is the highest radiation level at 1 meter from the surface of the package.

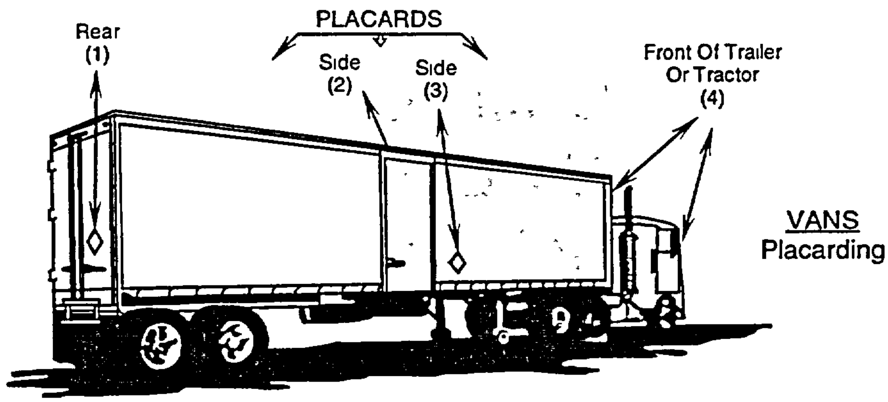
The three labels are commonly called, White 1, Yellow 2, and Yellow 3, referring to the color of the label and the roman numeral prominently displayed. A specific label is required if the surface radiation limit and the limit at 1 meter satisfy the following requirements:

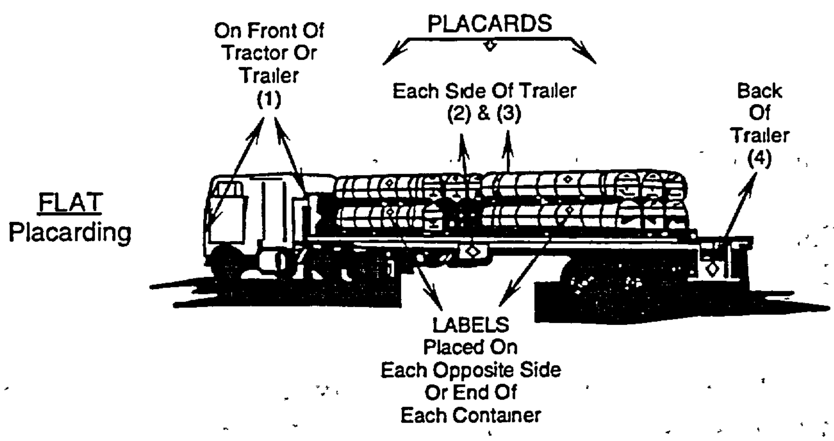
Label	Surface Radiation Level		Radiation Level at 1 Meter
White 1	Does not exceed 0.5 millirem/hour		Not applicable
Yellow 2	Does not exceed 50 millirems/hour	AND	Does not exceed 1 millirem/hour
Yellow 3	Exceeds 50 millirems/hour	OR	Exceeds 1 millirem/hour

Since the TI is the radiation level at 1 meter, it is clear that a White 1 label has no TI. A Yellow 2 must have a TI no greater than 1, and a Yellow 3 may have a TI greater than 1.

Referring to the radiation limits on page 11-19 for vehicles, it can be seen that the maximum TI for nonexclusive use vehicles (common carriers) and for exclusive use (contract carriers) open vehicles is 10. The radiation level at 1 meter from the surface of a package can exceed 10 mrem/hour only if the package is transported in an exclusive use (contract carrier), closed vehicle.

Placarding





Placards are just bigger labels which are placed on the outside of the vehicle. Unlike labels, there is only one placard and no information needs to be written on it (i.e., no TI). In fact, a placard on a vehicle is only required if the vehicle is carrying a package bearing a Yellow 3 label or low specific activity material. If the amount of material being transported constitutes a highway route controlled quantity, the diamond-shaped placard has a black square border surrounding it.

Carriers:

Common
Contract
Private

There are essentially three classes of carriers:

- Common,
- Contract, and
- Private.

Common and contract carriers provide a service to others. They carry other peoples' materials. Common carriers have published rates for hauling material, while contract carriers negotiate a specific contract with the shipper. Common and contract carriers are not licensed by the NRC. The responsibility for safety rests with the shipper.

Private carriers own the radioactive material which they carry. The transport of material is accomplished in direct support of the radioactive material user's business. These carriers are licensed by the NRC.

Some examples of private carriers who transport their sources from one job site to another are:

- Industrial radiographers,
- Portable gauge users, and
- Well loggers.

In addition to the above, radiopharmacies deliver their own radiopharmaceuticals to nuclear medicine clinics.

Radiation Limits

Type of Transport	Maximum Radiation Limit
Common carrier non-exclusive use:	
Open or closed transport	200 millirems/hour on the surface of the package and 10 millirems/hour at 1 meter from any surface of the package
Contract carrier exclusive use:	
Closed transport	1000 millirems/hour on the surface of the package, 200 millirems/hour at the surface of the vehicle, 10 millirems/hour at 2 meters from any surface of the vehicle, and 2 millirems/hour in the vehicle cab
Open transport	200 millirems/hour on the surface of the package, 200 millirems/hour on any imaginary surface of the vehicle, 10 millirems/hour at 2 meters from any imaginary surface of the vehicle, and 2 millirems/hour in the cab of the vehicle

For non-exclusive use vehicles, that is, vehicles which may be carrying other non-radioactive material as well (common carriers), the radiation limit is imposed on the package.

For exclusive use vehicles, that is, the vehicle is only carrying radioactive material for one shipper (contract or private carrier), the package limits are higher, but there are also limits on the outside of the vehicle.

Shipping Papers

SHIPPER'S CERTIFICATION FOR RADIOACTIVE MATERIALS

Two completed and signed copies of this certification shall be handed to the carrier
(Use block letters)

WARNING Failure to comply in all respects with the applicable regulations of the Department of Transportation, 49-CFR, CAB 82 and, for international shipments the IATA Restricted Articles Regulations may be a breach of the applicable law, subject to legal penalties This certification shall in no circumstances be signed by an IATA Cargo Agent or a consolidator for international shipments.

This shipment is within the limitations prescribed for (mark one)
X passanger aircraft cargo-only aircraft

NATURE AND QUANTITY OF CONTENT					PACKAGE			
PROPER SHIPPING NAME	RADIONUCLIDE	GROUP	FORM	ACTIVITY		CATEGORY	TRANSPORT INDEX	TYPE
FOR US SHIPMENTS SEE SECTION 2 CAB 82 TABLE 6-0	NAME OR SYMBOL OF PRINCIPAL RADIOACTIVE CONTENT	GROUP NUMBER OF GROUPS I TO VII	CHEMICAL FORM AND PHYSICAL STATE: GAS LIQUID SOLID or SPECIAL FORM or SPECIAL ENCAPSULATION	NUMBER OF CURIES OR MILLICURIES	NUMBER OF PACKAGES	I-WHITE OR II-YELLOW OR III-YELLOW LABEL	FOR YELOW LABEL CATEGORIES ONLY	INDUSTRIAL OR TYPE A OR TYPE B

ADDITIONAL INFORMATION REQUIRED FOR FISSILE MATERIALS ONLY

EXEMPTED FROM THE ADDITIONAL REQUIREMENTS FOR FISSILE MATERIALS SPECIFIED IN / 1 OF PART 2 OF THE IATA RESTRICTED ARTICLES REGULATIONS NAMES PLUS QUANTITY IN GRAMS OR CONCENTRATION OR ENRICHMENT IN U235

NOT EXEMPTED FISSILE CLASS I FISSILE CLASS II FISSILE CLASS III

Additional certificates obtained by the Shipper when necessary N/A

Special Form Encapsulation Certificate(s)
Type B Packaging Certificate(s)
Certificates for Fissile Material
Certificate(s) for Large Radioactive Source
Government Approvals / Permits

Special Handling Information

NONE

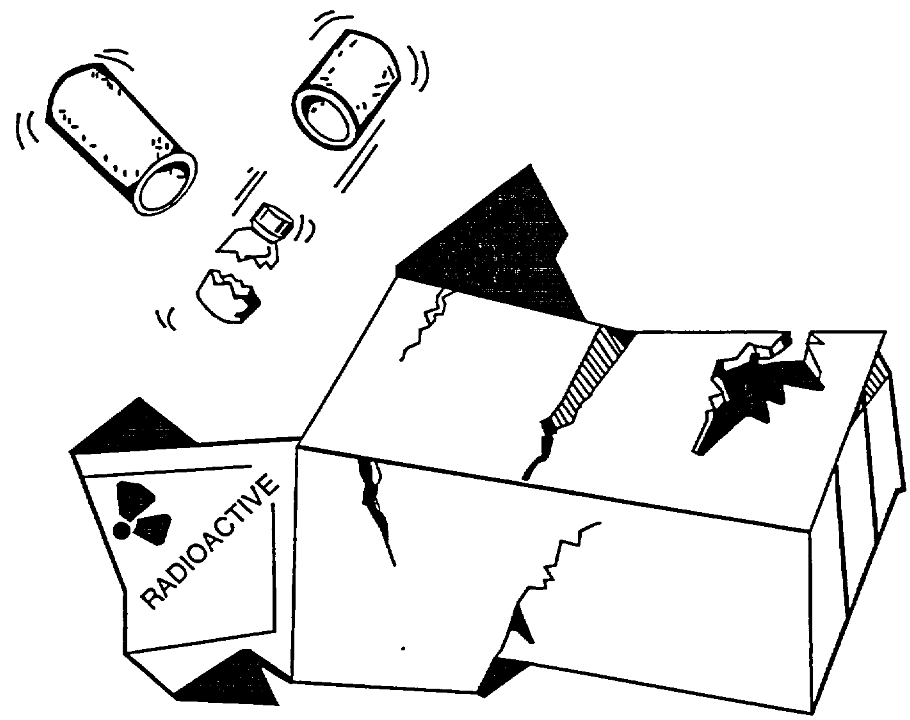
I hereby certify that the contents of this consignment are fully and accurately described above by Proper Shipping Name and are classified packed, marked, labeled and in proper condition for carriage by air according to applicable national governmental regulations, and for international shipments, The current IATA Restricted Articles Regulations.

Name and full address of Shipper	Name and title of person signing Certification
Date	Signature of the Shipper (see WARNING above)

Air Waybill No:	Airport of Departure:	Airport of Destination

The only way for anyone to know what is being transported inside a vehicle is by reviewing the shipping papers. These documents, by words and codes, clearly specify what is being transported. They must be readily accessible to the driver and to emergency response personnel, if the driver is not available.

Accidents



Many packages containing radioactive materials have been involved in transport accidents. The statistics verify the degree of protection expected of each class of packaging.

For strong tight containers, which do not have to pass any integrity tests, about 10% of those involved in accidents have failed. Of those, about 90% have released their contents.

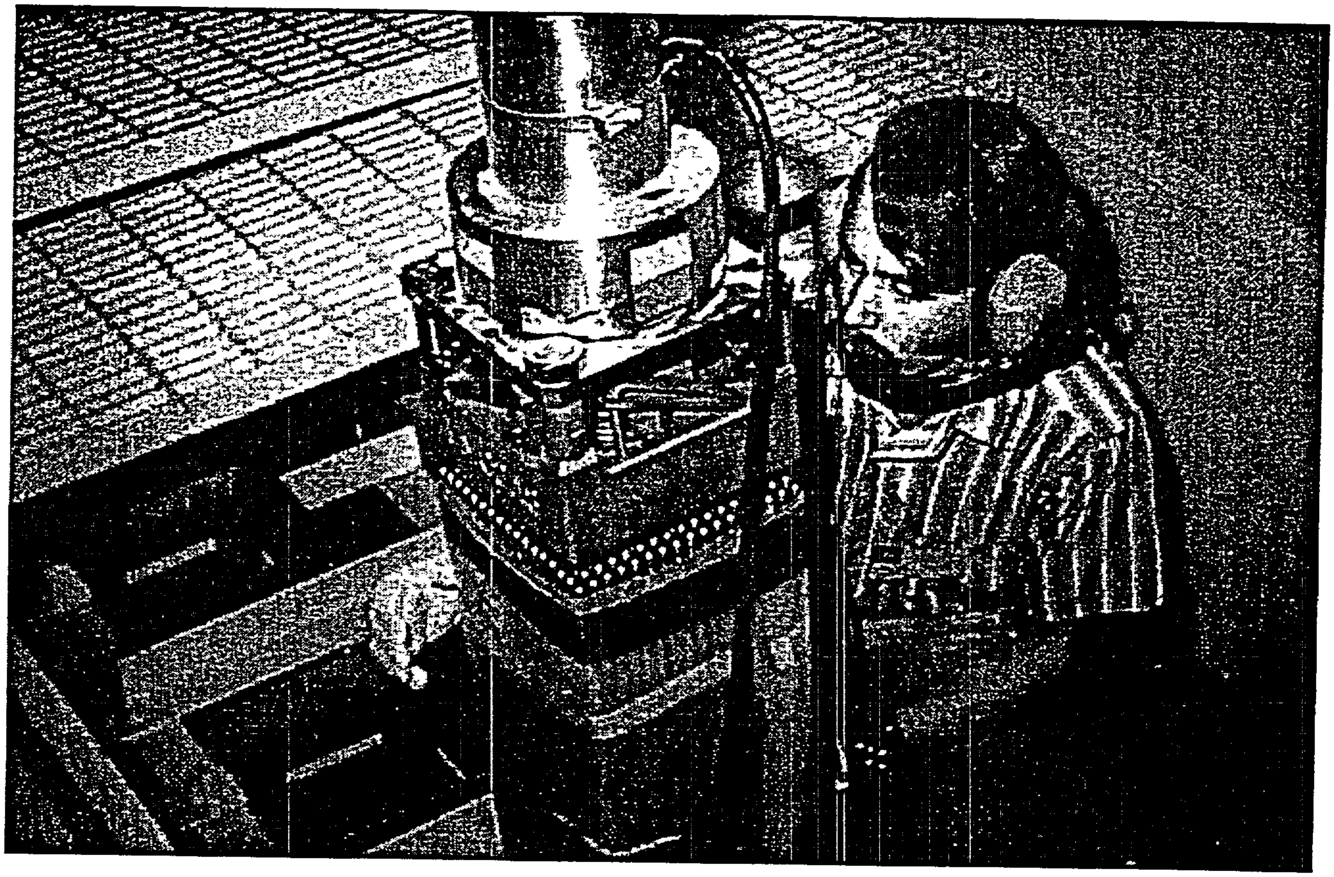
For Type A packages, which must pass stringent tests, only 1% of those involved in accidents have failed. Of those, only 39% have released their contents.

For Type B packages, which must pass the most rigorous tests, several have been involved in accidents. However, there has been only one documented case of a package failure, and that involved an industrial radiography source.

Refueling Operations

A reactor core is designed to operate at its full power output for a period of 12 to 24 months. After this time period, the reactor must undergo a refueling operation, or sometimes called a "fuel shuffle." During refueling, one third of the core will be replaced with fresh fuel, and the remaining two thirds will be repositioned.

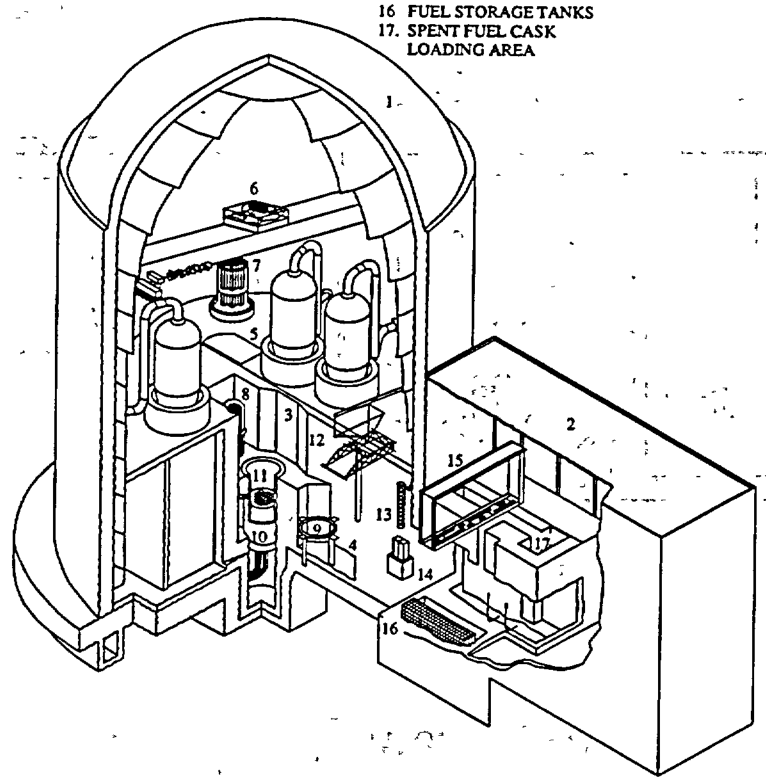
This section will describe some of the basic processes involved in the refueling process for a Westinghouse pressurized water reactor.



New Fuel Storage

Long before the actual refueling process takes place, plans are made for the refueling outage. The new fuel must be ordered, manpower considerations must be taken into account, and any other known maintenance to be performed during the outage is scheduled. Some period of time before the refueling is to occur, the new fuel is received onsite. The new fuel will be inspected and then stored in the new fuel storage area.

The new fuel storage area is a dry storage vault in the fuel handling building. Dry storage is sufficient because the fuel has not been used for power production. Therefore, there are no fission products to generate heat, and the radiation levels around the fuel are only slightly above background levels.

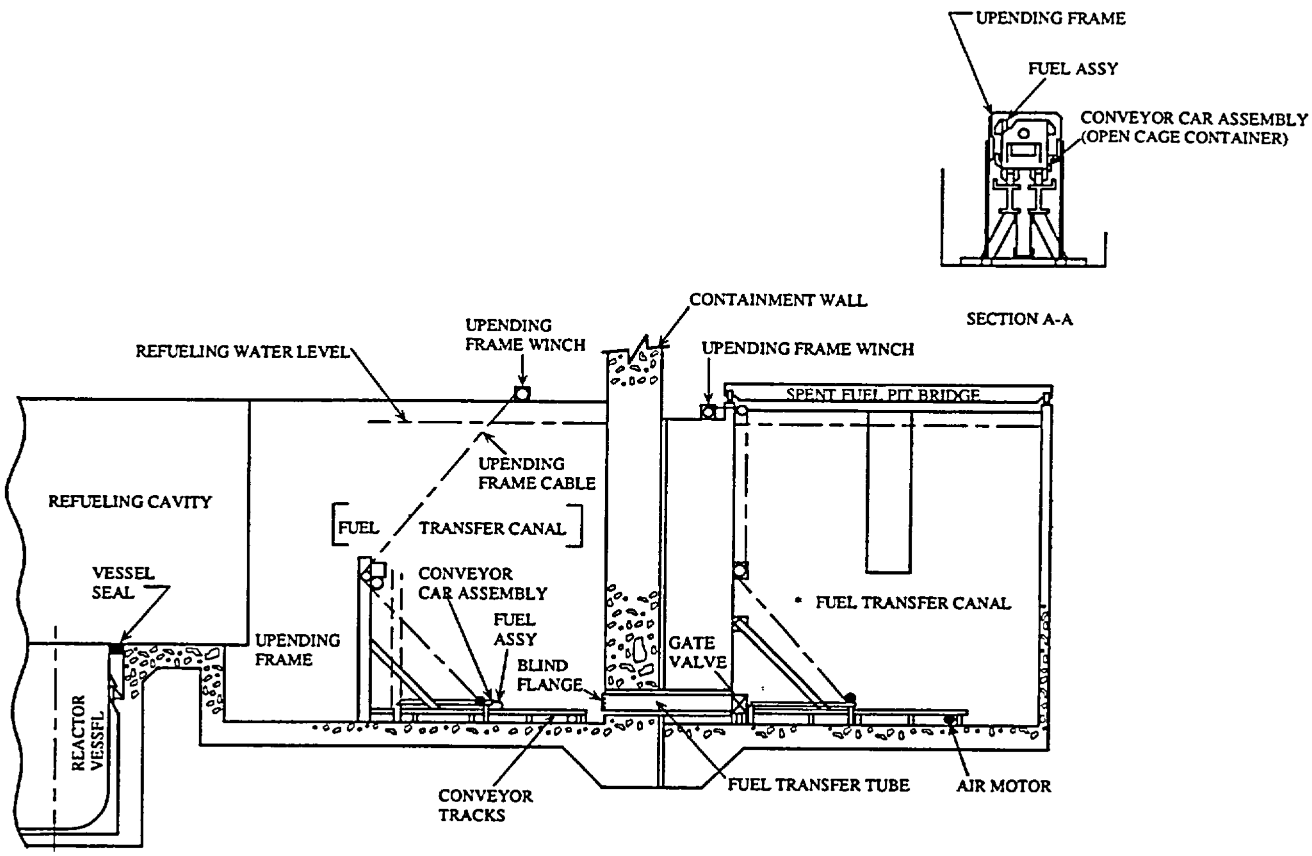


Fuel Handling Arrangement

When it is time to perform the refueling, the reactor is shutdown and cooled down. This is necessary to allow access to the vessel area and to allow the disassembly of the vessel. At this time, the fuel handling equipment will be tested to ensure proper operation.

After the plant is cooled down to the proper temperature and depressurized, the disassembly of the reactor will commence. First, all of the cables, ventilation ducts, cable trays, and insulation must be removed. Then, a seal must be installed between the reactor vessel and the reactor cavity wall (shown in the figure on page 12-4). This is due to the flooding of the cavity that will occur to perform the refueling. The seal will prevent any water from leaking down into the vessel cavity area.

To transfer the fuel from the containment to the fuel building and vice versa, the fuel transfer tube must be opened up. This is done by removing a blind flange (solid cover) from the end of the transfer tube in the containment. After the refueling cavity is flooded, a valve will be opened in the fuel building to open up the transfer path. The flange and the valve are shown in the figure on page 12-4.

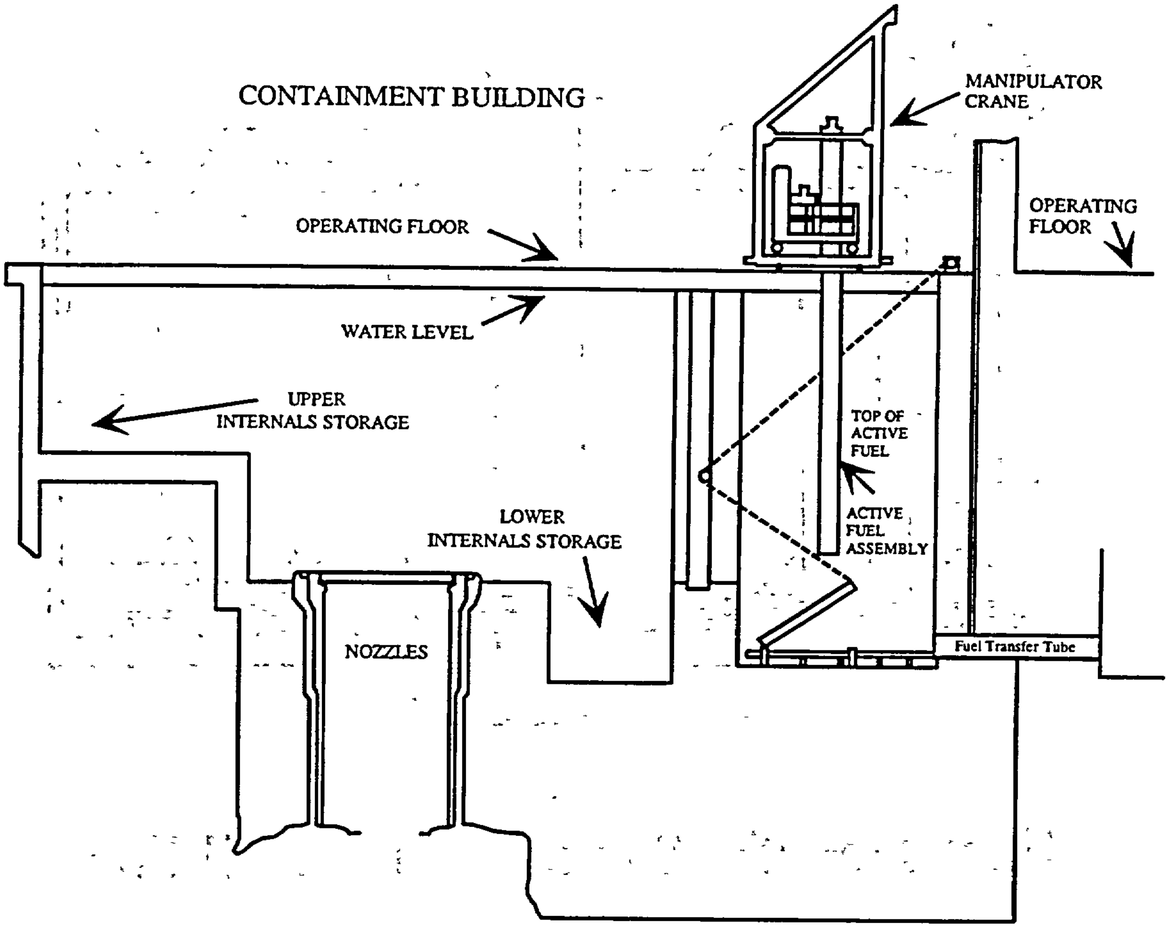


Fuel Transfer System

The studs that hold the vessel head on the reactor vessel are now removed. Guide studs are installed to provide points of alignment when removing and installing the vessel internals. Except for the three guide studs, the remaining stud holes are filled with plugs to protect the stud threads from the borated water. The vessel head is now removed to dry storage inside the containment. To move the head, and the other heavy components, there is an overhead crane installed inside the containment (called the polar crane).

The flooding of the refueling cavity may now commence. The cavity is flooded by pumping water from the refueling water storage tank, through the residual heat removal pumps, and into the reactor coolant system, where it will enter the reactor vessel and overflow into the cavity. The water level will be increased to a minimum of approximately 25 feet above the reactor vessel flange.

After the cavity is flooded, the upper internals must be removed. Prior to their removal, the control rod drive shafts must be disconnected from the control rods (to prevent pulling the control rods out of the fuel when the upper internals are pulled). The shafts are disconnected using a special tool. When all of the shafts are disconnected, the upper internals package is removed and stored underwater, as shown in the figures on pages 12-2 and 12-5. Fuel shuffling may now commence.



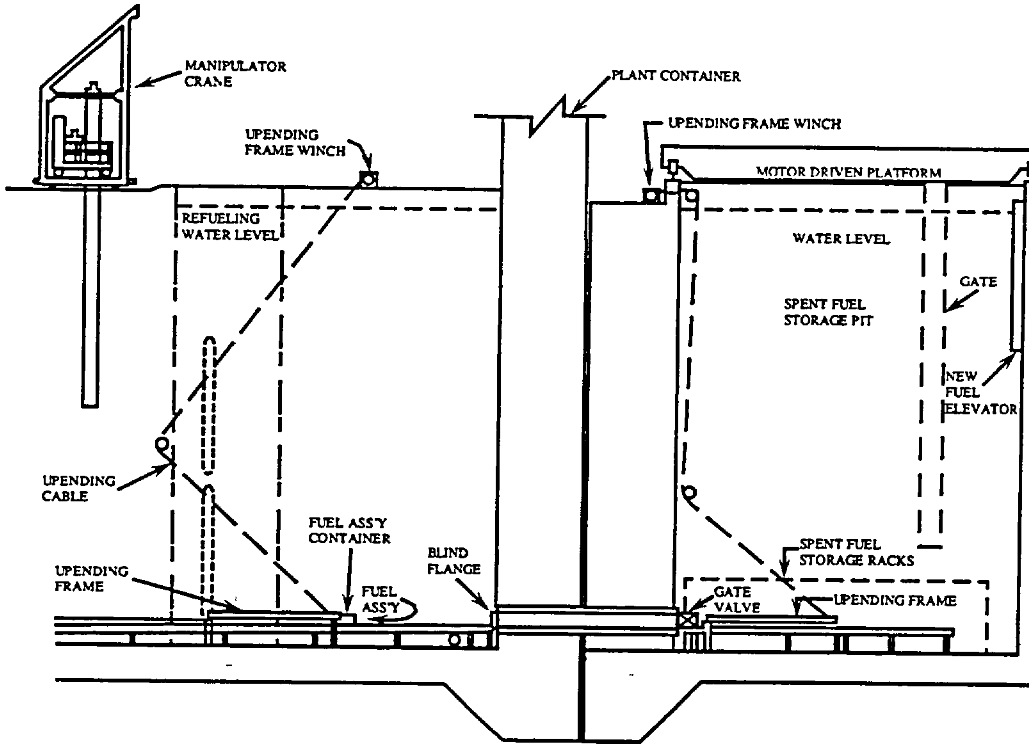
Fuel Transfer System - Containment

Before a new fuel assembly can be placed into the core, an old assembly must be removed. The manipulator crane is used to move fuel. The crane has a protective mast (cover) that surrounds the fuel assembly during movement. The manipulator crane will take the fuel to the control rod change fixture or to the area where it can be transferred to the spent fuel pool in the fuel building.

At the control rod change fixture, the control rod can be removed from the spent fuel assembly and inserted into the new fuel assembly that is going to be placed into the reactor.

When ready to be sent to the spent fuel pool, the fuel assembly is placed into the conveyor car assembly. The conveyor car is used to transport the fuel assembly to and from the fuel handling building and the containment.

The conveyor car will be in the upender. The upender is used to lower the conveyor car from the vertical position to the horizontal position. This must be done to move the conveyor car and fuel assembly through the fuel transfer tube. A second upender in the fuel handling building will raise the conveyor car back to the vertical position.



Fuel Transfer System - Fuel Building

The spent fuel pool bridge crane is used to move the fuel assemblies from the conveyor car in the upender to a storage location in the pool. A new fuel assembly can now be sent to the reactor.

In order for a new fuel assembly to be transferred to the containment, it must first be placed into the spent fuel pool using the fuel building crane and the new fuel elevator. From the fuel pool, the spent fuel bridge crane will take the assembly and place it into the conveyor car on the upender. The upender will lower the conveyor car and fuel assembly to the horizontal position to be sent through the fuel transfer tube to the containment. The upender in the containment will raise the fuel assembly and conveyor car to the vertical position, where the manipulator crane will pick up the fuel assembly and transfer it to its proper position in the core. The movement of fuel will continue until all fuel assemblies are in their proper location. Upon the completion of the fuel shuffle, a record is made of all fuel assemblies and their location in the core. Even though a refueling outage may last two months or more due to maintenance work, the fuel shuffling process usually takes less than a week.

The reassembly of the reactor can now commence. The reassembly process is the reverse of the disassembly process.

Instead of a fuel shuffle, some plants perform a full core offload. That is, they take all of the fuel out of the reactor vessel and place it in the spent fuel pool. In the spent fuel pool, special tools are used to transfer any fuel assembly inserts (control rods, thimble plugs, etc.) to new fuel assemblies. One major advantage of a full core offload is several Technical Specifications do not have to be met.

Emergency Classification Levels

This chapter covers the different emergency action levels which can be declared by a plant's emergency action plan (10 CFR 50, Appendix E). If an event occurs at a nuclear power plant, from a simple valve failure to the loss of the fission product barriers, the emergency action plan will provide guidance on event classification. The purpose of an Emergency Action Level (EAL) is to trigger the declaration of an emergency classification level (ECL), which, in turn, triggers a certain level of emergency response. Depending upon the severity of the event, the emergency plan will trigger the declaration of an emergency classification level as an UNUSUAL EVENT, an ALERT, a SITE EMERGENCY, or a GENERAL EMERGENCY.

EMERGENCY CLASSIFICATION LEVELS

(in order of increasing severity)

UNUSUAL EVENT

ALERT

SITE AREA EMERGENCY

GENERAL EMERGENCY

The emergency action levels have been established to provide prompt notification to the proper authorities of both minor and major events. Depending upon the severity of the event, the actions taken could range from notifying the Nuclear Regulatory Commission to the staffing of the emergency response facilities and the notifying of local, state, and federal agencies.

INITIATING CONDITIONS FOR UNUSUAL EVENTS:

Aircraft/train crash onsite
Tornado onsite or any hurricane
Earthquake felt onsite or detected
Fire lasting longer than 10 minutes
High reactor coolant system activity
Security threat (unauthorized entry of individuals)
Shutdown required by plant Technical Specifications
Abnormal reactor coolant temperature and/or pressure
Explosion onsite (no effect on safety related equipment)
Contaminated, injured person requiring offsite transport
Emergency core cooling system actuation and discharging

UNUSUAL EVENTS are minor events which have occurred, or are in progress, which indicate a potential for degradation of the level of safety of the plant. No releases of radioactive material requiring offsite response or monitoring are expected unless further degradation of safety systems occurs. The specific onsite and offsite agencies that are activated/notified will be determined by the plant specific action plan. For example, assistance could be requested of the local law enforcement officers, local fire department, or local hospital.

The purposes of this emergency classification are to:

a) Assure that the first step in any response later found to be necessary has been carried out,
b) Bring the operating staff to a state of readiness, and
c) Provide systematic handling of unusual event notification and decision making.

INITIATING CONDITIONS FOR ALERT:

Fuel handling accident
Excessive primary leakage
Tornado striking the facility
Loss of all onsite DC power
Severe damage to fuel cladding
Inability to shutdown the reactor
High radiation levels in the plant
Failure of a reactor coolant pump
Earthquake greater than OBE levels
Fire (does have an effect on safety systems)
Security threat (penetration of protected area)
Loss of offsite power and all onsite AC power

ALERT conditions are events which have occurred or in progress that involve actual or potential significant degradation in the level of safety of the plant. Minor releases of radioactive material are possible during the events associated with an ALERT, however, any release that occurs is expected to be a very small fraction of the allowed exposure levels. The specific onsite and offsite agencies to be notified/activated will be determined by the action plan. For example, the onsite technical support center will be activated, the Nuclear Regulatory Commission will be notified, and certain state organizations will be notified and will respond, if needed.

The purposes of this emergency classification are to:

a. Assure that emergency personnel are readily available to respond if the situation warrants,
b. Perform confirmatory radiation monitoring if required, and
c. Provide offsite agencies with current information.

INITIATING CONDITIONS FOR SITE AREA EMERGENCY:

High measured offsite doses
Earthquake greater than SSE
Station Blackout greater than 15 minutes
Toxic gas preventing access to vital areas
Loss of DC power for greater than 15 minutes
Unisolable steam break outside of containment
Loss of coolant greater than makeup capability
Security threat with imminent loss of plant control
Sustained winds or tornado greater than design levels
Core damage with potential loss of coolable geometry
Fire (compromises the functions of vital safety systems)
Loss of control room annunciators with transient in progress
Control room evacuation with no local control in 15 minutes

The declaration of a SITE AREA EMERGENCY implies events which are in progress or have occurred that involve actual or likely failure of plant functions needed for the protection of the public. The potential of significant releases of radioactive material exists, but these releases are not expected to exceed exposure limits (except possibly near the site boundary). Severe core damage has not occurred, but extensive offsite radiation monitoring and protective actions may be required. Many onsite and offsite agencies will be notified and activated. For example, the plant's emergency operations facility will be activated, the Federal Emergency Management Agency will be activated, and the public will be notified.

The declaration of a SITE AREA EMERGENCY will:

a. Assure that appropriate response centers are manned,
b. Assure that monitoring teams are dispatched,
c. Assure that personnel required for evacuation of near-site areas are available if needed,
d. Provide consultation with offsite authorities, and
e. Provide updates to the public through offsite authorities.

INITIATING CONDITIONS FOR GENERAL EMERGENCY:

Offsite doses of greater than 1 rem whole body or 5 rems to the thyroid at the exclusion area boundary

Loss of fuel cladding and reactor coolant system with a high potential for loss of containment

Loss of coolant accident with failure of the emergency core cooling systems to perform adequately

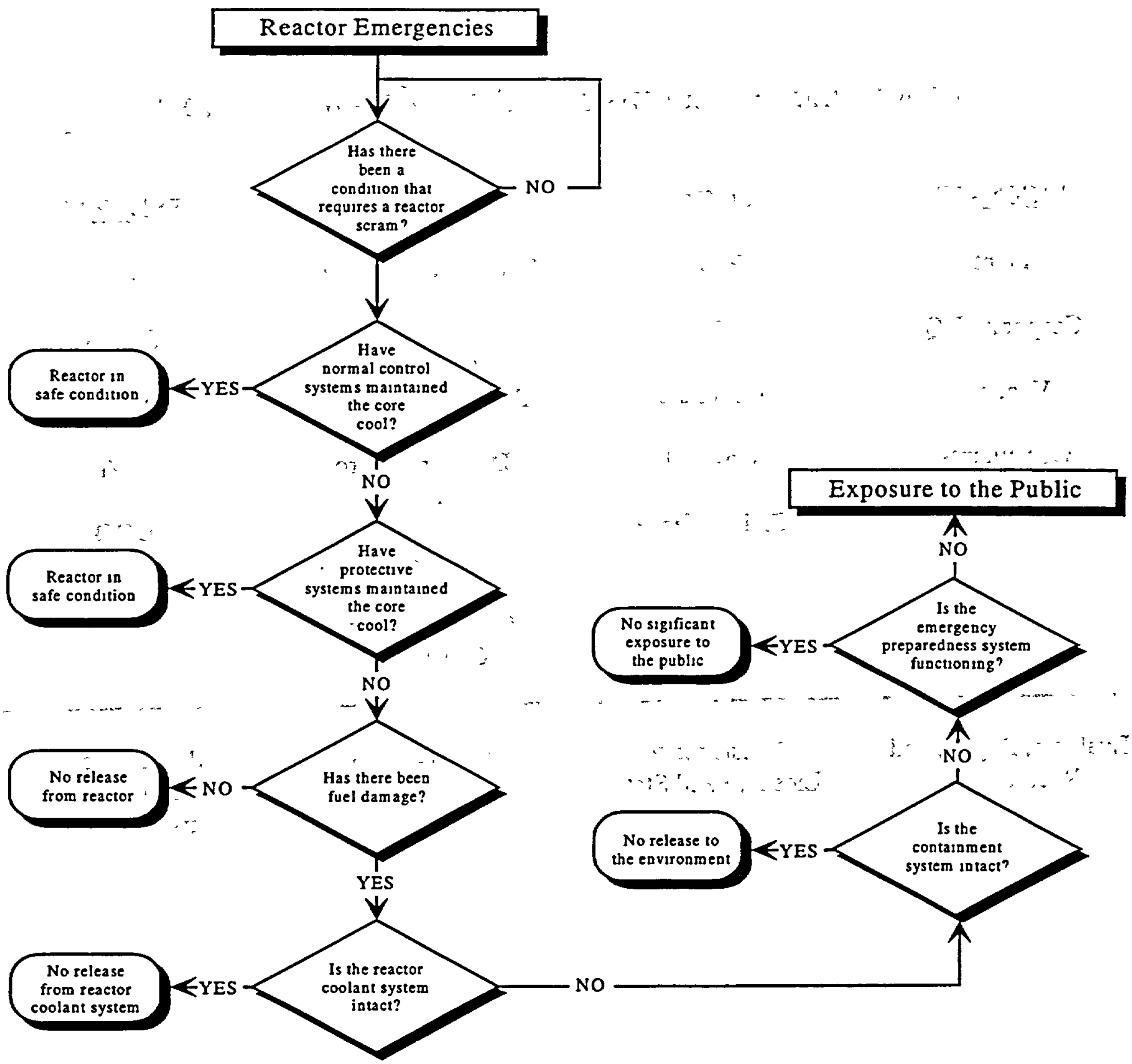
A physical attack on the plant that results in the loss of one or more vital areas

Complete loss of heat removal systems

The highest level of action is the GENERAL EMERGENCY. This classification is characterized by events in progress, or that have occurred, which involve actual or imminent substantial core damage with the potential for the loss of containment integrity. The release of radioactive material can be expected to exceed protective guidelines. Extensive offsite radiation monitoring, the projections of doses to the public, and other protective actions may be required. All onsite and offsite agencies are activated. The public will be notified and necessary protective measures (evacuation or taking of iodine pills, for example) shall be recommended.

The purposes of the GENERAL EMERGENCY are to:

a. Be prepared to initiate predetermined protective actions for the public,
b. Provide continuous dose assessment based upon available information,
c. Initiate additional measures as indicated by actual or potential releases,
d. Provide consultation with offsite authorities, and
e. Provide updates for the public through offsite authorities.



A common theme to all of these classifications is that with more severe damage to the fission product barriers and with a fewer number of safety systems available to counteract the accident, the higher the probability of a release to the public. The flowchart above demonstrates the combination of low probability failures that must occur in order to provide the flowpath for a significant release of fission products to the environment.

Emergencies may involve the following groups:

LICENSEE	LOCAL	STATE	FEDERAL
Plant	Police	Combined Emergency Operations Center	NRC
Corporate HQ	Fire	Division of Radiological Health	FEMA
Vendors	Ambulance	Disaster Control Agency	DOE
Consultants	Hospital	Other State Agencies	DOT
	Civil Defense	Laboratories and Consultants	DOD
			EPA
Evaluate, Repair, and Recommend	Assistance to Licensee and State	Lead Response Agency	Radiological, Technical, and Logistical Support

Depending upon the severity of the event, this chart shows some of the organizations that may be involved in responding to an emergency.

Federal Assistance Will Consist of:

Manpower
Heavy Equipment
Meteorological Data
Communication Facilities
Aerial Measurement Systems
Radiation Medical Specialists
Dispersion Computation Data
Radiochemical Analysis Facilities
Environmental Sampling Specialists
Radiation Monitoring/Assistance Personnel

These are examples of the types of assistance that could be expected from the Federal Government.

FEDERAL EMERGENCY RESPONSE TEAMS DO NOT:

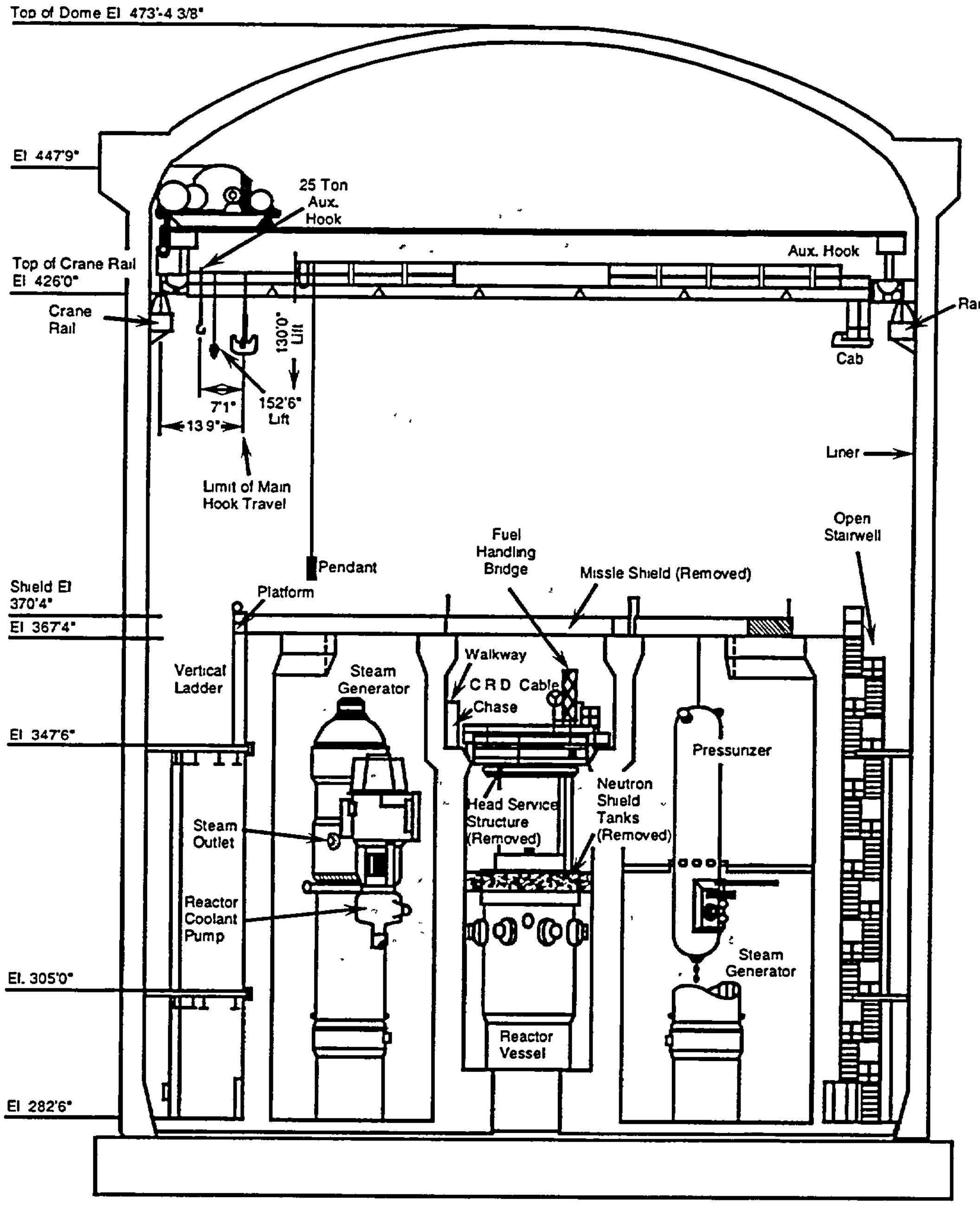
Direct overall emergency operations

Exercise control over private individuals or property

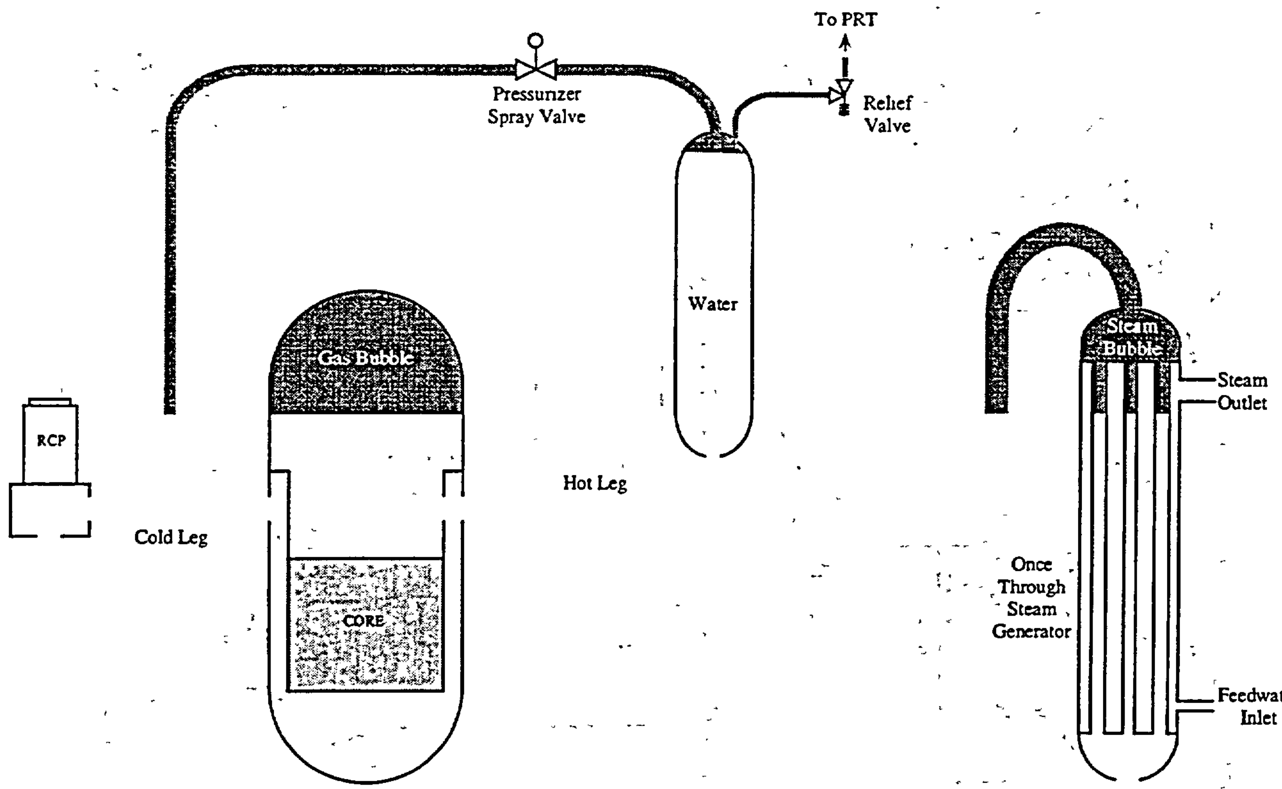
Relieve other organizations of their emergency responsibility

The Three Mile Island Accident

This section will provide a brief description of the accident at Three Mile Island Unit 2 that occurred on March 28, 1979. Also, the core damage and release of radioactive material will be discussed.

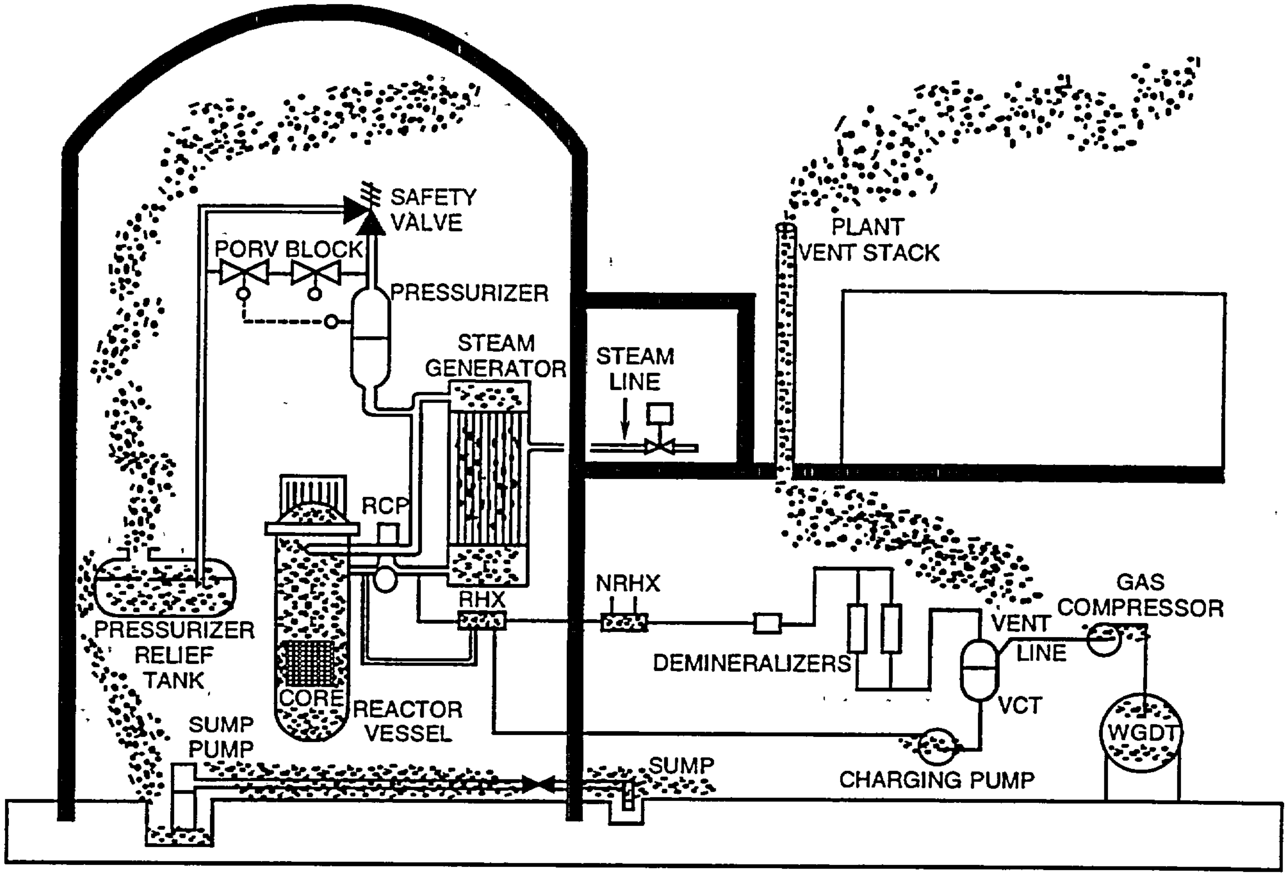


Three Mile Island is a Babcock & Wilcox design pressurized water reactor. The reactor coolant system consists of the reactor vessel, two steam generators, four reactor coolant pumps, and the pressurizer. The above figure shows the layout of the reactor coolant system inside the reactor building (containment).



Following a reactor trip, the pressurizer relief valve stuck open (shown above), causing a gradual loss of coolant pressure. Upon sensing the loss of coolant pressure, safety equipment automatically started, but was stopped in order to prevent the pressurizer from overfilling with water. Also, the amount of water being removed from the coolant system to the purification system was increased because of the high level in the pressurizer. The resultant low pressure and high temperature caused the coolant to boil. The low coolant pressure required the turning off of the reactor coolant pumps. With little or no cooling available to remove decay heat, the reactor fuel rods started to crack and break down due to the high temperatures. Some radioactive fission products (mostly gases such as xenon and krypton) were released into the coolant.

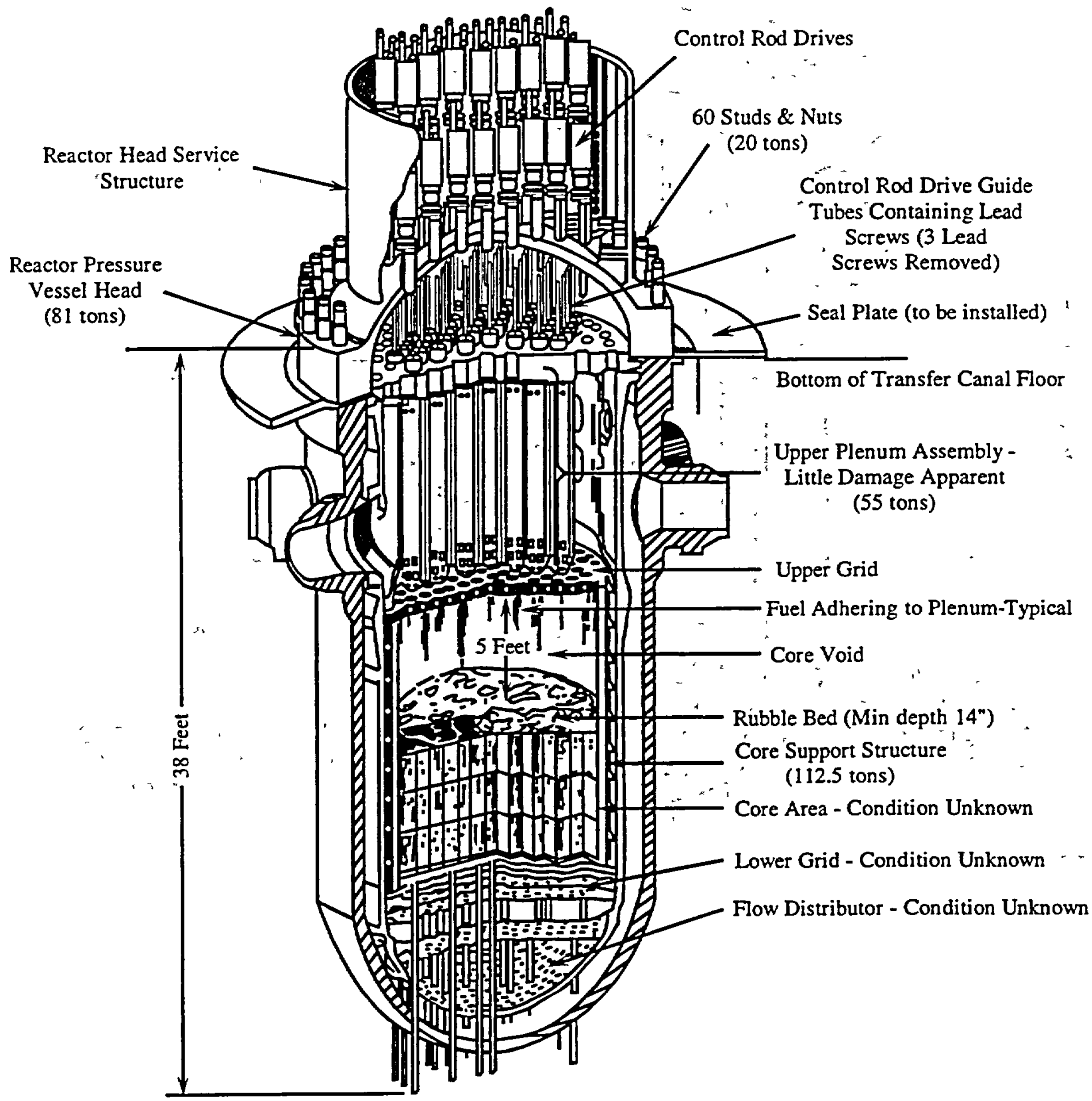
Later, the pressurizer relief valve was isolated, and reactor coolant pumps were restarted. The starting of the reactor coolant pumps caused cold water to be pumped onto the now very hot and very brittle fuel rods, causing severe core damage.



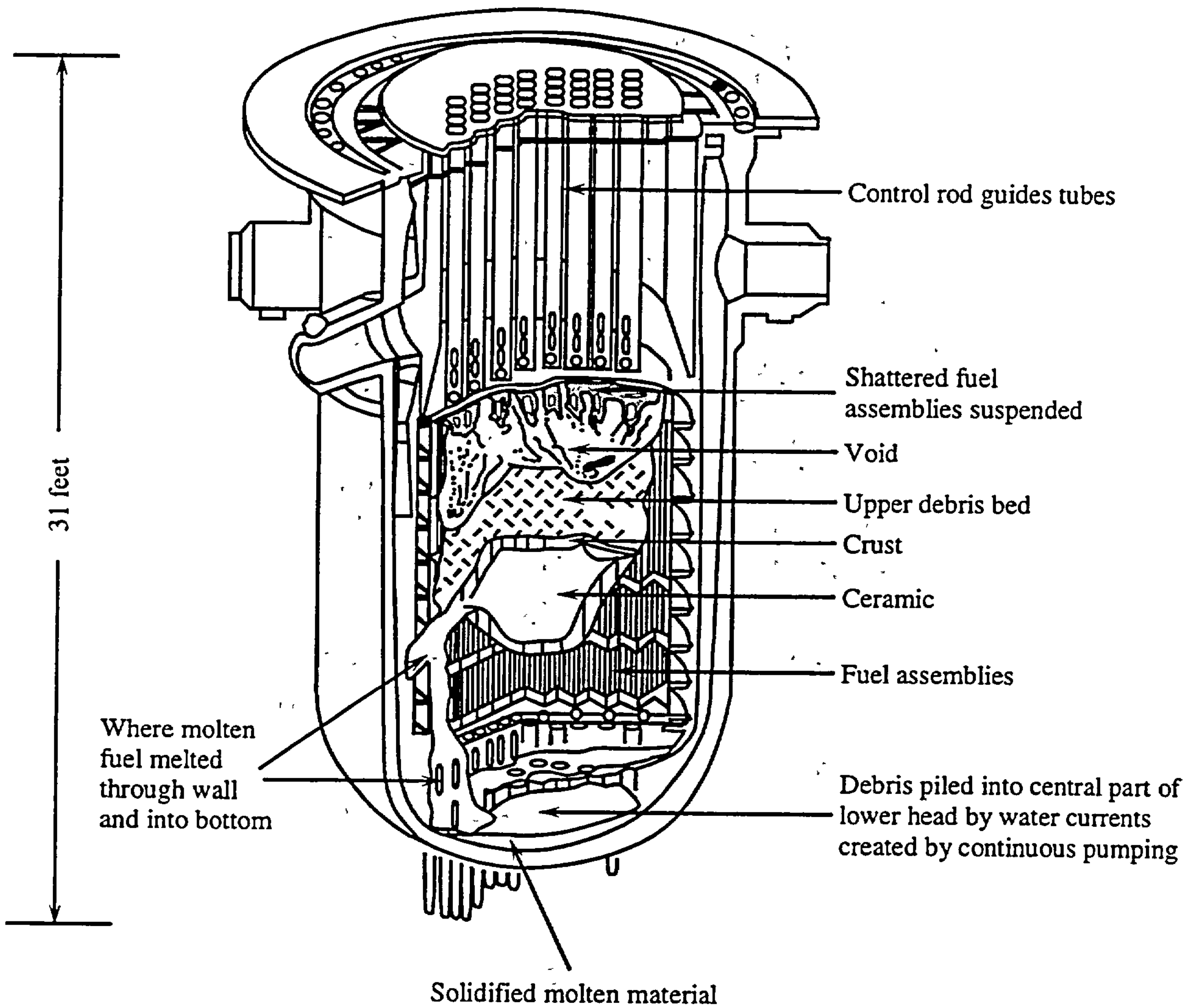
Fission products (mostly gases) escaped from the damaged reactor core into the reactor coolant system. Due to the stuck open pressurizer relief valve, the pressurizer relief tank pressure increased to the point of rupturing the rupture disk. The coolant was now being released into the containment building atmosphere. The coolant entering the containment was being collected in the sump. Upon reaching a high sump level, the sump pumps automatically started and pumped the water to the auxiliary building. The fission product gases in the coolant were picked up by the auxiliary building ventilation and blown out the plant stack.

The rupture of the pressurizer relief tank severely contaminated the containment. Also, due to the high concentration of fission products in the water from the containment sump and the water in the purification system, the auxiliary building had to be evacuated.

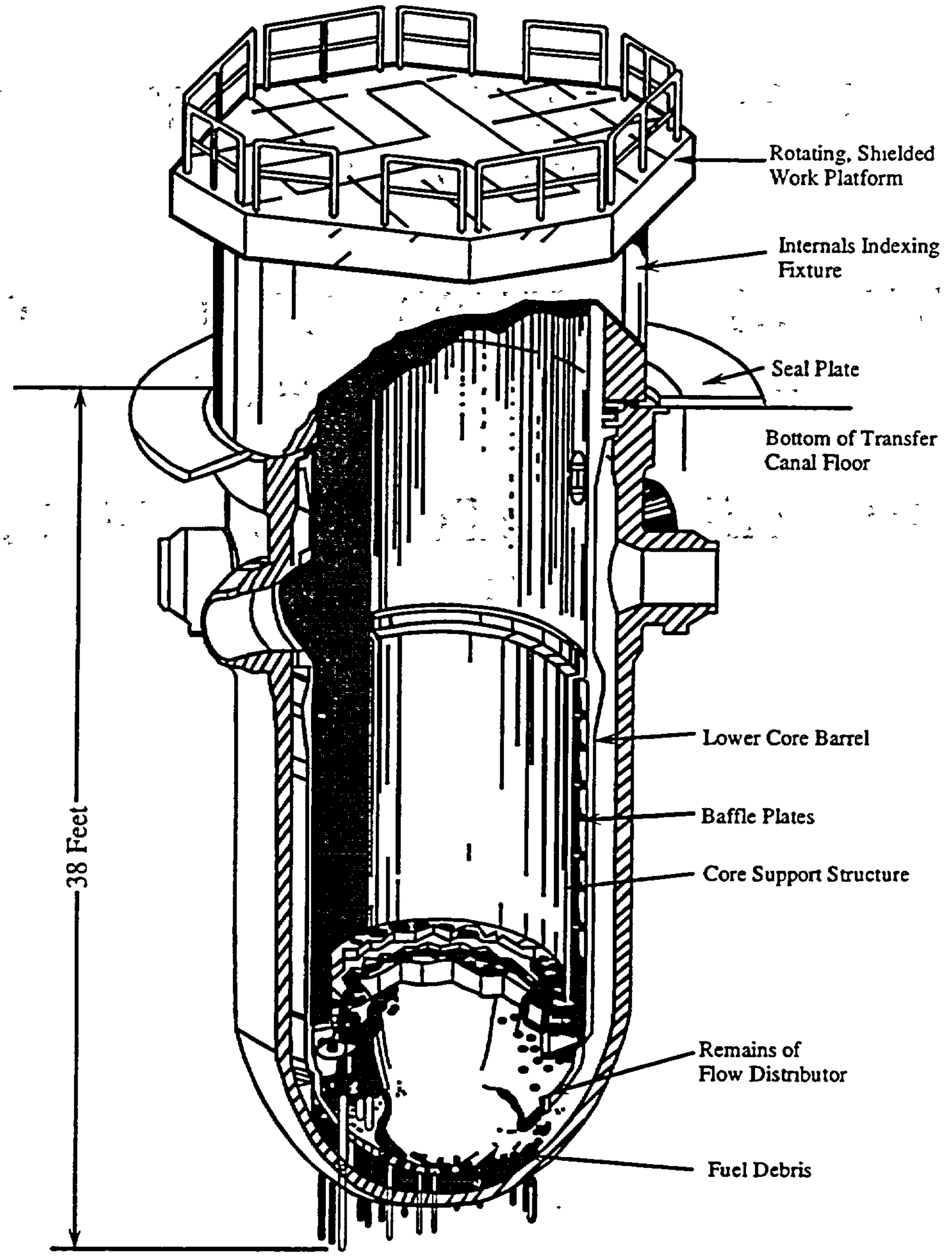
The major release point was the waste gas system. The fission product gases were being stripped out in the volume control tank and vented to the waste gas system. A leak in the waste gas system allowed the gases to be blown out the ventilation stack via the auxiliary building ventilation system.



Television cameras, lowered into the reactor core, indicated a large void area where the top half of the core should be. Also, a bed of rubble (fuel pellets, fuel rod debris, etc.) was found on the top of the lower half of the core. The exact condition of the lower portion of the core was not determined for several more years.



Disassembly of the reactor core revealed a significant amount of fuel melt. A portion of the molten core had flowed laterally after melting through the stainless steel core support assembly. That material then flowed down to the lower portion of the reactor vessel, where it cooled and became a solid material again. As shown in the diagram, some of the lower portion of the fuel assemblies remained intact.



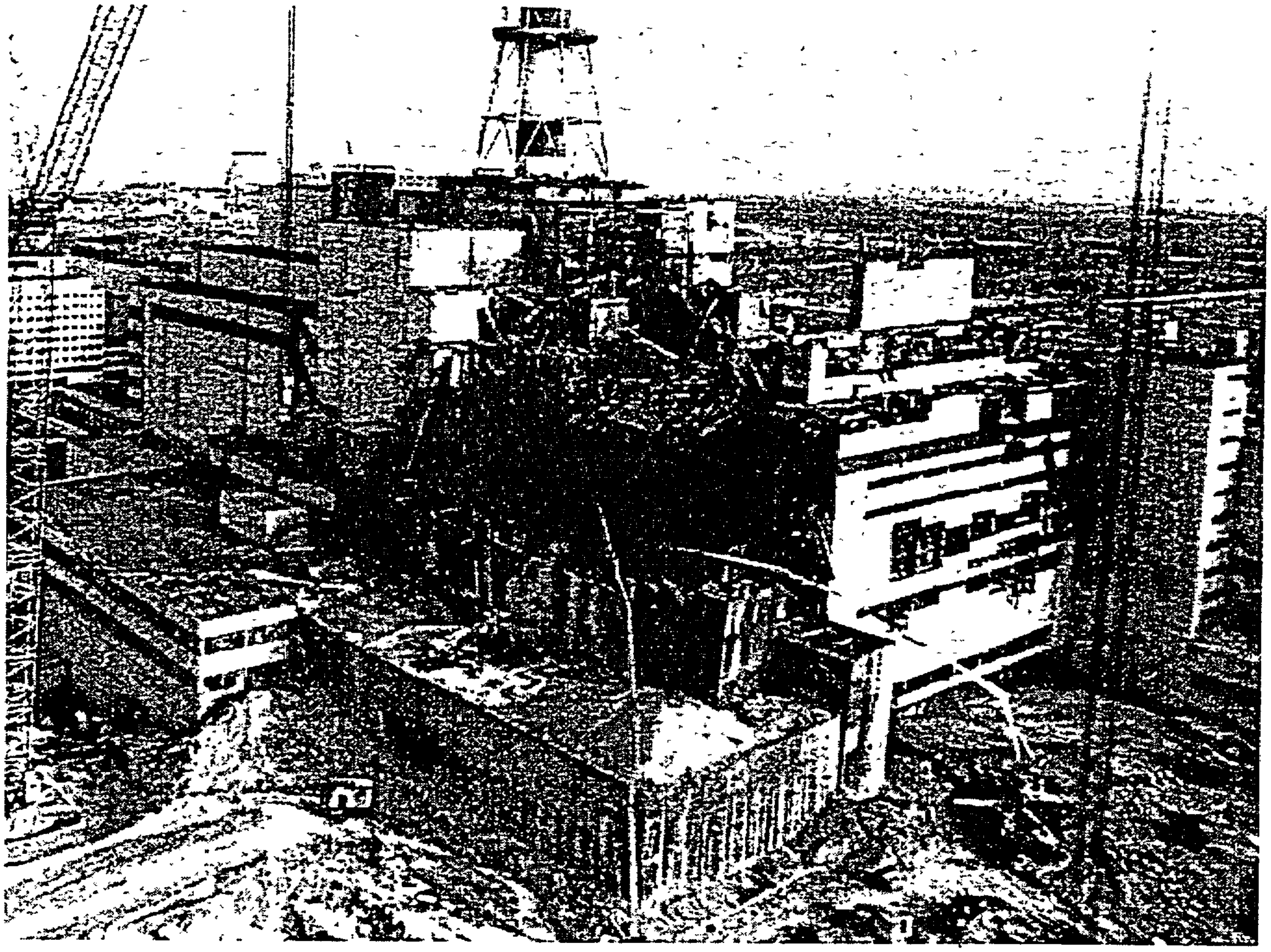
By the end of May, 1989, most of the internals of the vessel had been removed. The diagram above shows the cutaway of the vessel as of May, 1989. The material removed from the vessel has been placed in canisters and shipped from the site.

MAXIMUM PROJECTED OFFSITE DOSE:
Less than 100 millirems

AVERAGE DOSE TO POPULATION:
Approximately 1.4 millrems/person

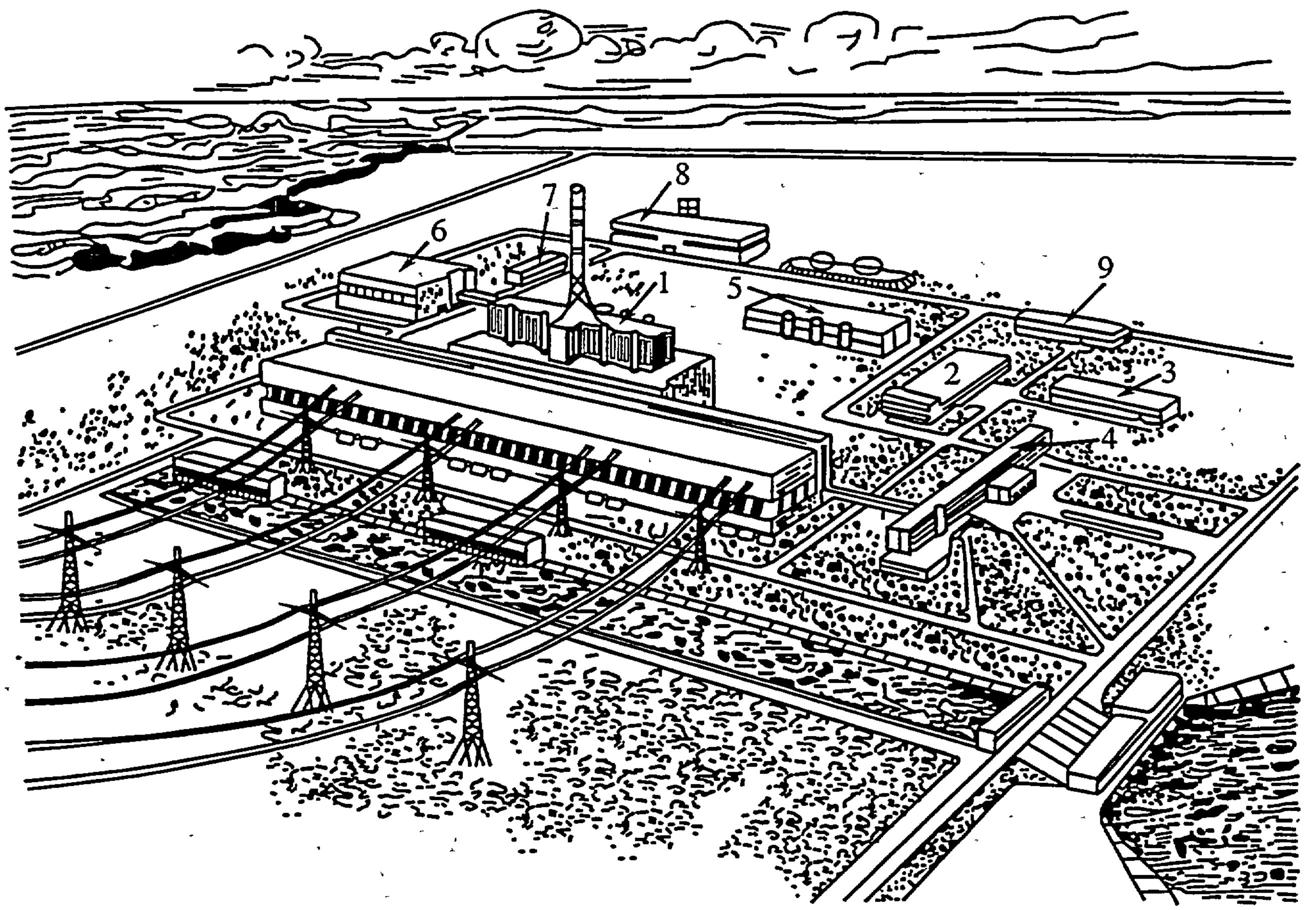
PROJECTED ADDITIONAL CANCERS:
0 to 1

The principal cause of exposure for individuals in the pathway of the release was noble gases (primarily xenon). Above is a summary of the radiological consequences of the Three Mile Island accident.



CHERNOBYL

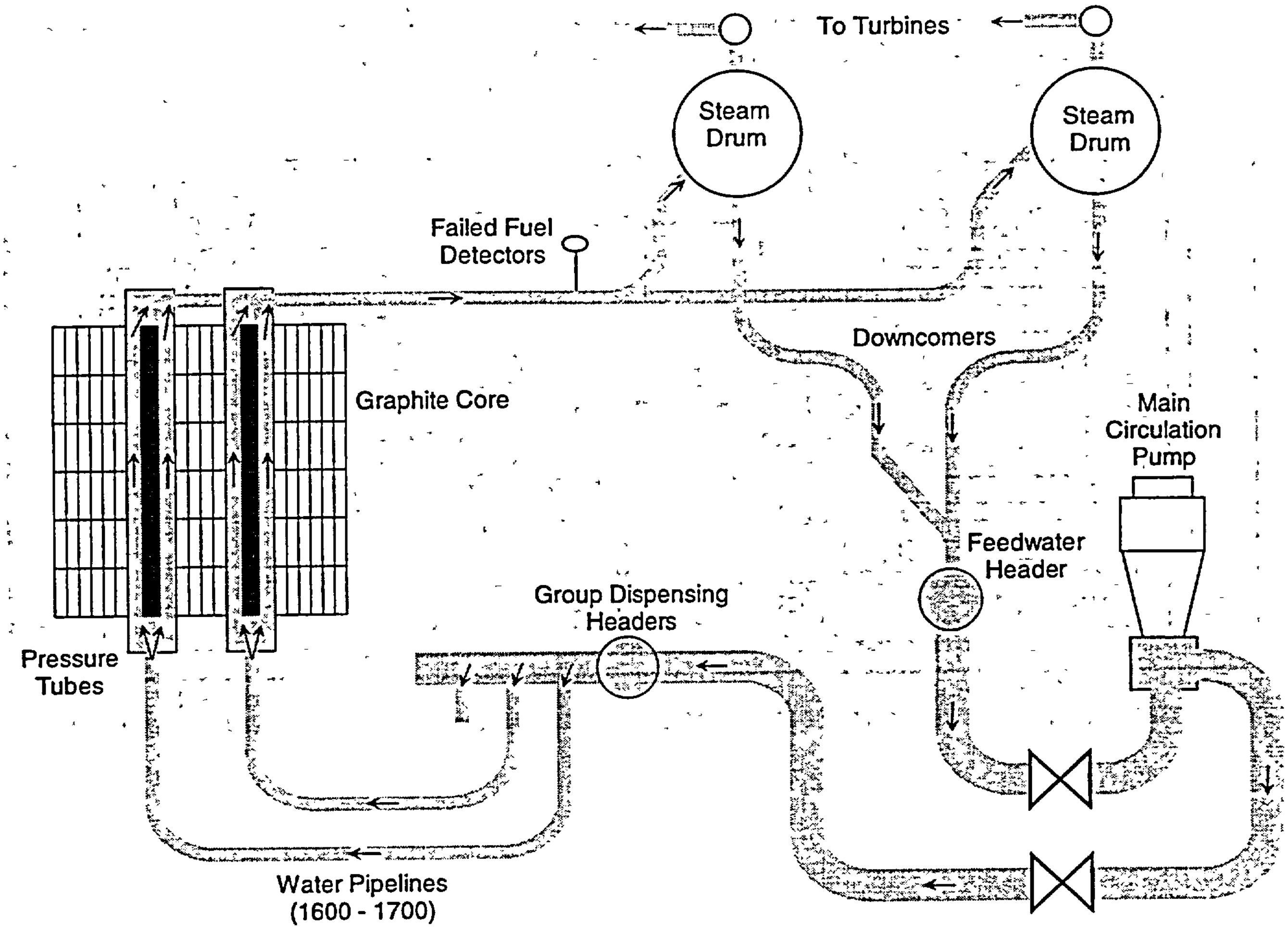
This section will briefly describe the Soviet Union's RBMK-1000 reactor design and discusses the events leading up to and immediately following the Chernobyl Unit 4 accident.



RBMK-1000 Site Layout

Above is the schematic of the typical layout for an RBMK-1000 site. The major structures are:

1. Reactor building and turbine hall
2. Auxiliary building
3. Chemical storage building
4. Administrative building
5. Diesel generator building
6. Waste handling and storage building
7. Nitrogen/Oxygen storage area
8. Auxiliary building
9. New fuel storage facility



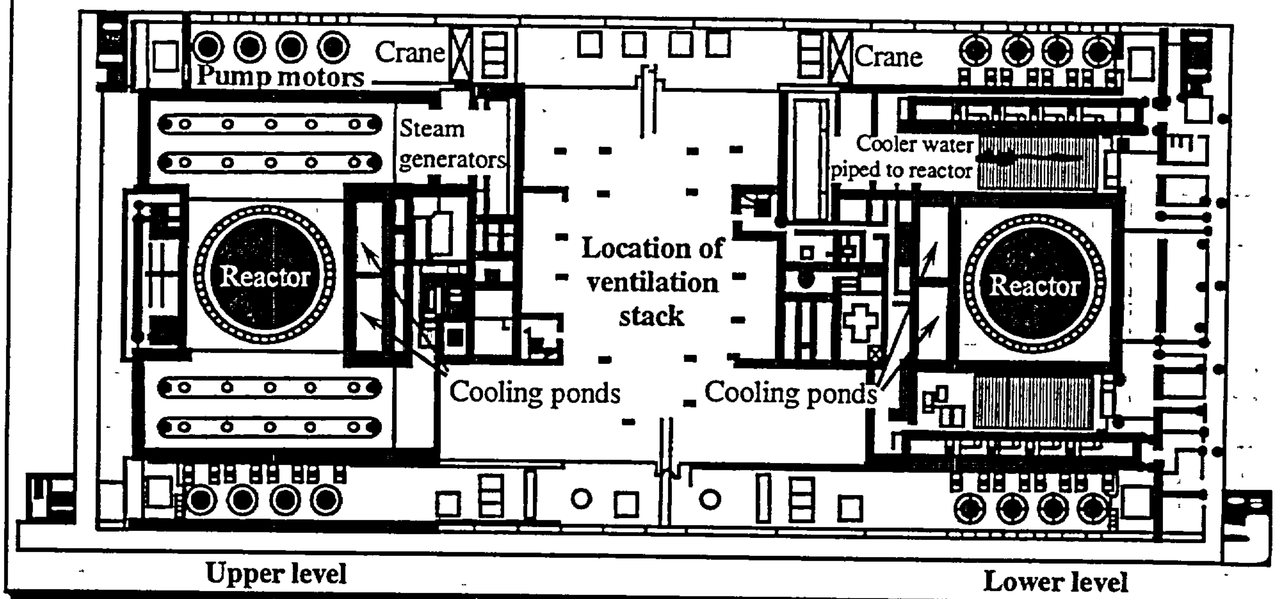
Schematic Diagram of the RBMK-1000

The RBMK-1000 is a boiling water, pressure tube, graphite moderated reactor. The cooling medium is water, which is converted into a steam/water mixture as it passes by the fuel rods. The coolant flows inside 1661 sealed pressure tubes. The steam/water mixture is physically separated in the steam drums. The separated steam is routed to the turbine generators, and the separated water is combined with the feedwater from the main condenser to be pumped back to the reactor via recirculation pumps.

The coolant flows inside the pressure tubes, from the bottom to the top. The pressure tubes are surrounded by large blocks of graphite. In an RBMK, the graphite serves to slow the neutrons down to the energy required to cause fission (acts as the moderator).

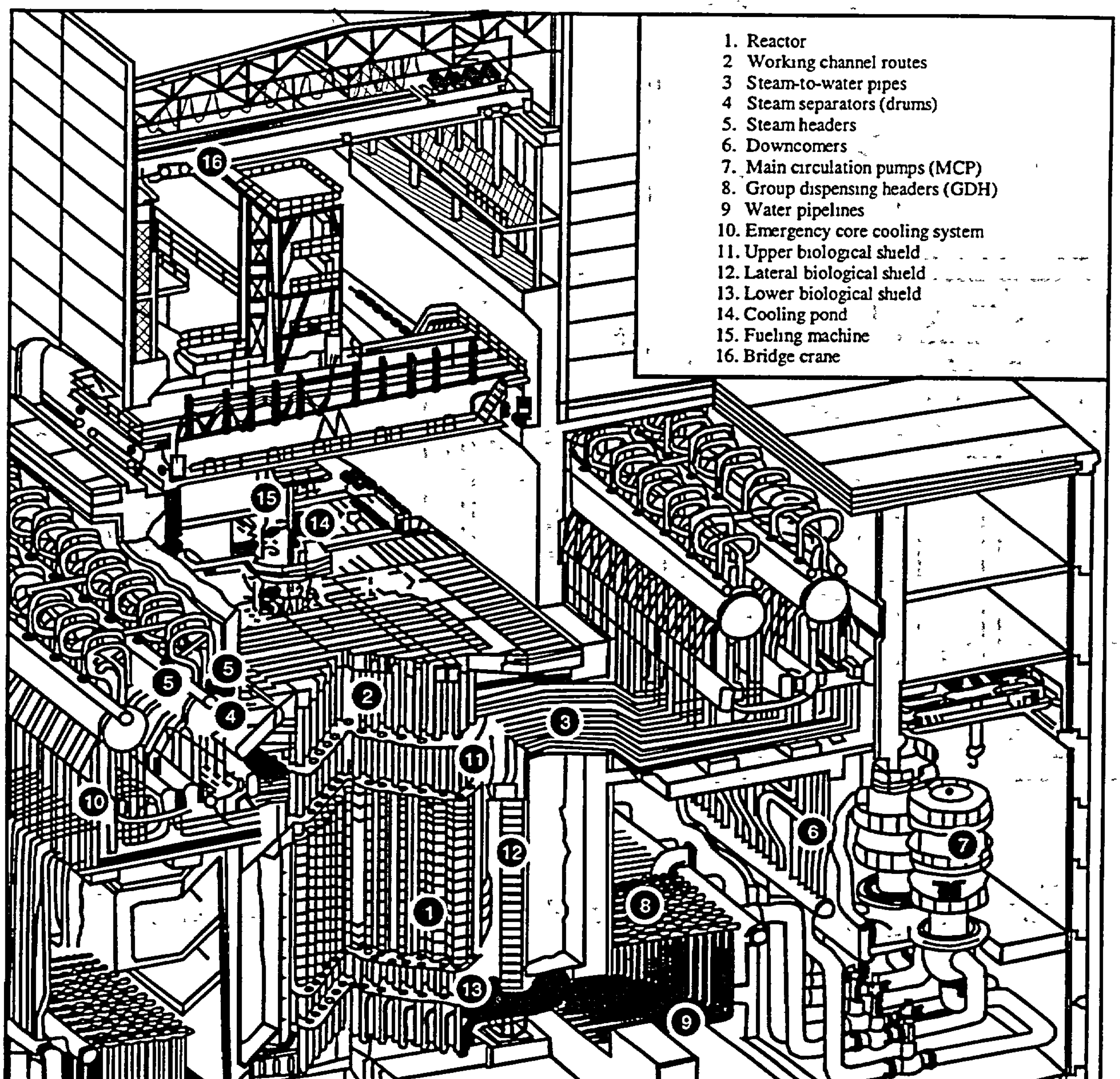
The RBMK-1000 reactor does not have to be shutdown to be refueled. Each pressure tube can be individually isolated, opened, and refueled by remotely controlled equipment while the remainder of the pressure tubes continue to operate at power.

Soviet Nuclear Power Plant: Cutaway View From Overhead
Floor plan of a Soviet nuclear reactor building with two graphite-moderated and water-cooled reactors similar to the ones at Chernobyl.



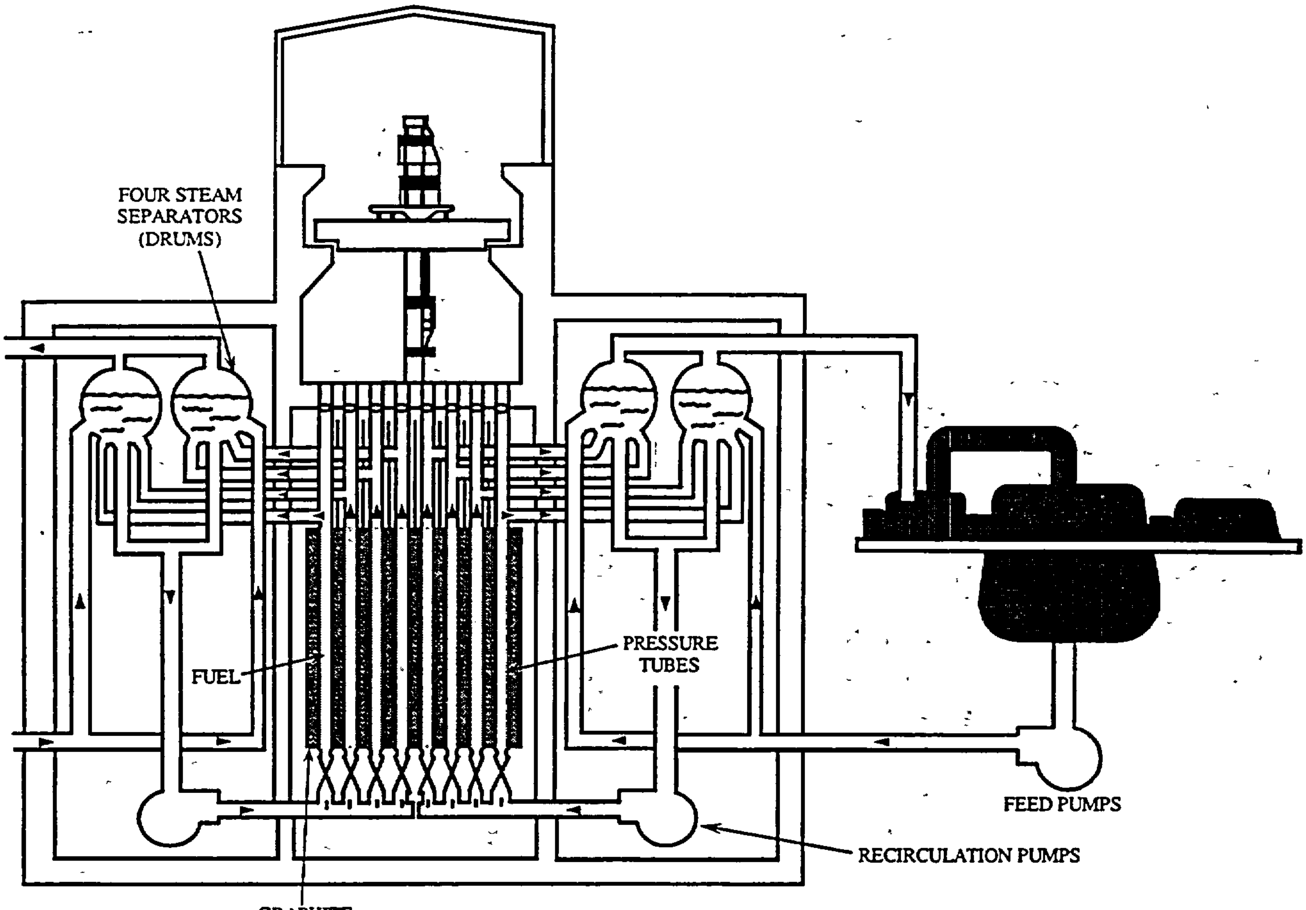
Two Unit Building Layout

A typical two unit layout houses both reactors inside a common building approximately 525 feet long and 236 feet wide. Spent fuel cooling ponds are located near the two reactors. A centralized ventilation and filtration system serves both units.



RBMK Design

The figure above shows a more detailed representation of the RBMK design. The design philosophy in reactor building construction called for the ability of each particular area to be able to withstand the pressure surge associated with the rupture of the largest pressurized pipe located within that area. For example, the area around the main recirculation pumps is designed to withstand a pressure of 36 psig. The area around the steam separators is also designed to withstand 36 psig. The area above the reactor core, however, is designed to withstand the pressure resulting from the failure of a single pressure tube, or only about 12 psig.

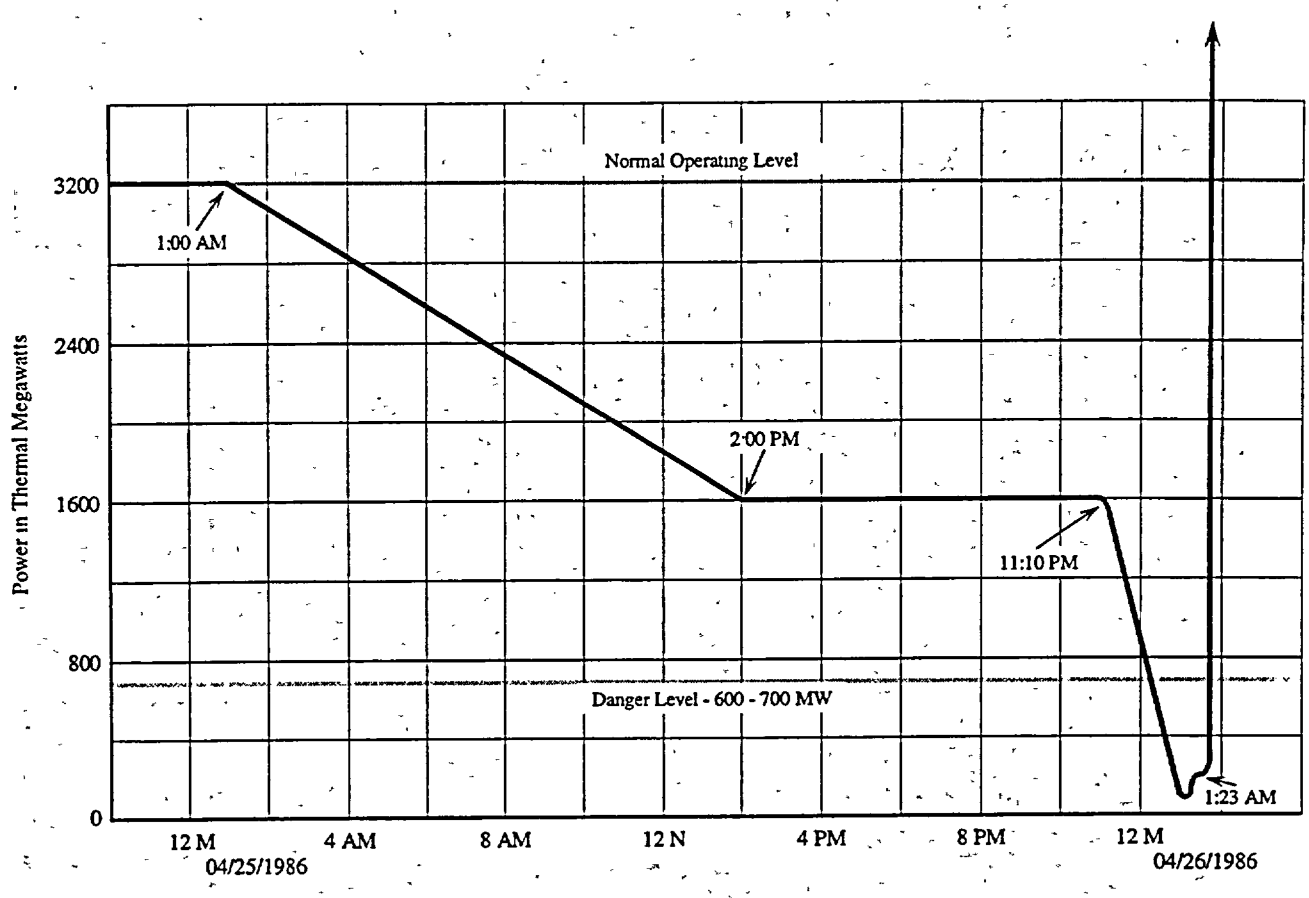


Boiling Water, Pressure Tube, Graphite Moderated Reactor

At Chernobyl Unit 4, a special test (written by non-nuclear trained electrical engineers) was to be performed to help evaluate a new voltage regulating system. This system would allow plant emergency equipment to be powered by the plant's electrical generator as it slowed following a turbine shutdown. Since the test's authors did not consider the test to be safety significant, the test procedure was not submitted for the ususal safety reviews. The test called for a reduction in power to 50% (1600 Mw), blocking of the automatic start signal for the plant's emergency core cooling system (ECCS), and connecting four of the reactor's eight recirculation pumps to the turbine generator under test.

Normally, the reactor would trip upon a turbine trip signal. To prevent this, and allow the performance of a second test if needed, the operators took several compensatory measures.

Due to an operator error, the planned power level of 50% was not maintained, and power was inadvertently allowed to drop to about 1% (30 Mw). Removing nearly all of the control rods from the core could only increase power to about 6%.

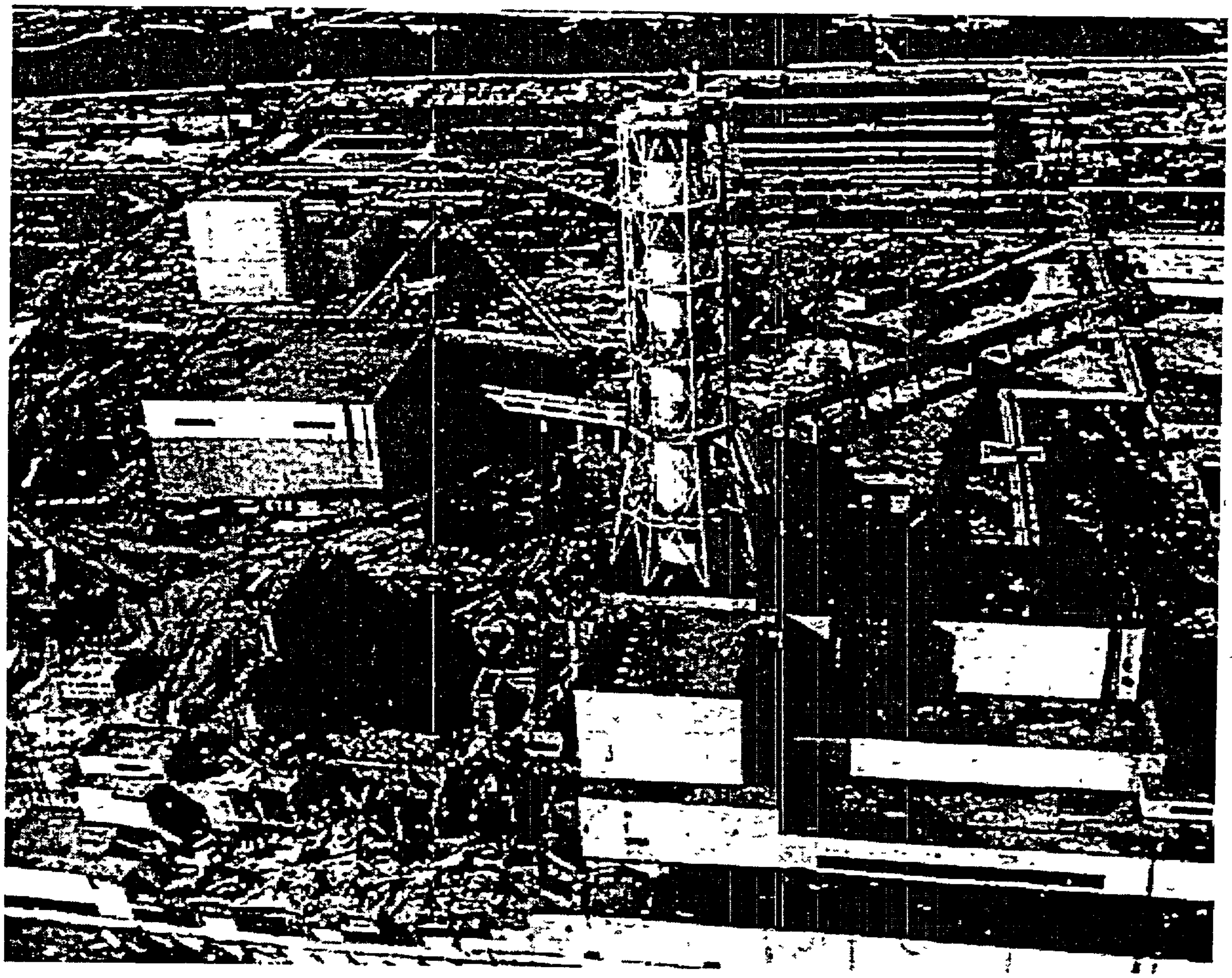


Graph of Power vs. Time (Reactor 4)

In an RBMK, extended operation below 20% is not permitted due to reactor instability. (Steam bubbles in the coolant increase reactor power, increasing reactor power creates more steam bubbles, which cause power to increase even further.) The operators decided to continue the test despite conditions that called for an immediate reactor shutdown.

In accordance with the test procedure, the operators turned on all reactor recirculation pumps. Due to the very low power level at which the plant was operating, the water entering the reactor was mostly from the steam separators and was very nearly at its boiling point even before reaching the fuel assemblies.

Continuing the test, the operators then tripped the turbine generator, and therefore, the principal method of heat removal was isolated. Temperature increased in the fuel channels, causing a significant increase in the steam bubble (void) formation. The increased boiling caused reactor power to rise rapidly. Operators tried to manually trip the reactor, but power was increasing far too rapidly. Fuel temperatures got so high so fast that the internal fuel rod pressure burst the fuel cladding, releasing extremely hot fuel fragments into the coolant channels.

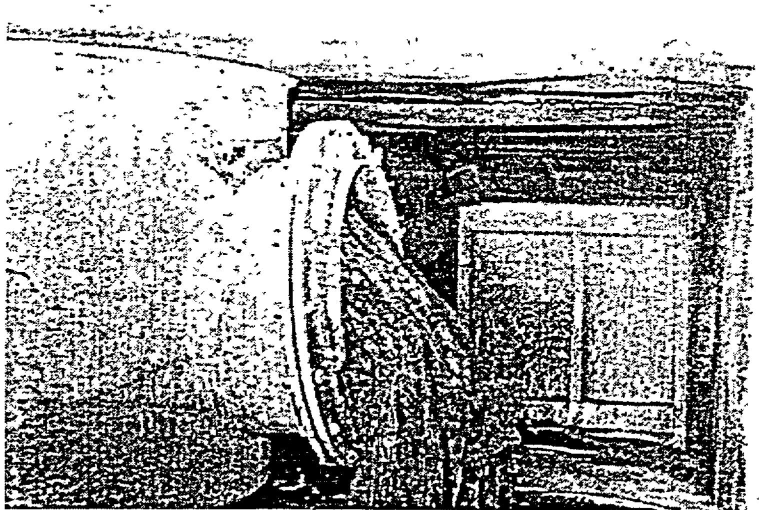


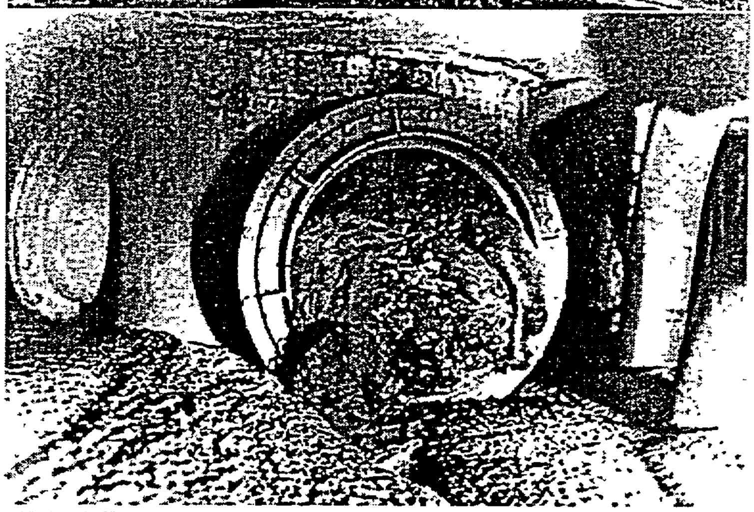
Damage Caused by Explosions

Extremely high pressures resulted from the mixing of the water with the intensely hot uranium fuel. Most, if not all, of the coolant pressure tubes ruptured immediately. The subsequent steam release (steam explosion) was more than sufficient to destroy the area above and around the unit 4 reactor, and to spread hot pieces of uranium and graphite onto the adjacent buildings. A second explosion, about three seconds later, caused further damage. About thirty fires were ignited by the materials ejected during the two explosions.

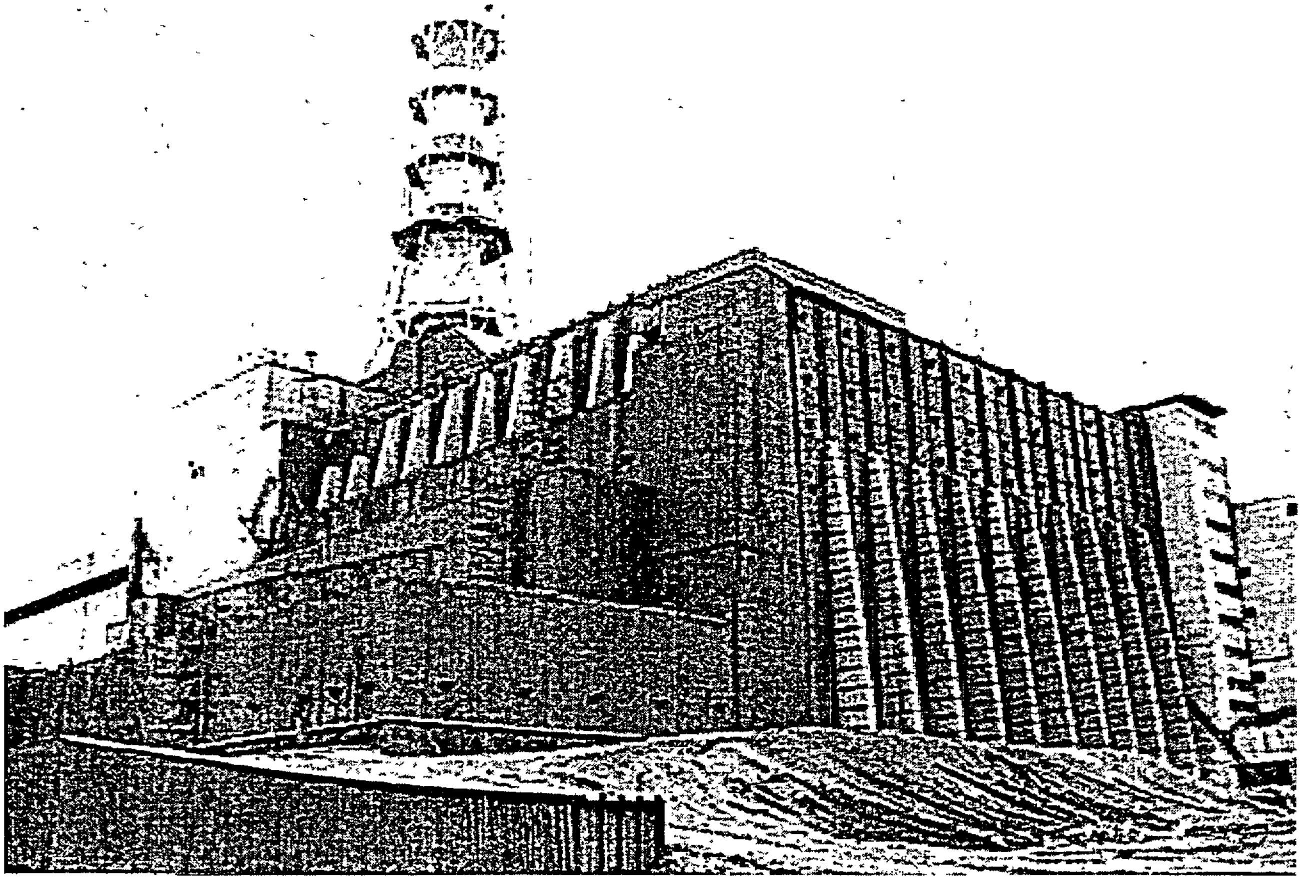
Twenty-nine fire fighters lost their lives extinguishing the various fires around units 4 and 3. Most of these deaths have been directly attributed to the intense radiation dose associated with the proximity to the reactor core materials.

The graphite inside of the unit 4 reactor continued to burn for several days. The heat generated by the fire continued to propel billions of curies of radioactive materials into the environment. The core fire was finally extinguished by dropping a blanketing mixture of sand, lead, boron, and dolomite (a type of limestone) onto the core by helicopter. Liquid nitrogen was injected into the bottom of the core to lower the reactor's temperature.





These pictures show the flows of the corium (melted fuel and core components) that were found after the accident.



Chernobyl Crypt

The decision was reached to not defuel the destroyed reactor. Instead, a crypt was designed and constructed to entomb the reactor.

Decommissioning

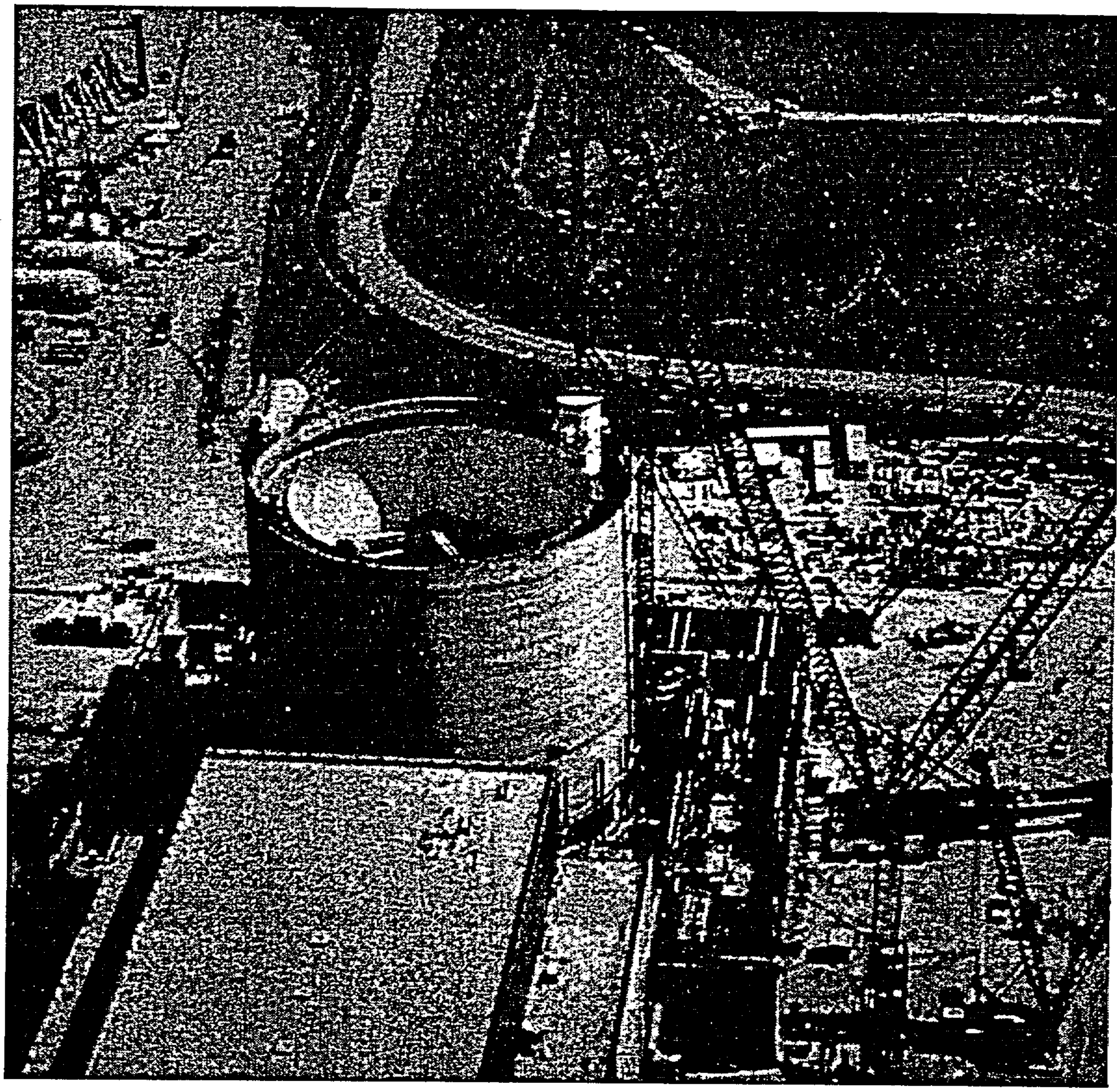
Decommissioning is defined as the safe removal of a facility from service and reduction of residual radioactivity (radioactivity in structures, materials, soils, groundwater, and other media at a site resulting from activities under the licensee's control) to a level that permits termination of the NRC license. The regulations require the completion of decommissioning within 60 years of the permanent cessation of operations.

The regulations for decommissioning are found in 10 CFR Part 20, 10 CFR Part 50, and 10 CFR Part 51. Specifically:

- 20.1402 - *Radiological criteria for unrestricted use*
- 20.1403 - *Criteria for license termination under restricted conditions*
- 20.1404 - *Alternate criteria for license termination*
- 20.1405 - *Public notification and public participation*
- 20.1406 - *Minimization of contamination*
- 50.75 - *Reporting and record keeping for decommissioning planning*
- 50.82 - *Termination of license*
- 51.53 - *Post-construction environmental reports*
- 51.95 - *Post-construction environmental impact statements*

This chapter will provide a brief discussion of the decommissioning activities associated with a power reactor facility. Other licensed facilities will undergo similar decommissioning processes.

Once the licensee has made the decision to permanently cease operations, the NRC must be informed in writing within 30 days. This notification must contain the date on which the power generation operations ceased or will cease. The licensee must remove the fuel from the reactor and submit a written certification to the NRC confirming its action. There is no time limit specified before the fuel must be removed or the certification received by the NRC. Once this certification has been submitted, the licensee is no longer permitted to operate the reactor, or to put fuel back into the reactor vessel. This also reduces the licensee's annual license fee to the NRC and eliminates the obligation to adhere to certain requirements that are needed only during reactor operations. The licensee must submit a post-shutdown decommissioning activities report (PSDAR) to the NRC and the affected state(s) no later than 2 years after the date of permanent cessation of operations. The post-shutdown decommissioning activities report must describe the planned decommissioning activities, contain a schedule for the accomplishment of significant milestones, provide an estimate of the expected cost, and provide documentation that environmental impacts associated with site-specific decommissioning activities have been considered in previously approved environmental impact statements.

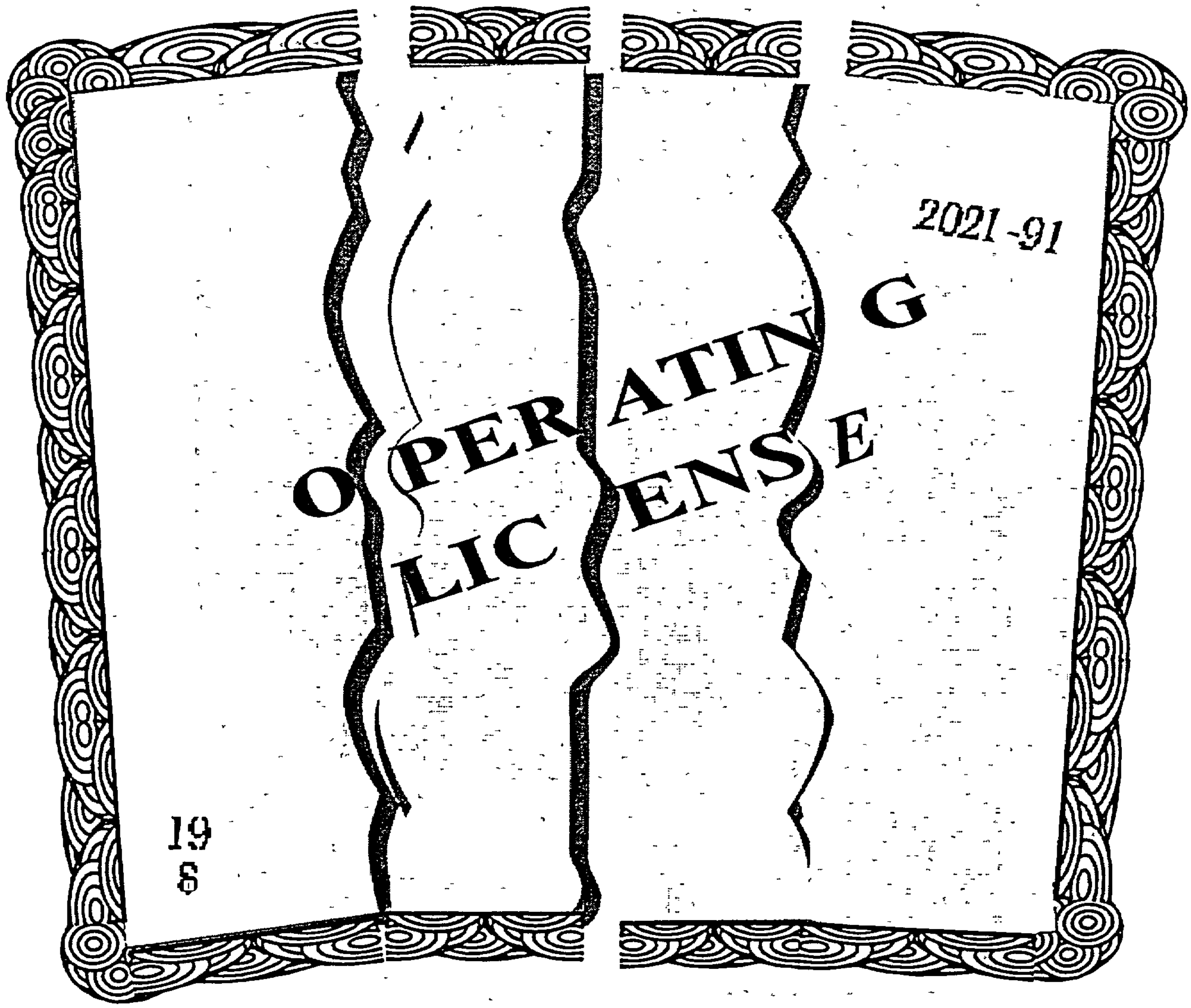


After receiving a PSDAR, the NRC publishes a notice of receipt, makes the PSDAR available for public review and comment, and holds a public meeting in the vicinity of the plant to discuss the licensee's plans.

Upon completion of the required submittals, and allowing for a 90-day waiting period after submittal of the PSDAR, the licensee may commence major decommissioning activities, which may include the following: permanent removal of major radioactive components (reactor vessel, steam generators, or other components that are comparably radioactive), permanent changes to the containment structure, and dismantling components resulting in "greater than Class C" waste.

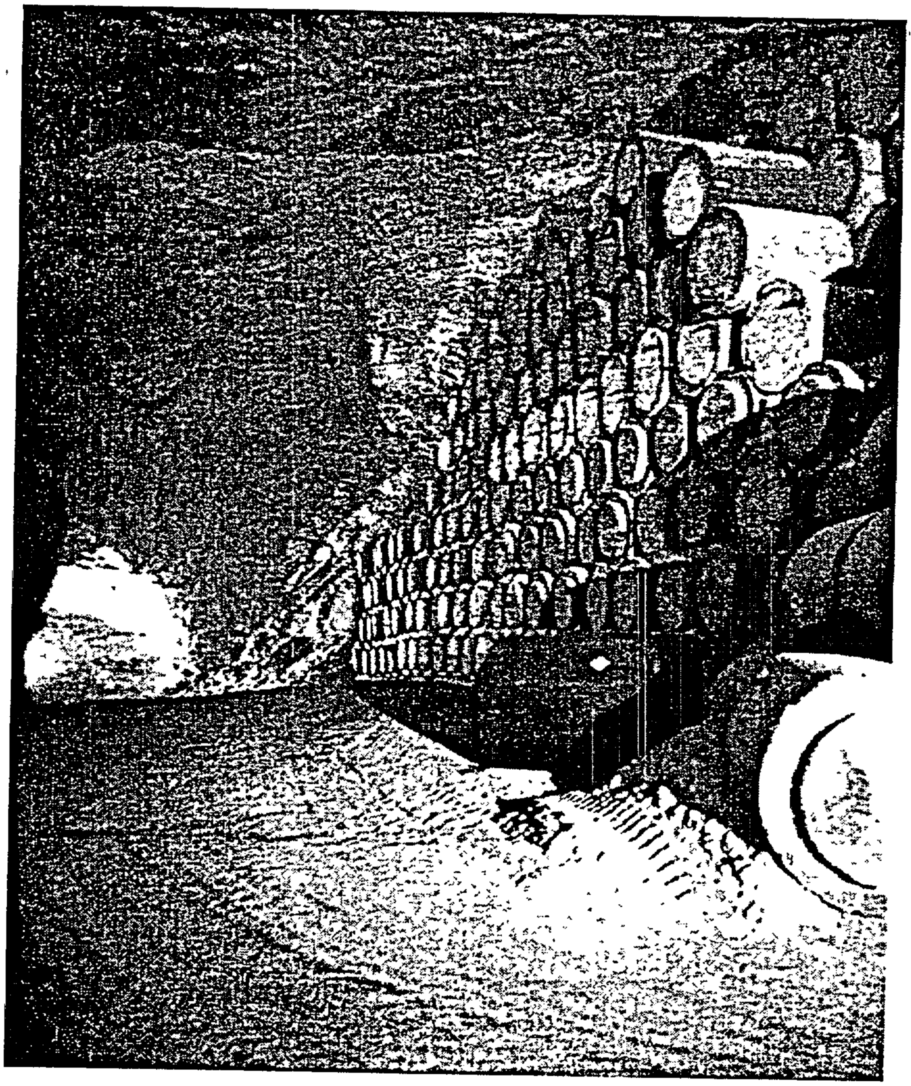
Within 2 years following the date of permanent cessation of operations, the licensee must submit a site-specific cost estimate for the decommissioning project. The licensee is prohibited from using the full amount of money that was accumulated during operations for the decommissioning process until the site-specific cost estimate is submitted to the NRC.

In order to conclude the decommissioning process, the licensee must submit a license termination plan to the NRC. This must be submitted at least 2 years before the termination date. It must include the following: a site characterization (a description of the radiological contamination on the site before any cleanup activities associated with decommissioning took place, a historical description of site operations, spills, and accidents, and a map of remaining contamination levels and contamination locations), identification of remaining dismantlement activities, plans for site remediation, detailed plans for the final survey of residual contamination on the site, a description of the end-use of the site (if restricted use is proposed, a description of institutional controls and maintenance and surveillance programs is required), an updated site-specific estimate of remaining decommissioning costs, and a supplement to the environmental report.



After receiving the license termination plan, the NRC will place a notice of receipt in the Federal Register, and will make the plan available to the public for comment. The NRC will schedule a public meeting near the facility to discuss the plan's contents with the public. The NRC will also offer an opportunity for a public hearing on the license amendment associated with the licensee termination plan. If the license termination plan demonstrates that the remainder of decommissioning activities will be performed in accordance with the NRC's regulations, is not detrimental to the health and safety of the public, and does not have a significant effect on the quality of the environment, the Commission will approve the plan by a license amendment (subject to whatever conditions and limitations the NRC deems appropriate and necessary). Once the license amendment is granted, the licensee is authorized to implement the license termination plan.

At the end of the license termination plan process, if the NRC determines that the remaining dismantlement has been performed in accordance with the approved license termination plan, and if the final radiation survey and associated documentation demonstrate that the facility and site are suitable for release, then the Commission will terminate the license, and the decommissioning process is considered complete.



To decommission a nuclear power plant, the radioactive material on the site must be reduced to levels that would permit termination of the NRC license. This involves removing the spent fuel (the fuel that has been in the reactor vessel), dismantling any systems or components containing activation products (such as the reactor vessel and primary loop), and cleaning up or dismantling contaminated materials. All activated materials generally have to be removed from the facility and shipped to a waste-storage facility. Contaminated materials may either be cleaned of contamination onsite, or the contaminated sections may be cut off and removed (leaving most of the component intact in the facility), or they may be removed and shipped to the waste-storage facility. The licensee decides how to decontaminate material and the decision is usually based on the amount of contamination, the ease with which it can be removed, and the cost to remove the contamination versus the cost to ship the entire structure or component to a waste-storage site.

There are three alternatives for decommissioning. These are DECON, SAFSTOR, and ENTOMB.

DECON

If the licensee decides on the DECON alternative, the equipment, structures, and portions of the facility and site that contain radioactive contaminants are removed or decontaminated to a level that permits termination of the license shortly after cessation of operations.

The advantages of this method are:

- The facility license is terminated quickly and the facility and site become available for other purposes,
- Availability of the operating reactor work force that is highly knowledgeable about the facility,
- Elimination of the need for long-term security, maintenance, and surveillance of the facility, which would be required for the other decommissioning alternatives,
- Greater certainty about the availability of low-level waste facilities that would be willing to accept the low-level radioactive waste, and
- Lower estimated costs compared to the alternative of SAFSTOR, largely as a result of future price escalation because most activities that occur during DECON would also occur during the SAFSTOR period, only at a later date. (This assumes that the later the date for completion of decommissioning, the greater the cost.)

The disadvantages of this method include:

- Higher worker and public doses (because there is less benefit from radioactive decay such as would occur in the SAFSTOR option),
- A larger initial commitment of money,
- A larger commitment of disposal site space than for the SAFSTOR option, and
- The potential for complications if spent fuel must remain on the site until a Federal repository for spent fuel becomes available.

SAFSTOR

If the SAFSTOR alternative is chosen, the facility is placed in a safe, stable condition and maintained in that state until it is subsequently decontaminated and dismantled to levels that permit license termination. During SAFSTOR, a facility is left intact, but the fuel has been removed from the reactor vessel and radioactive liquids have been drained from systems and components and then processed. Radioactive decay occurs during the SAFSTOR period, thus reducing the quantity of contaminated and radioactive material that must be disposed of during decontamination and dismantlement.

The benefits of this method are:

- A substantial reduction in radioactivity as a result of the radioactive decay that results during the storage period,
- A reduction in worker dose (as compared to the DECON) alternative,
- A reduction in public exposure because of fewer shipments of radioactive material to the low-level site (as compared to the DECON alternative),
- A reduction in the amount of waste disposal space required (as compared to the DECON alternative),
- Lower cost during the years immediately following permanent cessation of operations, and
- A storage period compatible with the need to store spent fuel onsite.

The disadvantages of this alternative are:

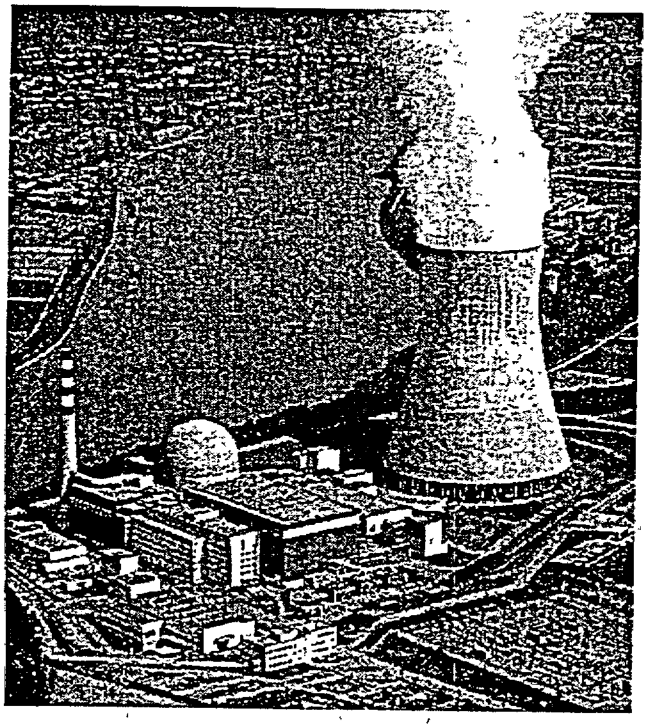
- A shortage of personnel familiar with the facility at the time of deferred dismantlement and decontamination,
- Site unavailable for alternate uses during the extended storage period,
- Uncertainties regarding the availability and costs of low-level radioactive waste sites in the future,
- Continuing need for maintenance, security, and surveillance, and
- Higher total cost for the subsequent decontamination and dismantlement period (assuming typical price escalation during the time the facility is stored).

ENTOMB

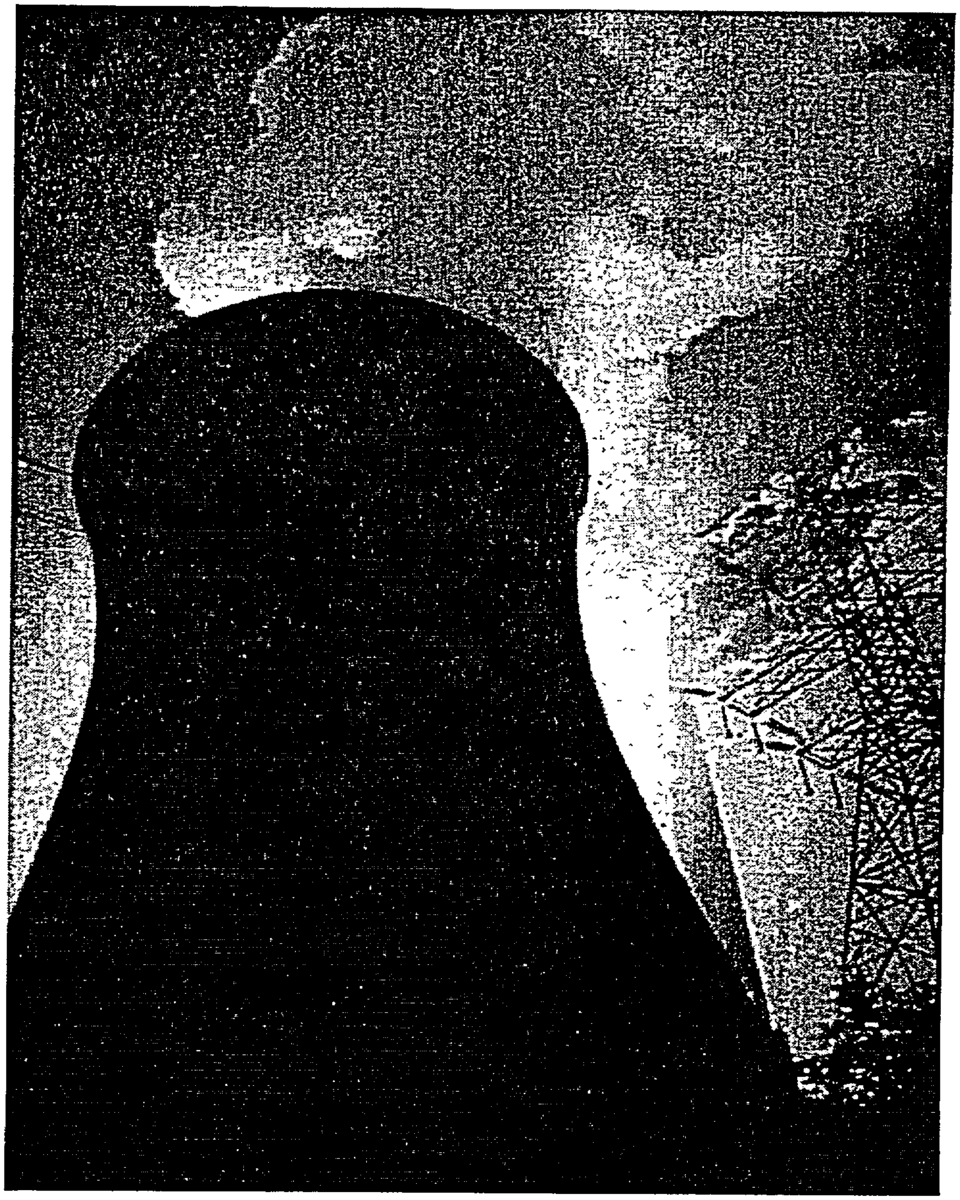
If the ENTOMB option is chosen, radioactive structures, systems, and components are encased in a structurally long-lived substance, such as concrete. The entombed structure is appropriately maintained, and continued surveillance is carried out until the radioactivity decays to a level that permits termination of the license.

The benefits of the ENTOMB process are primarily related to the reduced amount of work in encasing the facility in a structurally long-lived substance, and thus, reducing the worker dose from decontaminating and dismantling the facility. In addition, public exposure from waste transported to the low-level waste site would be minimized.

The ENTOMB option may have a relatively low cost, however, because most power reactors will have radionuclides in concentrations exceeding the limits for unrestricted use even after 100 years, this option may not be feasible. This option might be acceptable for reactor facilities that can demonstrate that radionuclide levels will decay to levels that will allow restricted use of the site. Three small demonstration reactors have been entombed. Currently, no power reactor licensees have proposed the ENTOMB option for any of the power reactors undergoing decommissioning.



Unrestricted use of a facility after license termination means that there are no restrictions on how the site may be used. The licensee is free to continue to dismantle any remaining buildings or structures, and to use the land or sell the land for any type of application.



Restricted use means that the licensee has demonstrated that further reductions in residual radioactivity would result in net public or environmental harm or residual levels are as low as is reasonably achievable, and the licensee made provisions for legally enforceable institutional controls (e.g., restrictions placed in the deed for the property describing what the land can and cannot be used for), which provide reasonable assurance that the radiological criteria set by the NRC will not be exceeded. In addition, the licensee must have provided sufficient financial assurance to an amenable independent third party to assume and carry out responsibilities for any necessary control and maintenance of the site. There are also regulations relating to the documentation of how the advice of individuals and institutions in the community who may be affected by the decommissioning has been sought and incorporated in the license termination plan related to decommissioning by restricted use.

A site could be classified as restricted use for a period of time to allow the decay of some of the radioactivity and then be released as unrestricted use.

Glossary

of

Terms

Appendix A

A

Term	Definition
Absorber	Any material that lessens the intensity of ionizing radiation by causing the radiation to deposit its energy in the material. Neutron absorbers (like boron, hafnium, and cadmium) are used in control rods for reactors. Concrete and steel absorb gamma rays and neutrons in reactor shields. A thin sheet of paper or metal will absorb alpha particles and low energy beta particles.
Absorption	The process by which the number of particles or photons entering a body of matter is reduced by interaction with matter. Also the process in which energy is absorbed from the particles or photons even if the number is not reduced.
Access Hatch	An airtight door system that preserves the pressure integrity of a reactor containment building while allowing access to personnel and equipment.
Activation	The process of making a radioisotope by bombarding a stable element with neutrons, protons, or other nuclear radiation.
Active Fuel Length	The end-to-end dimension of fuel material within a fuel element.
Air Sampling	The collection of samples of air to measure the radioactivity or to detect the presence of radioactive material, particulate matter, or chemical pollutants in the air.
Airborne Radioactivity Area	A room, enclosure, or area in which airborne radioactive materials, composed wholly or partly of licensed material, exist in concentrations that: 1) Exceed the derived air concentration limits, or 2) Would result in an individual present in the area without respiratory protection exceeding, during the hours the individual is present in the area during the week, 0.6% of the annual limit on intake or 12 DAC-hours.

A

Term	Definition
ALARA	Acronym for "As Low As is Reasonably Achievable," means making every reasonable effort to maintain exposures to radiation as far below the dose limits as practical consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest.
Alpha Particle	A positively charged particle ejected spontaneously from the nuclei of some radioactive elements. It is identical to a helium nucleus that has a mass number of 4 and an electrostatic charge of +2. It has low penetrating power and a short range. The most energetic alpha particle will generally fail to penetrate the dead layers of cells covering the skin. Alphas are hazardous when an alpha-emitting isotope is inside the body.
Anion	A negatively charged ion.
Annual Limit on Intake (ALI)	The derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. ALI is the smaller value of intake of a given radionuclide in a year by the reference man that would result in a committed effective dose equivalent of 5 rems (0.05 Sv) or a committed dose equivalent of 50 rems (0.5 Sv) to any individual organ or tissue.
Atom	The smallest particle of an element that cannot be divided or broken up by chemical means. It consists of a central core of protons and neutrons, called the nucleus. Electrons revolve in orbits in the region surrounding the nucleus.
Atomic Energy	Energy released in nuclear reactions. Of particular interest is the energy released when a neutron initiates the breaking up or fissioning of an atom's nucleus into smaller pieces (fission), or when two nuclei are joined together under millions of degrees of heat (fusion). It is more correctly called nuclear energy.
Atomic Energy Commission (AEC)	Federal agency created in 1946 to manage the development, use, and control of nuclear energy for military and civilian application. Abolished by the Energy Reorganization Act of 1974 and succeeded by the Energy Research and Development Administration (now part of the U.S. Department of Energy) and the U.S. Nuclear Regulatory Commission.

A

Term	Definition
Atomic Number	The number of positively charged protons in the nucleus of an atom.
Attenuation	The process by which the number of particles or photons entering a body of matter is reduced by absorption and scatter.
Auxiliary Building	Building at a nuclear power plant, frequently located adjacent to the reactor containment building, that houses most of the reactor auxiliary and safety systems, such as radioactive waste systems, chemical and volume control system, and emergency cooling water systems.
Auxiliary Feedwater	Backup feedwater supply used during nuclear plant startup and shutdown and is the supply of water to the steam generators during accident conditions for removing decay heat from the reactor.
Average Planar Linear Heat Generation Rate (APLGHR)	The average value of the linear heat generation rate of all the rods at any given horizontal plane along a fuel bundle.
Axial Flux Difference	The difference in normalized flux signals between the top and bottom halves of a two section excore neutron detector.

B

Term	Definition
Background Radiation	Radiation from cosmic sources, naturally occurring radioactive materials (including radon, except as a decay product of source or special nuclear material), and global fallout as it exists in the environment from the testing of nuclear explosive devices. It does not include radiation from source, byproduct, or special nuclear materials regulated by the Commission. The typically quoted average individual exposure from background radiation is 360 millirems per year.
Becquerel (Bq)	The unit of radioactive decay equal to 1 disintegration per second. 3.7×10^{10} Bq = 1 Curie.
Beta Particle	A charged particle emitted from a nucleus during radioactive decay, with a mass equal to 1/1837 that of a proton. A negatively charged beta particle is identical to an electron. A positively charged beta particle is called a positron. Large amounts of beta radiation may cause skin burns, and beta emitters are harmful if they enter the body. Beta particles may be stopped by thin sheets of metal or plastic.

B

Term	Definition
Binding Energy	The minimum energy required to separate a nucleus into its component neutrons and protons.
Bioassay	The determination of kinds, quantities or concentrations, and in some cases, the locations of radioactive material in the human body, whether by direct measurement (in vivo counting) or by analysis and evaluation of materials excreted or removed from the human body.
Biological Halflife	The time required for a biological system, such as that of a human, to eliminate, by natural processes, half of the amount of a substance (such as a radioactive material) that has entered it.
Biological Shield	A mass of absorbing material placed around a reactor or radioactive source to reduce the radiation to a level safe for humans.
Boiling Water Reactor (BWR)	A reactor in which water, used as both coolant and moderator, is allowed to boil in the core. The resulting steam can be used directly to drive a turbine and electrical generator.
Bone Seeker	A radioisotope that tend to accumulate in the bones when it is introduced into the body. An example is strontium-90, which behaves chemically like calcium.
Breeder	A reactor that produced more nuclear fuel than it consumes. A fertile material, such as uranium-238, when bombarded by neutrons, is transformed into a fissile material, such as plutonium-239, which can be used as a fuel. (See: fissile, fissionable, fertile material.)
Btu	A British thermal unit. The amount of heat required to change the temperature of one pound of water one degree Fahrenheit at sea level.

C

Term	Definition
Calibration	The adjustment, as necessary, of a measuring device such that it responds within the required range and accuracy to known values of input.
Cask	A heavily shielded container used to store and/or ship radioactive materials. Lead and steel are common materials used in the manufacture of casks.
Cation	A positively charged ion.

C

Term	Definition
Chain Reaction	A reaction that stimulates its own repetition. In a fission chain reaction, a fissionable nucleus absorbs a neutron and fissions, releasing additional neutrons. These, in turn, can be absorbed by other fissionable nuclei, releasing still more neutrons. A fission chain reaction is self-sustaining when the number of neutrons released in a given time equals or exceeds the number of neutrons lost by absorption in non-fissionable material or by escape from the system.
Charged Particle	An ion. An elementary particle carrying a positive or negative electric charge.
Chemical Recombination	Following an ionization event, the positively and negatively charged ion pairs may or may not realign themselves to form the same chemical substance they formed before ionization. Thus, chemical recombination could change the chemical composition of the material bombarded by radiation.
Cladding	The thin-walled metal tube that forms the outer jacket of a nuclear fuel rod. It prevents corrosion of the fuel by the coolant and the release of fission products into the coolant. Aluminum, stainless steel, and zirconium alloys are common cladding materials.
Cleanup System	A system used for continuously filtering and demineralizing the reactor coolant system to reduce contamination levels and to minimize corrosion.
Coastdown	An action that permits the reactor power level to decrease gradually as the fuel in the core is depleted.
Cold Shutdown	The term used to define a reactor coolant system at atmospheric pressure and at a temperature below 200°F following a reactor cooldown.
Compound	A chemical combination of two or more elements combined in a fixed and definite proportion by weight.
Condensate	Water that has been produced by the cooling of steam in a condenser.

Term	Definition
Condenser	A large heat exchanger designed to cool exhaust steam from a turbine below the boiling point so that it can be returned to the heat source as water. In a pressurized water reactor, the water is returned to the steam generator. In a boiling water reactor, it returns to the reactor core. The heat removed from the steam by the condenser is transferred to a circulating water system and is exhausted to the environment, either through a cooling tower or directly into a body of water.
Contamination	The deposition of unwanted radioactive material on the surfaces of structures, areas, objects, or personnel. It may also be airborne or internal (inside components or personnel).
Containment	The provision of a gas-tight shell or other enclosure around a reactor to confine fission products that otherwise might be released to the atmosphere in the event of an accident.
Control Rod	A rod, plate, or tube containing a material such as hafnium, boron, etc., used to control the power of a nuclear reactor. By absorbing neutrons, a control rod prevents the neutrons from causing further fissions.
Controlled Area	An area outside of a restricted area but within the site boundary, access to which can be limited by the licensee for any reason.
Control Room (building)	The area in a nuclear power plant from which most of the plant power production and emergency safety equipment can be operated by remote control.
Coolant	A substance circulated through a nuclear reactor to remove or transfer heat. The most commonly used coolant in the United States is water. Other coolants include heavy water, air, carbon dioxide, helium, liquid sodium, and a sodium-potassium alloy.
Cooldown	The gradual decrease in reactor fuel rod temperature caused by the removal of heat from the reactor coolant system.
Cooling Tower	A heat exchanger designed to aid in the cooling of water that was used to cool exhaust steam exiting the turbines of a power plant. Cooling towers transfer exhaust heat into the air instead of into a body of water.
Core	The central portion of a nuclear reactor containing the fuel elements, moderator, neutron poisons, and support structures.

C

Term	Definition
Core Melt Accident	An event or sequence of events that result in the melting of part of the fuel in the reactor core.
Cosmic Radiation	Penetrating ionizing radiation, both particulate and electromagnetic, originating in outer space. Secondary cosmic rays, formed by interactions in the earth's atmosphere, account for about 45 to 50 millirems of the 360 millirems background radiation that an average individual receives in a year.
Counter	A general designation applied to radiation detection instruments or survey meters that detect and measure radiation. The signal that announces an ionization event is called a count.
Critical Mass	The smallest mass of fissionable material that will support a self-sustaining chain reaction.
Criticality	A term used in reactor physics to describe the state when the number of neutrons released by fission is exactly balanced by the neutrons being absorbed (by the fuel and poisons) and escaping the reactor core. A reactor is said to be "critical" when it achieves a self-sustaining nuclear chain reaction.
Crud	A colloquial term for corrosion and wear products (rust particles, etc.) that become radioactive (i.e., activated) when exposed to radiation. The term is actually an acronym for Chaulk River Unidentified Deposits, the Canadian plant at which the activated deposits were first discovered.
Cumulative Dose	The total dose resulting from repeated exposures of radiation to the same portion of the body, or to the whole body, over a period of time.
Curie (Ci)	The basic unit used to describe the intensity of radioactivity in a sample of material. The curie is equal to 37 billion disintegrations per second, which is approximately the rate of decay of 1 gram of radium. A curie is also the quantity of any radionuclide that decays at a rate of 37 billion disintegrations per second. Named for Marie and Pierre Curie, who discovered radium in 1898.

Term	Definition
Daughter Products	Isotopes that are formed by the radioactive decay of some other isotope. In the case of radium-226, for example, there are 10 successive daughter products, ending in the stable isotope lead-206.
Decay Heat	The heat produced by the decay of radioactive fission products after the reactor has been shut down.
Decay, Radioactive	The decrease in the amount of any radioactive material with the passage of time, due to the spontaneous emission from the atomic nuclei of either alpha or beta particles, often accompanied by gamma radiation.
Declared Pregnant Woman	A woman who has voluntarily informed her employer, in writing, of her pregnancy and the estimated date of conception.
Decontamination	The reduction or removal of contaminating radioactive material from a structure, area, object, or person. Decontamination may be accomplished by: 1) Treating the surface to remove or decrease the contamination. 2) Letting the material stand so that the radioactivity is decreased as a result of natural decay. 3) Covering the contamination to shield or attenuate the radiation emitted.
Departure from Nucleate Boiling (DNB)	The point at which the heat transfer from a fuel rod rapidly decreases due to the insulating effect of a steam blanket that forms on the rod surface.
Departure from Nuclear Boiling Ratio (DNBR)	The ratio of the heat flux required to cause departure from nucleate boiling to the actual local heat flux.
Depleted Uranium	Uranium having a percentage of uranium-235 smaller than the 0.7% found in natural uranium. It is obtained from spent (used) fuel elements or as byproduct tails, or residues, from uranium isotope separation.
Derived Air Concentration (DAC)	The concentration of a given radionuclide in air, which if breathed by the reference man for a working year of 2,000 hours under conditions of light work (inhalation of 1.2 cubic meters of air per hour), results in an intake of one ALI.

D

Term	Definition
Design-Basis Accident	A postulated accident that a nuclear facility must be designed and built to withstand without loss to the systems, structures, and components necessary to assure public health and safety.
Design-Basis Phenomena	Earthquakes, tornadoes, hurricanes, floods, etc., that a nuclear facility must be designed and built to withstand without loss of systems, structures, and components necessary to assure public health and safety.
Detector	A material or device that is sensitive to radiation and can produce a response signal suitable for measurement or analysis. A radiation detection instrument.
Deuterium	An isotope of hydrogen with one proton and one neutron in the nucleus.
Deuteron	The nucleus of deuterium. It contains one proton and one neutron.
Differential Pressure (dp or ΔP)	The difference in pressure between two points of a system, such as between the inlet and outlet of a pump.
Doppler Coefficient	Another name used for the fuel temperature coefficient of reactivity.
Dose	The absorbed dose, given in rads or grays, that represents the energy absorbed from the radiation in a gram of any material. Furthermore, the biological dose or dose equivalent, given in rems or sieverts, is a measure of the biological damage to living tissue from the radiation exposure.
Dose, Absorbed	The amount of energy deposited in any substance by ionizing radiation per unit mass of the substance. It is expressed numerically in rads or grays.
Dose Equivalent	A term used to express the amount of biologically effective radiation dose when modifying factors have been considered. The product of absorbed dose, a quality factor, and a distribution factor. It is expressed numerically in rems or sieverts.
Dosimeter	A portable instrument for measuring and registering the total accumulated dose to ionizing radiation.
Dosimetry	The theory and application of the principles and techniques involved in the measurement and recording of radiation doses.

D

Term	Definition
Dose Rate	The radiation dose delivered per unit time, for example, rem per hour.
Drywell	The containment structure enclosing a boiling water reactor vessel and its recirculation system. The drywell provides both a pressure suppression system and a fission product barrier under accident conditions.

E

Term	Definition
Effective Halflife	The time required for the amount of a radioactive element deposited in a living organism to be diminished 50% as a result of the combined action of radioactive decay and biological elimination.
Efficiency, Plant	The percentage of the total energy content of a power plant's fuel that is converted into electricity. The remaining energy is lost to the environment as heat.
Electrical Generator	An electromagnetic device that converts mechanical (rotational) energy into electrical energy. Most large electrical generators are driven by steam or water turbine systems.
Electromagnetic Radiation	A traveling wave motion resulting from changing electric or magnetic fields. Familiar electromagnetic radiations range from x-rays (and gamma rays) of short wavelength, through the ultraviolet, visible, and infrared regions, to radar and radio waves of relatively long wave lengths. All electromagnetic radiations travel in a vacuum at the velocity of light.
Electron	An elementary particle with a negative charge and a mass 1/1837 that of the proton. Electrons surround the positively charged nucleus and determine the chemical properties of the atom.
Element	One of the 113 known chemical substances that cannot be broken down further without changing its chemical properties. Some examples include hydrogen, nitrogen, oxygen, gold, lead, and uranium.
Emergency Core Cooling Systems (ECCS)	Reactor system components (pumps, valves, heat exchangers, tanks, and piping) that are specifically designed to remove residual heat from the reactor fuel rods should the normal core cooling system (reactor coolant system) fail.

E

Term	Definition
Emergency Feedwater	A name that may be used for auxiliary feedwater.
Exclusion Area	That area surrounding the reactor, in which the reactor licensee has the authority to determine all activities, including the exclusion or removal of personnel and property from the area.
Excursion	A sudden, very rapid rise in the power level of the reactor caused by supercriticality. Excursions are usually quickly suppressed by the negative fuel temperature coefficient, the moderator temperature coefficient, or the void coefficient (depending upon reactor design), and by rapid insertion of the control rods.
Exposure	Being exposed to ionizing radiation or to radioactive material.
External Radiation	Exposure to ionizing radiation when the radiation source is located outside the body.
Extremities	The hands, forearms, elbows, feet, knee, leg below the knee, and ankles. The permissible radiation exposures in these regions are generally greater than in the whole body because they contain less blood forming organs and have smaller volumes for energy absorption.

F

Term	Definition
Fast Fission	Fission of a heavy atom (such as uranium-238) when it absorbs a high energy (fast) neutron. Most fissionable materials need thermal (slow) neutrons in order to fission.
Fast Neutron	A neutron released during fission with kinetic energy greater than its surroundings.
Fast Reactor	A reactor in which the fission chain reaction is sustained primarily by fast neutrons rather than by slow moving neutrons. Fast reactors contain little or no moderator to slow down the neutrons from the speeds at which they are ejected from the fissioning nuclei.
Feedwater	Water supplied to the reactor pressure vessel (in a BWR) or to the steam generator (in a PWR) that removes heat from the reactor fuel rods by boiling and becoming steam. The steam becomes the driving force for the plant turbine generator.

Term	Definition
Fertile Material	A material, which is not itself fissile (fissionable by thermal neutrons), that can be converted into a fissile material by irradiation in a reactor. There are two basic fertile materials, uranium-238 and thorium-232. When these fertile materials capture neutrons, they are converted into fissile plutonium-239 and uranium-233, respectively.
Film Badge	A pack of photographic film used for measurement of radiation exposure for personnel monitoring purposes. The badge may contain two or three films of differing sensitivities, and it may contain a filter that shields part of the film from certain types of radiation.
Fissile Material	Although sometimes used as a synonym for fissionable material, this term has acquired a more restricted meaning. Namely, any material fissionable by thermal (slow) neutrons. The three primary fissile materials are uranium-233, uranium-235, and plutonium-239.
Fission	The splitting of a nucleus into at least two other nuclei and the release of a relatively large amount of energy. Two or three neutrons are usually released during this type of transformation.
Fission Gases	Those fission products that exist in the gaseous state, primarily, the noble gases (krypton, xenon, etc.).
Fission Products	The nuclei (fission fragments) formed by the fission of heavy elements, plus the nuclide formed by the fission fragments' radioactive decay.
Fissionable Material	Commonly used as a synonym for fissile material, the meaning of this term has been extended to include material that can be fissioned by fast neutrons, such as uranium-238.
Flux	A term applied to the amount of some type of particle (neutrons, alpha radiation, etc.) or energy (photons, heat, etc.) crossing a unit area per unit time. The unit of flux is the number of particles, energy, etc., per square centimeter per second.
Fuel Assembly	A cluster of fuel rods (or plates). Also called a fuel element. Many fuel assemblies make up a reactor core.

F

Term	Definition
Fuel Cycle	The series of steps involved in supplying fuel for nuclear power reactors. It can include mining, milling, isotopic enrichment, fabrication of fuel elements, use in a reactor, chemical reprocessing to recover the fissionable material remaining in the spent fuel, re-enrichment of the fuel material, refabrication into new fuel elements, and waste disposal.
Fuel Reprocessing	The processing of reactor fuel to separate the unused fissionable material from waste material.
Fuel Rod	A long, slender tube that holds fissionable material (fuel) for nuclear reactor use. Fuel rods are assembled into bundles called fuel elements or fuel assemblies, which are loaded individually into the reactor core.
Fuel Temperature Coefficient of Reactivity	The change in reactivity per degree change in the fuel temperature. The physical property of fuel pellet material (uranium-28) that causes the uranium to absorb more neutrons away from the fission process as fuel pellet temperature increases. This acts to stabilize power reactor operations. This coefficient is also known as the Doppler coefficient.
Fusion (thermonuclear reaction)	A nuclear reaction characterized by the joining together of light nuclei to form heavier nuclei, the energy for the reaction being provided by violent thermal agitation of particles at very high temperatures. If the colliding particles are properly chosen and the agitation is violent enough, there will be a release of energy from the reaction. The energy of the stars is derived from such reactions.

G

Term	Definition
Gap	The space inside a reactor fuel rod that exists between the fuel pellet and the fuel rod cladding.
Gamma Ray (gamma radiation)	High-energy, short wavelength, electromagnetic radiation (a packet of energy) emitted from the nucleus. Gamma radiation frequently accompanies alpha and beta emissions and always accompanies fission. Gamma rays are very penetrating and are best stopped or shielded by dense materials, such as lead or uranium. Gamma rays are similar to x-rays.
Gas-Cooled Reactor	A nuclear reactor in which a gas is the coolant.

G

Term	Definition
Gases	Normally, formless fluids that completely fill the space, and take the shape of, their container.
Gaseous Diffusion (plant)	A method of isotopic separation based on the fact that gas atoms of molecules with different masses will diffuse through a porous barrier (or membrane) at different rates. This method is used to separate uranium-235 from uranium-238. It requires large gaseous diffusion plants and enormous amounts of electrical power.
Geiger-Mueller Counter	A radiation detection and measuring instrument. It consists of a gas-filled tube containing electrodes, between which there is an electrical voltage, but no current flowing. When ionizing radiation passes through the tube, a short, intense pulse of current passes from the negative electrode to the positive electrode and is measured or counted. The number of pulses per second measures the intensity of the radiation field. It was named for Hans Geiger and W. Mueller, who invented it in the 1920's. It is sometimes called simply a Geiger counter or a G-M counter.
Graphite	A form of carbon, similar to the lead used in pencils, used as a moderator in some nuclear reactors.
Gray (Gy)	The unit of absorbed radiation dose equal to 1 Joule/kilogram. 1 Gy = 100 rad.

H

Term	Definition
Halflife	The time in which one half of the atoms of a particular radioactive substance disintegrates into another nuclear form. Measured half-lives vary from millionths of a second to billions of years. Also called physical or radiological halflife.
Halflife, Biological	The time required for the body to eliminate one half of the material taken in by natural biological means.
Halflife, Effective	The time required for a radionuclide contained in a biological system, such as a human or an animal, to reduce its activity by one half as a combined result of radioactive decay and biological elimination.
Half-thickness	The thickness of any given absorber that will reduce the intensity of a beam of radiation to one half of its initial value.

H

Term	Definition
Head, Reactor Vessel	The removable top section of a reactor pressure vessel. It is bolted in place during power operation and removed during refueling to permit access of fuel handling equipment to the core.
Health Physics	The science concerned with recognition, evaluation, and control of health hazards from ionizing radiation.
Heat Exchanger	Any device that transfer heat from one fluid (liquid or gas) to another fluid or to the environment.
Heat Sink	Anything that absorbs heat, usually part of the environment, such as the air, river, or outer space.
Heatup	The rise in temperature of the reactor fuel rods resulting from an increase in the rate of fission in the core.
Heavy Water (D_2O)	Water containing significantly more than the natural proportions (one in 6,500) of heavy hydrogen (deuterium) atoms to ordinary hydrogen atoms. Heavy water is used as a moderator in some reactors because it slows down neutrons effectively and also has a low probability of absorption of neutrons.
Heavy Water Moderated Reactor	A reactor that uses heavy water as its moderator. Heavy water is an excellent moderator and thus permits the use of inexpensive (unenriched) uranium as a fuel.
High Radiation Area	Any area with dose rates greater than 100 mrems in one hour 30 cm from the source or from any surface through which the radiation penetrates. These areas must be posted as high radiation areas and access into these areas is maintained under strict control.
Hot	A colloquial term meaning highly radioactive.
Hot Spot	The region in a radiation/contamination area in which the level of radiation/contamination is noticeably greater than in neighboring regions in the area.

I

Term	Definition
Induced Radioactivity	Radioactivity that is created when stable substances are bombarded by ionizing radiation. For example, the stable isotope cobalt-59 becomes the radioactive isotope cobalt-60 under neutron bombardment.
Internal Radiation	Nuclear radiation resulting from radioactive substances in the body. Some examples are iodine-131 (found in the thyroid gland) and strontium-90 and plutonium-239 (found in bone).
Ion	1) An atom that has too many or too few electrons, causing it to have an electrical charge, and therefore, be chemically active. 2) An electron that is not associated (in orbit) with a nucleus.
Ionization	The process of adding one or more electrons to, or removing one or more electrons from, atoms or molecules, thereby creating ions. High temperatures, electrical discharges, or nuclear radiations can cause ionizations.
Ionization Chamber	An instrument that detects and measures ionizing radiation by measuring the electrical current that flows when ionizing radiation ionizes gas in a chamber, making the gas a conductor of electricity.
Ionizing Radiation	Any radiation capable of displacing electrons from atoms or molecules, thereby producing ions. Some examples are alpha, beta, gamma, x-rays, neutrons, and ultraviolet light. High doses of ionizing radiation may produce severe skin or tissue damage.
Irradiation	Exposure to radiation.
Isotone	One of several different nuclides having the same number of neutrons in their nuclei.
Isotope	One of two or more atoms with the same number of protons, but different numbers of neutrons in their nuclei. Thus, carbon-12, carbon-13, and carbon-14 are isotopes of the element carbon, the numbers denoting the approximate atomic weights. Isotopes have very nearly the same chemical properties, but often different physical properties (for example, carbon-12 and carbon-13 are stable, carbon-14 is radioactive).

I

Term	Definition
Isotope Separation	The process of separating isotopes from one another, or changing their relative abundances, as by gaseous diffusion or electromagnetic separation. Isotope separation is a step in the isotopic enrichment process.
Isotopic Enrichment	A process by which the relative abundance of the isotopes of a given element are altered, thus producing a form of the element that has been enriched in one particular isotope and depleted in its other isotopic forms.

K

Term	Definition
Kilo-	A prefix that multiplies a basic unit by 1,000.
Kilovolt	The unit of electrical potential equal to 1,000 volts.
Kinetic Energy	The energy that a body possesses by virtue of its mass and velocity. Also called the energy of motion.

L

Term	Definition
Lethal Dose 50/60 (LD 50/60)	The dose of radiation expected to cause death within 60 days to 50% of those exposed. Generally accepted to range from 400 to 450 rem received over a short period of time.
Light Water	Ordinary water (H_2O) as distinguished from heavy water (D_2O).
Light Water Reactor	A term used to describe reactors using ordinary water as coolant, including boiling water reactors (BWRs) and pressurized water reactors (PWRs), the most common type used in the United States.
Limiting Conditions for Operation	The section of Technical Specifications that identifies the lowest functional capability or performance level of equipment required for safe operation of the facility.

L

Term	Definition
Limiting Safety System Settings	Settings for automatic protective devices related to those variables having significant safety functions. Where a limiting safety system setting is specified for a variable on which a safety limit has been placed, the setting will assure that automatic protective action will correct the abnormal situation before a safety limit is exceeded.
Linear Heat Generation Rate	The heat generation rate per unit length of fuel rod, commonly expressed in kilowatts per foot of fuel rod (kw/ft).
Loop	In a pressurized water reactor, the coolant flow path through piping from the reactor pressure vessel to the steam generator, to the reactor coolant pump, and back to the reactor pressure vessel. Large PWRs may have as many as four separate loops.
Loss of Coolant Accident (LOCA)	Those postulated accidents that result in a loss of reactor coolant at a rate in excess of the capability of the reactor makeup system from breaks in the reactor coolant pressure boundary, up to and including a break equivalent in size to the double-ended rupture of the largest pipe of the reactor coolant system.
Low Population Zone (LPZ)	An area of low population density often required around a nuclear installation. The number and density of residents is of concern in emergency planning so that certain protective measures (such as notification and instructions to residents) can be accomplished in a timely manner.

M

Term	Definition
Mass-Energy Equation	The equation developed by Albert Einstein which is usually given as: $E = mc^2$ showing that, when the energy of a body changes by an amount E (no matter what form the energy takes), the mass, m, of the body will change by an amount equal to E/c^2. The factor c^2, the square of the speed of light in a vacuum, may be regarded as the conversion factor relating units of mass and energy. The equation predicted the possibility of releasing enormous amounts of energy by the conversion of mass to energy. It is also called the Einstein Equation.

Term	Definition
Mass Number	The number of nucleons (neutrons and protons) in the nucleus of an atom. Also known as the atomic weight of an atom.
Maximum Exposed Organ	The body organ receiving the highest radiation dose.
Mega-	A prefix that multiplies a basic unit by 1,000,000.
Megacurie	One million curies.
Micro-	A prefix that divides a basic unit into one million parts.
Microcurie	One millionth of a curie.
Microsecond	One millionth of a second.
Mill Tailings	Natural radioactive residue from the processing of uranium ore into yellowcake in a mill. Although the milling process recovers about 93% of the uranium, the residues, or tailings, contain several radioactive elements, including uranium, thorium, radium, polonium, and radon.
Milli-	A prefix that divides a basic unit by 1,000.
Millirem	One thousandth of a rem.
Milliroentgen	One thousandth of a roentgen.
Moderator	A material, such as ordinary water, heavy water, or graphite, that is used in a reactor to slow down high-velocity neutrons, thus increasing the likelihood of fission.
Moderator Temperature Coefficient of Reactivity	The change in reactivity per degree change in moderator temperature due to the property of reactor moderator to slow down fewer neutrons as its temperature increases. This acts to stabilize power reactor operations.
Molecule	A group of atoms held together by chemical forces. A molecule is the smallest unit of a compound that can exist by itself and retain all of its chemical properties.
Monitoring	Periodic or continuous determination of the amount of ionizing radiation or radioactive contamination present in an occupied region, as a safety measure, for the purpose of health protection.

Term	Definition
Nano-	A prefix that divides a basic unit by one billion.
Nanocurie	One billionth of a curie.
Natural Circulation	The circulation of the coolant in the reactor coolant system without the use of the reactor coolant pumps. The circulation is due to the natural convection resulting from the different densities of relative cold and heated portions of the system.
Natural Uranium	Uranium as found in nature. It contains 0.7% uranium-235, 99.3% uranium-238, and a trace of uranium-234.
Neutron	An uncharged elementary particle with a mass slightly greater than that of the proton, and found in the nucleus of every atom heavier than hydrogen.
Neutron Capture	The process in which an atomic nucleus absorbs or captures a neutron.
Neutron Chain Reaction	A process in which some of the neutrons released in one fission event cause other fissions to occur. There are three types of chain reactions: 1) Non-sustaining chain reaction - An average of less than one fission is produced by the neutrons released by each previous fission (reactor subcriticality). 2) Sustaining chain reaction - An average of exactly one fission is produced by the neutrons released by each previous fission (reactor criticality). 3) Multiplying chain reaction - An average of more than one fission is produced by the neutrons released by previous fission (reactor supercriticality).
Neutron Flux	The number of neutrons passing through a unit area per second.
Neutron Generation	The release, thermalization, and absorption of fission neutrons by a fissile material and the fission of that material producing a second generation of neutrons. In a typical reactor system, there are about 40,000 generations of neutrons every second.

N

Term	Definition
Neutron Leakage	Neutrons that escape from the vicinity of the fissionable material in a reactor core. Neutrons that leak out of the fuel region are no longer available to cause fission and must be absorbed by shielding placed around the reactor pressure vessel for that purpose.
Neutron Source	A radioactive material (decays by neutron emission) that can be inserted into a reactor to ensure that a sufficient quantity of neutrons is available to register on neutron detection equipment for power level indication.
Neutron, Thermal	A neutron that has (by collision with other particles) reached an energy state equal to that of its surroundings.
Noble Gas	A gaseous chemical element that does not readily enter into chemical combination with other elements, such as an inert gas.
Non-Vital Plant Systems	Systems at a nuclear facility that may or may not be necessary for the operation of the facility (i.e., power production), but that would have little or no effect on public health and safety should they fail. These systems are not safety related.
Nozzle	As used in PWRs and BWRs, the interface for fluid (inlet and outlet) between reactor plant components (pressure vessel, coolant pumps, steam generators, etc.) and their associated piping systems.
Nuclear Energy	The energy liberated by a nuclear reaction (fission or fusion) or by radioactive decay.
Nuclear Force	A powerful, short-ranged, attractive force that holds together the particles inside an atomic nucleus.
Nuclear Power Plant	An electrical generating facility using a nuclear reactor as its power (heat) source.
Nuclear Steam Supply System	The reactor and the reactor coolant pumps (and steam generators for a pressurized water reactor) and associated piping in a nuclear power plant used to generate the steam needed to drive the turbine generator unit.
Nucleon	Common name for a constituent particle of the atomic nucleus. At present, applied to protons and neutrons, but may include any other particles found to exit in the nucleus.

N

Term	Definition
Nucleus; nuclei (plural)	The small, central, positively charged region of an atom that carries essentially all of the mass. Except for the nucleus of ordinary (light) hydrogen, which has a single proton, all atomic nuclei contain both protons and neutrons. The number of protons determines the total positive charge, or atomic number. This is the same for all the atomic nuclei of a given chemical element. The total number of neutrons and protons is called the mass number.
Nuclide	A general term referring to all known isotopes, both stable (279) and unstable (about 5,000), of the chemical elements.

O

Term	Definition
Operable	A system, subsystem, train, component, or device shall be operable or have operability when it is capable of performing its specified function(s), and when all necessary attendant instrumentation, controls, electrical power, cooling or seal water, lubrication, or other auxiliary equipment that are required for the system, subsystem, train, component, or device to perform its function(s) are also capable of performing their related support function(s).
Operating Basis Earthquake	An earthquake that could be expected to affect the plant site, but for which the plant power production equipment is designed to remain functional without undue risk to public health and safety.
Operational Mode	An operational mode shall correspond to any one inclusive combination of core reactivity condition, power level, and average reactor coolant temperature. An example of an operation mode table that would be found in a plant's Technical Specifications is given below:

Mode	Reactivity Condition K_{eff}	% Rated Thermal Power	Average Coolant Temperature
1. Power Operation	≥ 0.99	> 5%	$\geq 350°F$
2. Startup	≥ 0.99	< 5%	$\geq 350°F$
3. Hot Standby	< 0.99	0	$\geq 350°F$
4. Hot Shutdown	< 0.99	0	$350°F > T_{avg} > 200°F$
5. Cold Shutdown	< 0.99	0	$\leq 200°F$
6. Refueling	≤ 0.95	0	$\leq 140°F$

P

Term	Definition
Parent	A radionuclide that upon radioactive decay or disintegration yields a specific nuclide (the daughter).
Parts per Million (ppm)	Parts (molecules) of a substance contained in a million parts of another substance (water, for example).
Pellet, Fuel	As used in PWRs and BWRs, a fuel pellet is a small cylinder approximately 3/8" in diameter and 5/8" in length, consisting of uranium fuel in a ceramic form - uranium dioxide, UO_2. Typical fuel pellet enrichments range from 2.0% to 4.5% uranium-235.
Periodic Table	An arrangement of chemical elements in order of increasing atomic number. Elements of similar properties are placed one under the other, yielding groups or families of elements. Within each group, there is a variation of chemical and physical properties, but in general, there is a similarity of chemical behavior within each group.
Personnel Monitoring	The use of survey meters to determine the amount of radioactive contamination on an individual, or the use of dosimetry to determine an individual's radiation dose.
Photodosimetry	The determination of the cumulative dose of ionizing radiation by use of photographic film.
Photon	A quantum (or packet) of energy emitted in the form of electromagnetic radiation. Gamma rays and x-rays are examples of photons.
Pico-	A prefix that divides a basic unit by one trillion.
Picocurie	One trillionth of a curie.
Pig	A container (usually lead) used to ship or store radioactive materials. The thick walls protect the person handling the container from radiation. Large containers are commonly called casks.
Pile	A nuclear reactor. It is called a pile because the earliest reactors were "piles" of graphite and uranium blocks.
Planned Special Exposure	An infrequent exposure to radiation, separate from, and in addition to, the annual dose limits.

Term	Definition
Plutonium	A heavy, radioactive, manmade metallic element with atomic number 94. Its most important isotope is fissile plutonium-239, which is produced by neutron irradiation of uranium-238.
Pocket Dosimeter	A small ionization detection instrument that indicates radiation exposure directly. An auxiliary charging device is usually necessary.
Poison (neutron poison)	In reactor physics, a material, other than fissionable material, in the vicinity of the reactor core that will absorb neutrons. The addition of poisons, such as control rods or boron, into the reactor is said to be an addition of negative reactivity.
Pool Reactor	A reactor in which the fuel elements are suspended in a pool of water that serves as the reflector, moderator, and coolant. Popularly called a "swimming pool reactor," it is used for research and training, nor for electrical generation.
Positron	Particle equal in mass, but opposite in charge, to the electron (a positive electron).
Power Coefficient of Reactivity	The change in reactivity per percent change in power. The power coefficient is the summation of the moderator temperature coefficient of reactivity, the fuel temperature coefficient of reactivity, and the void coefficient of reactivity.
Power Defect	The total amount of reactivity added due to a given change in power. It can also be expressed as the integrated power coefficient over the range of the power change.
Power Reactor	A reactor designed to produce heat for electric generation, as distinguished from reactors used for research, for producing radiation or fissionable materials, or for reactor component testing.
Pressure Vessel	A strong-walled container housing the core of most types of power reactors. It usually also contains the moderator, neutron reflector, thermal shield, and control rods.
Pressurized Water Reactor (PWR)	A power reactor in which heat is transferred from the core to a heat exchanger by high temperature water kept under high pressure in the primary system. Steam is generated in the secondary circuit. Many reactors producing electric power in the United States are pressurized water reactors.

P

Term	Definition
Pressurizer	A tank or vessel that acts as a head tank (or surge volume) to control the pressure in a pressurized water reactor.
Primary System	A term that may be used for referring to the reactor coolant system.
Proportional Counter	An instrument in which an electronic detection system receives pulses that are proportional to the number of ions formed in a gas-filled tube by ionizing radiation.
Proton	An elementary nuclear particle with a positive electric charge located in the nucleus of an atom.

Q

Term	Definition
Quadrant Power Tilt Ratio (QPTR)	The ratio of the maximum upper excore detector calibrated output to the average of the upper excore detector calibrated outputs, or the ratio of the maximum lower excore detector calibrated output to the average of the lower excore detector calibrated outputs, whichever is greater.
Quality Factor	The factor by which the absorbed dose (rad) is to be multiplied to obtain a quantity that expresses, on a common scale for all ionizing radiation, the biological damage (rem) to exposed persons. It is used because some types of radiation, such as alpha particles, are more biologically damaging than other types.
Quantum Theory	The concept that energy is radiated intermittently in units of definite magnitude called quanta, and absorbed in a like manner.

R

Term	Definition
Rad	Acronym for radiation absorbed dose, the basic unit of absorbed dose of radiation. A dose of one rad means the absorption of 100 ergs (a small but measurable amount of energy) per gram of absorbing tissue.
Radiac	An acronym derived from "radioactivity detection, indication, and computation." It is a generic term applied to radiological instruments or equipment.

Term	Definition
Radiation, Nuclear	Particles (alpha, beta, neutrons) or photons (gamma) emitted from the nucleus of an unstable radioactive atom as a result of radioactive decay.
Radiation Area	Any area with radiation levels greater than 5 mrem in one hour at 30 cm from the source or from any surface through which the radiation penetrates.
Radiation Detection Instrument	A device that detects and records the characteristics of ionizing radiation.
Radiation Shielding	Reduction of radiation by interposing a shield of absorbing material between any radioactive source and a person, work area, or radiation-sensitive device.
Radiation Sickness (syndrome)	The complex of symptoms characterizing the disease known as radiation injury, resulting from excessive exposure of the whole body (or large part of the whole body) to ionizing radiation. The earliest of these symptoms are nausea, fatigue, vomiting, and diarrhea, which may be followed by loss of hair (epilation), hemorrhage, inflammation of the mouth and throat, and general loss of energy. In severe cases, where the radiation exposure has been relatively large, death may occur within two to four weeks. Those who survive 6 weeks after the receipt of a single large dose of radiation may generally be expected to recover.
Radiation Source	Usually a manmade sealed source of radiation used in teletherapy, radiography, as a power source for batteries, or in various types of industrial gauges. Machines such as accelerators and radioisotope generators and natural radionuclides may be considered sources.
Radiation Standards	Exposure standards, permissible concentrations, rules for safe handling, regulations for transportation, regulations for industrial control of radiation, and control of radioactive material by legislative means.
Radiation Warning Symbol	An officially prescribed symbol (a magenta or black trefoil) on a yellow background that must be displayed where certain quantities of radioactive materials are present or where certain doses of radiation could be received.
Radioactive	Exhibiting radioactivity or pertaining to radioactivity.

Term	Definition
Radioactive Contamination	Deposition of radioactive material in any place where it may harm persons or equipment.
Radioactive Isotope	A radioisotope.
Radioactive Series	A succession of nuclides, each of which transforms by radioactive disintegration into the next until a stable nuclide results. The first member is called the parent, the intermediate members are called daughters, and the final stable member is called the end product.
Radioactivity	The spontaneous emission of radiation, generally alpha or beta particles, often accompanied by gamma rays, from the nucleus of an unstable isotope.
Radiography	The making of a shadow image on photographic film by the action of ionizing radiation.
Radioisotope	An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation. Approximately 5,000 natural and artificial radioisotopes have been identified.
Radiological Survey	The evaluation of the radiation hazards accompanying the production, use, or existence of radioactive materials under a specific set of conditions. Such evaluation customarily includes a physical survey of the disposition of materials and equipment, measurements or estimates of the levels of radiation that may be involved, and a sufficient knowledge of processes affecting these materials to predict hazards resulting from expected or possible changes in materials or equipment.
Radiology	That branch of medicine dealing with the diagnostics and therapeutic applications of radiant energy, including x-rays and radioisotopes.
Radionuclide	A radioisotope.
Radiosensitivity	The relative susceptibility of cells, tissues, organs, organisms, or other substances to the injurious action of radiation.
Radium (Ra)	A radioactive metallic element with atomic number 88. As found in nature, the most common isotope has a mass number of 226. It occurs in minute quantities associated with uranium in pitchblend, carnotite, and other minerals.

Term	Definition
Radon (Rn)	A radioactive element that is one of the heaviest gases known. Its atomic number is 86. It is a daughter of radium.
Reaction	Any process involving a chemical or nuclear change.
Reactivity	A term expressing the departure of a reactor system from criticality. A positive reactivity addition indicates a move toward supercriticality (power increase). A negative reactivity addition indicates a move toward subcriticality (power decrease).
Reactor Coolant System	The cooling system used to remove energy from the reactor core and transfer that energy either directly or indirectly to the steam turbine.
Reactor, Nuclear	A device in which nuclear fission may be sustained and controlled in a self-supporting nuclear reaction. The varieties are many, but all incorporate certain features, including fissionable material or fuel, a moderating material (unless the reactor is operated on fast neutrons), a reflector to conserve escaping neutrons, provisions for removal of heat, measuring and controlling instruments, and protective devices.
Recycling	The reuse of fissionable material after is has been recovered by chemical processing from spent or depleted reactor fuel, reenriched, and then refabricated into new fuel elements.
Reflector	A layer of material immediately surrounding a reactor core that scatters back (or reflects) into the core many neutrons that would otherwise escape. The returned neutrons can then cause more fissions and improve the neutron economy of the reactor. Common reflector materials are graphite, beryllium, water, and natural uranium.
Rem	The special unit of dose equivalent. The dose equivalent equals the absorbed dose multiplied by the quality factor.
Restricted Area	Any area to which access is controlled for the protection of individuals from exposure to radiation and radioactive materials.
Roentgen (R)	A unit of exposure to ionizing radiation. It is the amount of gamma or x-rays required to produce ions resulting in a charge of 0.000258 coulombs/kilogram of air under standard conditions. Named after Wilhelm Roentgen, German scientist who discovered x-rays in 1895.

S

Term	Definition
Safeguards	The protection of special nuclear material (SNM) to prevent theft, loss, or sabotage.
Safe Shutdown Earthquake	A design-basis earthquake.
Safety Injection	The rapid insertion of a chemically soluble neutron poison (such as boric acid) into the reactor coolant system to ensure reactor shutdown.
Safety Limit	A limit placed upon important process variables which are found to be necessary to reasonably protect the integrity of the physical barriers which guard against the uncontrolled release of radioactivity.
Safety Related	The managerial controls, administrative documents, operating procedures, systems, structures, and components that have been designed to mitigate the consequences of postulated accidents that could cause undue risk to public health and safety.
Scattered Radiation	Radiation that, during its passage through a substance, has been changed in direction. It may also have been modified by a decrease in energy. It is one form of secondary radiation.
Scintillation Detector	The combination of phosphor, photomultiplier tube and associated electronic circuits for counting light emissions produced in the phosphor by ionizing radiation.
Scram	The term used to mean the sudden shutting down of a nuclear reactor, usually by rapid insertion of control rods, either automatically or manually by the reactor operator. May also be called a reactor trip. It is actually an acronym for safety control rods axe man, the man assigned to insert the emergency rod on the first reactor (the Chicago pile).
Secondary Radiation	Radiation originating as the result of absorption of other radiation in matter. It may be either electromagnetic or particulate in nature.
Secondary System	The steam generator tubes, steam turbine, condenser, and associated pipes, pumps, and heaters used to convert the heat energy of the reactor coolant system into mechanical energy for electrical generation. Most commonly used in reference to pressurized water reactors.
Seismic Category I	A term used to define structures, systems, and components that are designed and built to withstand the maximum potential (earthquake) stresses for the particular region that a nuclear plant is sited.

S

Term	Definition
Shielding	Any material or obstruction that absorbs radiation and thus tends to protect personnel or materials from the effects of ionizing radiation.
Shutdown	A decrease in the rate of fission (and heat production) in a reactor (usually by the insertion of control rods into the core).
Shutdown Margin	The instantaneous amount of reactivity by which the reactor is subcritical or would be subcritical from its present condition assuming all full-length rod cluster assemblies (shutdown and control) are fully inserted except for the single rod cluster assembly of highest reactivity worth, which is assumed to be fully withdrawn.
Sievert (Sv)	The unit of dose equivalent equal to 1 Joule/kilogram. 1 Sv = 100 rem.
Somatic Effects of Radiation	Effects of radiation limited to the exposed individual, as distinguished from genetic effects, which may also affect subsequent unexposed generations.
Special Nuclear Material	Includes plutonium, uranium-233, or uranium enriched in the isotopes uranium-233 or uranium-235.
Spent (depleted) Fuel	Nuclear reactor fuel that has been used to the extent that it can no longer effectively sustain a chain reaction.
Spent Fuel Pool	An underwater storage and cooling facility for fuel elements that have been removed from a reactor.
Stable Isotope	An isotope that does not undergo radioactive decay.
Startup	An increase in the rate of fission (and heat production) in a reactor (usually by the removal of control rods from the core).
Stay Time	The period during which personnel may remain in a restricted area before accumulating some permissible dose.
Steam Generator	The heat exchanger used in some reactor designs to transfer heat from the primary (reactor coolant) system to the secondary (steam) system. This design permits heat exchange with little or no contamination of the secondary system equipment.
Subcriticality	The condition of a nuclear reactor system when the rate of production of fission neutrons is lower than the rate of production in the previous generation due to increased neutron leakage and poisons.

S

Term	Definition
Subcritical Mass	An amount of fissionable material insufficient in quantity or of improper geometry to sustain a fission chain reaction.
Supercriticality	The condition for increasing the level of operation of a reactor. The rate of fission neutron production exceeds all neutron losses, and the overall neutron population increases.
Supercritical Reactor	A reactor in which the power level is increasing.
Superheating	The heating of a vapor, particularly steam, to a temperature much higher than the boiling point at the existing pressure. This is done in some power plants to improve efficiency and to reduce water damage to the turbine.
Survey	A study to: 1) Find the radiation or contamination level of specific objects or locations within an area of interest; 2) Locate regions of higher-than-average intensity, i.e., hot spots.
Survey Meter	Any portable radiation detection instrument especially adapted for inspecting an area to establish the existence and amount of radioactive material present.

T

Term	Definition
Tenth Thickness	The thickness of a given material that will decrease the amount (or dose) of radiation to one-tenth of the amount incident upon it. Two tenth thicknesses will reduce the dose by a factor of 10 x 10 (or 100) and so on.
Terrestrial Radiation	The portion of the natural radiation (background) that is emitted by naturally occurring radioactive materials in the earth.
Thermal Breeder Reactor	A breeder reactor in which the fission chain reaction is sustained by thermal neutrons.
Thermalization	The process undergone by high-energy (fast) neutrons as they lose energy by collision.
Thermal Power	The total core heat transfer rate to the reactor coolant.

Term	Definition
Thermal Reactor	A reactor in which the fission chain reaction is sustained primarily by thermal neutrons. Most current reactors are thermal reactors.
Thermal Shield	A layer, or layers, of high-density material located within a reactor pressure vessel or between the vessel and the biological shield to reduce radiation heating in the vessel and the biological shield.
Thermoluminescent Detector	A device used to measure radiation by measuring the amount of visible light emitted from a crystal in the detector when exposed to radiation.
Thermonuclear	An adjective referring to the process in which very high temperatures are used to bring about the fusion of light nuclei, such as those of the hydrogen isotopes deuterium and tritium, with the accompanying liberation of energy.
Transient	A change in the reactor coolant system temperature and/or pressure due to a change in power output of the reactor. Transients can be caused by adding or removing neutron poisons, by increasing or decreasing electrical load on the turbine generator, or by accident conditions.
Trip, Reactor	A term that is used by pressurized water reactors for a reactor scram.
Tritium	A radioactive isotope of hydrogen (one proton, two neutrons). Because it is chemically identical to natural hydrogen, tritium can easily be taken into the body by any ingestion path. It decays by beta emission. It has a radioactive halflife of about 12.5 years.
Turbine	A rotary engine made with a series of curved vanes on a rotating shaft, usually turned by water or steam. Turbines are considered the most economical means to turn large electrical generators.
Turbine Generator (TG)	A steam (or water) turbine directly coupled to an electrical generator. The two devices are often referred to as one unit.

U

Term	Definition
Ultraviolet	Electromagnetic radiation of a wavelength between the shortest visible violet and low energy x-rays.
Unrestricted Area	The area outside the owner-controlled portion of a nuclear facility (usually the site boundary). An area in which a person could not be exposed to radiation levels in excess of 2 mrem in any one hour from external sources.
Unstable Isotope	A radioisotope.
Uranium (U)	A radioactive element with the atomic number 92 and, as found in natural ores, an atomic weight of approximately 238. The two principal natural isotopes are uranium-235 (0.7% of natural uranium), which is fissile, and uranium-238 (99.3% of natural uranium), which is fissionable by fast neutrons and is fertile. Natural uranium also includes a minute amount of uranium-234.

V

Term	Definition
Vapor	The gaseous form of substances that are normally in liquid or solid form.
Void	An area of lower density in a moderating system (such as steam bubbles in water) that allows more neutron leakage than does the more dense material around it.
Very High Radiation Area	An area in which radiation levels exceed 500 rad in one hour at 1 meter from the source or from any surface that the radiation penetrates.
Void Coefficient of Reactivity	The change in reactivity per percent change in void content due to an increase in the neutron leakage as the density of the moderator decreases with an increasing void content.

W

Term	Definition
Waste, Radioactive	Solid, liquid, and gaseous materials from nuclear operations that are radioactive or become radioactive and for which there is no further use. Wastes are generally classified as high level (having radioactivity concentrations of hundreds of thousands of curies per gallon or foot), low level (in the range of 1 microcurie per gallon or foot), or intermediate level (between these extremes).
Whole-Body Counter	A device used to identify and measure the radioactive material in the body (body burden) of human beings and animals. It uses heavy shielding to keep out background radiation and ultrasensitive radiation detectors and electronic counting equipment.
Whole-Body Exposure	An exposure of the body to radiation, in which the entire body, rather than an isolated part, is irradiated. Where a radioisotope is uniformly distributed throughout the body tissues, rather than being concentrated in certain parts, the irradiation can be considered as whole-body exposure.
Wipe Sample	A sample made for the purpose of determining the presence of removable radioactive contamination on a surface. It is done by wiping, with slight pressure, a piece of soft filter paper over a representative type of surface area. It is also known as a "swipe sample," or "smear."

X

Term	Definition
X-rays	Penetrating electromagnetic radiation (photon) having a wavelength that is much shorter than that of visible light. These rays are usually produced by excitation of the electron field around certain nuclei. In nuclear reactions, it is customary to refer to photons originating in the nucleus as gamma rays, and to those originating in the electron field of the atoms as x-rays. These rays are sometimes called roentgen rays after their discoverer, W. K. Roentgen.

Y

Term	Definition
Yellowcake	A solid uranium-oxygen compound (U_3O_8) that takes it name from its color and texture. It is a product of the uranium milling process and is the feed material used for fuel enrichment and pellet fabrication.

List of Abbreviations & Acronyms

Appendix B

A

AAM airborne activity monitor

AB auxiliary boiler

ABB-CE Asea Brown Boveri-Combustion Engineering, Inc.

ABT automatic bus transfer

ABWR advanced boiling water reactor

ac alternating current

ACB air-operated circuit breaker

ACC accumulator

ACRS Advisory Committee on Reactor Safeguards

ADAMS Agencywide Documents Access and Management System

ADS automatic depressurization system
automatic dispatch system

ADV atmospheric dump valve

AE air ejector

AEDE annual effective dose equivalent

AFD axial flux difference

AFP auxiliary feedwater pump

AFW auxiliary feedwater

AFWAS auxiliary feedwater actuation system

AGCR advanced gas-cooled reactor

AHU air-handling unit

AIT augmented inspection team

ALARA as low as reasonably achievable

ALARP as low as reasonably practicable

ALI annual level of intake

ALPHGR average linear planar heat generation rate

ALWR advanced light-water reactor

AMSAC ATWS (anticipated transient without scram) mitigating system actuation circuitry

AMU atomic mass unit

ANS American Nuclear Society

ANSI American National Standards Institute

AO abnormal occurrence
auxiliary operator
air operator
axial offset

AOI abnormal operating instruction

AOP abnormal operating procedure

AOV air-operated valve

API absolute position indication

APLHGR average planar linear heat generation rate

APM air particulate monitor

APRM average power range monitor

AP600 Advanced Plant, 600 MWe

APSR axial power shaping rod

APWR advanced pressurized-water reactor

ARM area radiation monitor

ARO all rods out

ARP alarm response procedure
annunciator response procedure

ARPI absolute rod position indication

ARS — acute radiation syndrome

ASLAB — Atomic Safety and Licensing Appeal Board

ASLAP — Atomic Safety and Licensing Appeal Panel

ASLB — Atomic Safety and Licensing Board

ASLBP — Atomic Safety and Licensing Board Panel

ASME — American Society of Mechanical Engineers

ASME Code — American Society of Mechanical Engineers Boiler and Pressure Vessel Code

ASTM — American Society for Testing and Materials

ASW — auxiliary service water

ATOG — anticipated transient operating guideline

ATR — advanced test reactor

ATWS — anticipated transient without scram

AVB — anti-vibration bar

AVT — all-volatile treatment

AVV — atmospheric vent valve

B

BAST — boric acid storage tank

BAT — backup auxiliary transformer
boric acid tank

BCMS — boron concentration measurement system

BD — blowdown

BIT — boron injection tank

BOL — beginning of life

BOP — balance of plant

BPR — burnable poison rod

BPRA — burnable poison rod assembly

BPV — bypass valve

Bq — becquerel

BRC — below regulatory concern

BRS — boron recycle system

B/S — bistable

BST — boron storage tank

BTRS — boron thermal regeneration system

BUSS — backup scram system

B&W — Babcock & Wilcox Co. (now Framatome)

BWR — boiling water reactor

BWROG — Boiling Water Reactor Owners Group

BWST — borated water storage tank

C

CAC — containment atmosphere control
containment air cooler

CANDU — Canadian Deuterium-Natural Uranium Reactor
Canadian Deuterium Uranium Reactor
Canadian Natural-Uranium, Heavy-Water-Moderated and Cooled Power Reactor

CAOC — constant axial offset control

CAP — corrective action program

CAR condenser air removal
correction action report

CARS condenser air removal system

CAS compressed air system

CB containment building
control building

CBP condensate booster pump

CCDF conditional core damage frequency

CCF common-cause failure

CCGC containment combustible gas control

CCP centrifugal charging pump

CCW component cooling water
condenser circulating water

CCWS component cooling water system
component cooling water system

C/D cooldown

CDF core damage frequency

CEA control element assembly

CEAC control element assembly calculator

CEADS control element assembly drive system

CEDM control element drive mechanism

CEDMCS control element drive mechanism control system

CEDS control element drive system

CEOG Combustion Engineering Owners Group

CET core exit thermocouple

CFC containment fan cooler unit

CFR Code of Federal Regulations

CFS condensate and feedwater system
core flood system

CFT core flood tank

CFW condensate and feedwater

CFWS condensate and feedwater system

CGCS combustible gas control system

cGy centigray

CHF critical heat flux

CHFR critical heat flux ratio

Ci curie

CIA containment isolation phase A

CIAS containment isolation actuation signal

CIB containment isolation phase B

CIS containment isolation signal
containment isolation system

CIV combined intercept valve
combined intermediate valve
containment isolation valve

CLA cold leg accumulator

CLCW closed-loop cooling water

CLWR commercial light-water reactor

CMF common-mode failure
core-melt frequency

COG condenser off-gas

COL combined operating license

COLR core operating limits report

COLSS core operating limit supervisory system
core operating limit support system

COPS cold overpressure protection system

CP charging pump
containment purge
coolant pump

C/P current/pneumatic

CPC core protection calculator
core protection computer

CPIS containment purge isolation signal

cpm counts per minute

CPS containment purge system

cps counts per second

CR control rod
control room

CRA control rod assembly

CRD control rod drive

CRDCS control rod drive control system

CRDHS control rod drive hydraulic system

CRDM control rod drive mechanism

CRDS control rod drive system

CREVS control room emergency ventilation system

CRIS control room isolation signal

CRO control room operator

CRPI control rod position indication

CRUD Chalk River unidentified deposits

CS containment spray
core spray

CSAS containment spray actuation signal

CSCC caustic stress-corrosion cracking

CSD cold shutdown

CSF critical safety function

CSHX containment spray heat exchanger

CSIS containment spray injection system

CSP containment spray pump
core spray pump

CSRS containment spray recirculation system

CSS condensate storage system
containment spray system
core spray system

CST condensate storage tank

CSTS condensate storage and transfer system

CT cooling tower
current transformer

CV check valve
containment vessel
control valve

CVC chemical and volume control

CVCS chemical and volume control system

CVIS containment ventilation isolation signal

CW circulating water

CWS circulating water system

D

DAW dry active waste

DBA design-basis accident

DBE design-basis earthquake
design-basis event

DBLOCA design-basis loss-of-coolant accident

dc direct current

DE dose equivalent

DEI dose equivalent iodine

DET	diagnostic evaluation team
DF	decontamination factor
DFBN	debris-filter bottom nozzle
DG	diesel-engine generator diesel generator
D/G	diesel generator
DGB	diesel generator building
DH	decay heat
DHR	decay heat removal
DHRS	decay heat removal system
DMW	demineralized makeup water
DNB	departure from nucleate boiling
DNBR	departure from nucleate boiling ratio
DP	differential pressure
D/P	differential pressure
ΔP	differential pressure
dpm	decades per minute
DRA	dropped rod accident
DRPI	digital rod position indication digital rod position indicator
DRPIS	digital rod position indication system
DT	differential temperature
D/T	differential temperature
ΔT	differential temperature
DTI	diagnostic team inspection
DW	demineralized water drywell
DWMS	demineralized water makeup system
DWS	demineralized water system
DWST	demineralized water storage tank

E

EA	enforcement action
EAB	exclusion area boundary
EAG	emergency action guidelines
EAL	emergency action level equipment air lock
EAP	emergency action plan
EC	eddy current
ECA	emergency contingency action
ECCS	emergency core cooling system
ECCW	emergency core cooling water
ECI	essential controls and instrumentation
ECP	estimated critical position
ECT	eddy current test
ECW	emergency cooling water
EDG	emergency diesel generator
ED/G	emergency diesel generator
EFAS	emergency feedwater actuation signal emergency feedwater actuation system
EFIC	emergency feedwater initiation and control
EFP	electric fire pump
EFPD	effective full-power day equivalent full-power day
EFPH	effective full-power hour

EFS	emergency feedwater system
EFW	emergency feedwater
EFWS	emergency feedwater system
EFWST	emergency feedwater storage tank
EG	emergency generator
EHC	electrohydraulic control
EHR	emergency heat removal
EI	emergency injection engineering instruction
EOC	emergency operations center end of cycle
EOC-RPT	end-of-cycle recirculation pump trip
EOF	emergency operations facility
EOI	emergency operating instruction
EOL	end of life
EOP	emergency operating plan emergency operating procedure
EP	emergency plan emergency procedure
E/P	electrical to pneumatic
EPG	emergency procedure guideline
EPRI	Electric Power Research Institute
EPZ	emergency planning zone
EQ	environmental qualification environmentally qualified equipment qualification
ERCW	emergency raw cooling water essential raw cooling water
ERCWS	emergency raw cooling water system
ERF	emergency response facility
ESF	engineered safety feature
ESFA	engineered safety feature actuation
ESFAS	engineered safety features actuation system
ESW	emergency service water essential service water
ESWS	emergency service water system essential service water system

F

FA	fuel assembly
F/A	fuel assembly
FAI	fail as is
FBR	fast breeder reactor
FC	fail closed flow controller fuel cycle
FCI	fuel coolant interaction
FCV	flow control valve
F/D	filter/demineralizer
FDW	feedwater
FE	flow element fuel element
FERP	fire emergency response plan
FFE	full field exercise
FHB	fuel handling building
FI	flow indicator
FIFO	first in, first out
FME	foreign material exclusion

FO	fail open
FOGG	feed-only-good generator
FP	fire protection fission product full power
FPCCS	fuel pool cooling and cleanup system
FPD	full-power day
FPS	fire protection system
FSAR	final safety analysis report
FSF	fuel storage facility
FSSAR	final standard safety analysis report
FT	flow transmitter
FTA	fault tree analysis
FTC	fuel temperature coefficient
FW	feedwater
FWC	feedwater control
FWCS	feedwater control system
FWIV	feedwater isolation valve
FWLB	feedwater line break
FWRV	feedwater regulating valve
FWS	feedwater supply feedwater system
FWST	fueling water storage tank

G

gBq	gigabecquerel
GDC	general design criterion
GDP	gaseous diffusion plant
GDT	gas decay tank
GET	general employee training
GI	gastrointestinal generic issue
GIF	gamma irradiation facility
GL	generic letter
GM	Geiger-Mueller
GN	general notic
GOI	general operating instruction
GS	gland seal
GSC	gland seal condenser gland steam condenser
GSER	generic safety evaluation report
GSI	generic safety issue
Gy	gray

H

H/A	hand/automatic
HCS	hydrazine control system hydrogen control system
HCU	hydraulic control unit
HCV	hand control valve hydraulic control valve
HE	human error
HEPA	high efficiency particulate air
HEPB	high energy pipe break
HEU	highly enriched uranium
HEX	uranium hexaflouride

HFE	human factors engineering
HFP	hot full power
HFT	hot functional testing
HG	hydrogen gas
HG/NG	hydrogen gas/nitrogen gas
HHSI	high head safety injection
HLW	high level liquid waste high level radioactive waste high level waste
HM	heavy metal
HO	hydraulic operator
HOV	hydraulically operated valve
HP	health physicist health physics high pressure
HPCI	high pressure coolant injection
HPCIS	high pressure coolant injection system
HPCS	high pressure core spray
HPI	high pressure injection
HPIS	high pressure injection system
HPR	high pressure recirculation
HPRS	high pressure recirculation system
HPSI	high pressure safety injection
HPSIP	high pressure safety injection pump
HPSP	high power set point
HPT	high pressure turbine
HPU	hydraulic power unit
HR	hydrogen recombiner
HS	hand switch
HSP	hot shutdown panel
HTGCR	high-temperature gas-cooled reactor
HTGR	high-temperature gas-cooled reactor high temperature gas reactor
HTV	half thickness value
H/U	heatup
HU	hydraulic unit
HUT	holdup tank
HV	hand valve high voltage
H&V	heating and ventilation
HVAC	heating, ventilation, and air conditioning
HVD	heaters, vents, and drains
Hvdc	high-voltage direct current
HW	heavy water hot water hotwell
HWGCR	heavy-water-moderated, gas-cooled reactor
HWLC	hotwell level control
HWR	heavy water reactor
HX	heat exchange heat exchanger
HZP	hot zero power

I

IA	instrument air
I/A	isolation amplifier
IAL	immediate action letter

IAS	instrument air system
IASCC	irradiation-assisted stress-corrosion cracking
I&C	instrumentation and control
ICC	inadequate core cooling
ID	inner diameter inside diameter
IE	initiating event
IFBA	integral fuel burnable absorber
IFM	intermediate flow mixing
IGA	intergranular attack
IGSCC	intergranular stress-corrosion cracking
IHSI	intermediate head safety injection
IHX	intermediate heat exchanger
IM	instrumentation and measurement integrated master
IMS	in-core monitoring system
IN	information notice
INPO	Institute of Nuclear Power Operations
INR	immediate notification report
INX	ion exchange
I/O	input/output
IP	inspection procedure
IPE	individual plant examination
IPEEE	individual plant examination of external events
IR	information request inspection report intermediate range
IRB	inside reactor building
IRC	incident response center inside reactor containment
IRM	intermediate-range monitor
IRP	incident response plan
IRPI	individual rod position indicator
ISFSF	independent spent fuel storage facility
ISFSI	independent spent fuel storage installation
ISGTR	induced steam generator tube rupture
ISI	inservice inspection
ISLOCA	interfacing-systems loss-of-coolant accident
IST	inservice test inservice testing integral systems test
ISTS	Improved Standard Technical Specifications
ITAAC	inspection, test, analysis, and acceptance criterion/criteria
ITC	isothermal temperature coefficient
ITM	in-core temperature monitor
ITMS	in-core temperature monitoring system
IX	ion exchanger

J

JCO	justification for continued operation
JTA	job task analysis/analyses

K

K/A knowledge and abilities

K_{eff} effective multiplication factor

KSAs knowledge, skills, and abilities0

kw kilowatt

L

LA local alarm

LAR license amendment request
licensing action report

LBE licensing-basis event

LBLOCA large-break loss-of-coolant accident

LBP lumped burnable poison

LBPR lumped burnable poison rod

LC level controller
local control
locked closed

LCO limiting condition for operation

LCRM linear count rate meter

LCS level control system

LCV level control valve
local control valve

LD letdown
lethal dose

LDR low dose rate

LDS leak detection system

LER licensee event report

LEU low-enriched uranium

LH low head

LHGR linear heat generation rate

LHR linear heat rate

LHSI low-head safety injection

LI level indicator

LIFO last in, first out

LLD low-level dose

LLRW low-level radioactive waste

LLW low-level radioactive waste
low-level waste

LM local manual

LMTD logarithmic mean temperature difference

LNT linear, no-threshold

LN_2 liquid nitrogen

LO lock open
locked open
lube oil

LOA local operator action

LOCA loss-of-coolant accident

LOCF loss of coolant flow

LOCV loss of condenser vacuum

LOF loss of feedwater
loss of flow

LOFA loss-of-feedwater accident
loss-of-flow accident

LOFC loss of forced circulation
loss of forced cooling

LOFW loss of feedwater

LOHS loss of heat sink

LOMF loss of main feedwater

LOMFW	loss of main feedwater
LOOP	loss of offsite power
LOP	loss of offsite power
LOPAR	low parasitic fuel
LOSP	loss of offsite power loss of station power loss of system pressure
LOST	lube oil storage tank
LP	low pressure
LPCI	low-pressure coolant injection low-pressure core injection
LPCIS	low-pressure coolant injection system
LPCS	low-pressure core spray
LPD	linear power density local power density
LPI	low-pressure injection
LPIS	low-pressure injection system
LPMA	loose-parts-monitor assembly
LPMS	loose-parts monitoring system
LPRM	local power range monitor low-power range monitor
LPRS	low-pressure recirculation system
LPSI	low-pressure safety injection
LPSIP	low-pressure safety injection pump
LPSP	low-power set point
LPT	liquid penetrant testing low-pressure turbine
LPZ	low-population zone
LRA	locked-rotor accident
LS	level switch locked shut
LSA	low specific activity
LSP	level set point
LSSS	limiting safety system setting
LT	level transmitter
LTD	letdown
LTMD	less than minimum detectable
LTOP	low-temperature overpressure protection
LVDT	linear variable differential transformer
LWR	light-water reactor

M

M/A	manual/automatic
MAD	modulating atmospheric dump
MAN	manual
MAPLHGR	maximum average planar linear heat-generation rate maximum average planar linear heat-generation ratio
MAR	maintenance action request
MB	mixed bed
Mbq	megabecquerel
MC	main condenser
MCB	main control board
MCC	motor control center
MCHFR	minimum critical heat flux rate minimum critical heat flux ratio

mCi	millicurie
MCPR	maximum critical power ratio minimum critical power ratio
MCR	main control room
MDA	minimum detectable activity
MDAFWP	motor-driven auxiliary feedwater pump
MDC	maximum dependable capacity minimum detectable concentration
MDCT	mechanical draft cooling tower
MDEFWP	motor-driven emergency feedwater pump
MDL	minimum detectable limit
MDNBR	minimum departure from nucleate boiling ratio
MDU	motion detection unit
MEU	medium-enriched uranium
MeV	million electron volts
MFC	master flow controller
MFCS	main feedwater control system
MFIS	main feedwater isolation signal
MFIV	main feedwater isolation valve
MFP	main feedwater pump
MFPT	main feedwater pump turbine
MFRV	main feedwater regulation valve
MFS	main feedwater system
MFV	main feedwater valve
MFW	main feedwater
MFWCS	main feedwater and condensate system
MFWLB	main feedwater line break
MFWRV	main feedwater regulating valve
MFWV	main feedwater valve
MG	motor generator
M/G	motor generator
M-G	motor generator
MHTGR	modular high-temperature gas-cooled reactor
MIC	microbiologically induced corrosion microbiologically influenced corrosion
MICDS	movable in-core detector system
MIDS	movable instrument drive system
MLHGR	maximum linear heat generation rate maximum linear heat generation ratio
MLO	main lube oil
MLW	mean low water
MO	mixed oxide modulate open motor operator
MOA	memorandum/memoranda of agreement
MOC	middle of cycle minimum operable channel
MODE	maximum organ dose equivalent
MOU	memorandum/memoranda of understanding
MOV	motor-operated valve
MOVATS	motor-operated valve analysis and test system
MOX	mixed oxide

MOXF	mixed-oxide fuel
MPAI	maximum permissible annual intake
MPBB	maximum permissible body burden
MPC	maximum permissible concentration
MPCA	maximum permissible concentration in air
MPCW	maximum permissible concentration in water
MPD	maximum permissible dose
MPE	maximum permissible exposure
MPL	maximum permissible level
mps	meter per second
MREM	millirem
MRS	monitorable, retrievable storage
MRSS	main and reheat steam system
MS	main steam
MSB	main steamline break multi-assembly sealed basket
MSICV	main steam isolation check valve
MSIS	main steam isolation signal
MSIV	main steam isolation valve
MSL	main steamline mean sea level
MSLA	main steamline accident
MSLB	main steamline break
MSLI	main steamline isolation
MSR	moisture separator reheater
MSRV	main steam relief valve
MSS	main steam system main support structure modified scram system
MSSR	main steam safety relief (valve)
MSSS	main steam supply system main steam support structure
MSSV	main steam safety valve
MTBF	mean time between failures
MTC	minimum temperature for criticality moderator temperature coefficient
MTF	mean time to failure
MTG	main turbine generator
MT/G	main turbine generator
MTPF	maximum total peaking factor
MTTF	mean time to failure
MTTR	mean time to repair mean time to replacement
MTU	metric ton of uranium
MU	makeup
MU&P	makeup and purification
MUT	makeup tank
MVP	mechanical vacuum pump
MW	megawatt
Mwe	megawatt electric
MWO	maintenance work order
MWS	makeup water system
MWST	makeup water storage tank miscellaneous waste storage tank
Mwt	megawatt thermal
MW-yr	megawatt-year

N

NC normally closed

NCV non-cited violation

NDCT natural draft cooling tower

NDE nondestructive examination

NDT nil ductility temperature
nondestructive testing

NDTT nil ductility transition temperature

NI nuclear instrument
nuclear instrumentation

NIS nuclear instrumentation system

NNI nonnuclear instrumentation

NNIS nonnuclear instrumentation system

NO normally open

NOD notice of deviation

NOP normal operating procedure
normal operating pressure

NOT normal operating temperature

NOUE notice of unusual event
notification of unusual event

NOV notice of violation

NPO nuclear plant operator

NPP nuclear power plant

NPR nonpower reactor

NPSH net positive suction head

NRHE nonregenerative heat exchanger

NRHX nonregenerative heat exchanger

NS normally shut

NSCW nuclear service cooling water

NSO nuclear station operator

NSR non-safety-related

NSS nuclear steam system

NSSS nuclear steam supply system

NSSSS nuclear steam supply shutoff system

NSW nuclear service water

NSWS nuclear service water system

NTE not to exceed

NTP normal temperature and pressure

NTR nuclear test reactor

O

OBE operating-basis earthquake

OCB oil-operated circuit breaker

OD outside diameter

ODCM offsite dose calculation manual

ODSCC outer-diameter stress-corrosion cracking
outside-diameter stress-corrosion cracking

OEM original equipment manufacturer

OER operating event report

OERTS operational events report tracking system

OFA optimized fuel assembly

OG off-gas
owners group

OGS off-gas system

OI	operating instruction optical isolator
OLMCPR	operating limit maximum critical power ratio
O&M	operation and maintenance
OOS	out of sequence out of service
OPS	overpressure protection system overpressurization protection system
ORB	outside reactor building
ORC	outside reactor containment
ORR	operational readiness review
OTC	once-through cooling
OTM	overspeed trip mechanism
OTSG	once-through steam generator

P

PAMS	- postaccident monitoring system
PARV	power-activated relief valve power-actuated relief valve
PASS	postaccident sampling system
PBR	pebble bed reactor
PCB	power circuit breaker
PCIS	primary containment isolation system
PCIV	primary containment isolation valve
PCS	plant computer system plant control system power conversion system pressure control system primary coolant system
PCT	peak centerline temperature peak cladding temperature
PCV	pressure control valve pressurizer control valve
PDL	power distribution limit
PDP	positive displacement pump
PDS	plant damage state power distribution system
PEO	plant equipment operator
PER	problem event report
PERMS	process and effluent radiological monitoring system
PERMSS	process and effluent radiological monitoring and sampling system
PFCS	primary flow control system
PFS	private fuel storage
PFSF	private fuel storage facility
PHD	pulse height discriminator
PI	performance indicator pressure indicator proportional integral
P&I	piping and instrumentation
P&ID	piping and instrumentation diagram
PID	proportional integral derivative
PIS	pressure-indicating switch process instrumentation system
PIV	pressure isolation valve
PLOCAP	post-loss-of-coolant-accident protection
PLS	precautions, limitations, and setpoints

PM	preventive maintenance
PMIS	plant monitoring and information system
PMP	preventive maintenance procedure
PMS	plant monitoring system primary makeup system
PMU	plant makeup
PN	preliminary notification
PNO	preliminary notification of occurrence
POAH	point of adding heat
POP	peak overpressure
POPS	pressurizer overpressure protection system
PORV	pilot-operated relief valve power-operated relief valve
POS	plant operating system plant operational state
PP	primary pressure
PPIS	plant protection and instrumentation system
ppm	part per million
pps	pulse per second
PR	power range
PRA	probabilistic risk analysis/analyses probabilistic risk assessment
PRG	procedure review group
PRM	power range monitor process radiation monitor
PRMS	process radiation monitoring system
PRT	pressurized relief tank
PRV	pressure relief valve
PS	pressure switch
PSAR	preliminary safety analysis report
PSMS	plant safety monitoring system
PSS	primary sampling system process sampling system
PSV	pressurizer safety valve
PSW	plant service water
PSWS	potable and sanitary water system
PT	periodic test periodic testing preoperational test preoperational testing pressure and temperature pressure transmitter
P/T	pressure and temperature
PTS	pressurized thermal shock
PW	potable water
PWR	pressurized-water reactor
PWROG	Pressurized-Water Reactor Owners Group
PWSCC	primary water stress-corrosion cracking
PZR	pressurizer

Q

QA	quality assurance
QC	quality control
QF	quality factor
QPT	quadrant power tilt

QPTR	quadrant power tilt ratio

R

rad	radiation absorbed dose
RADCON	radiologic control
RAOC	relaxed axial offset control
RAT	reserve auxiliary transformer
RB	reactor building
RBC	reactor building cooling
RBCCW	reactor building closed cooling water
RBCS	reactor building cooling system
RBCU	reactor building cooling unit
RBCW	reactor building cooling water
RBFC	reactor building fan cooler
RBM	rod-block monitor
RBPVS	reactor building purge ventilation system
RBS	reactor building spray
RC	reactor cavity reactor coolant
RCA	radiological controlled area reactor coolant activity root cause analysis
RCAP	root cause analysis program
RCB	reactor containment building
RCBT	reactor coolant bleed tank
RCC	rod cluster control
RCCA	rod cluster control assembly
RCCS	reactor cavity cooling system
RCDT	reactor coolant drain tank
RCFC	reactor containment fan cooler
RCIC	reactor core isolation cooling
RCICS	reactor core isolation cooling system
RCIS	rod control and information system
RCMU	reactor coolant makeup
RCP	reactor coolant pump
RCPB	reactor coolant pressure boundary
RCS	reactor coolant system
RCW	raw cooling water
RDA	rod drop accident
RDS	reactor depressurization system
RDT	reactor drain tank
RE	radiation equipment radiation element
REA	rod ejection accident
rem	roentgen equivalent man
REP	radiological emergency plan resonance escape probability
RESAR	reference safety analysis report
RFC	recirculation flow control
RFCS	recirculation flow control system
RFP	reactor feed pump
RFPT	reactor feed pump turbine
RH	relative humidity
RHR	residual heat removal
RHRP	residual heat removal pump

RHRS	residual heat removal system
RHT	recycle holdup tank
RHX	regenerative heat exchanger
RI	radiation indicator
RM	radiation monitor radiation monitoring remote manual
RMC	remote manual control
RMCS	reactor makeup control system reactor manual control system
RMS	radiation monitoring system radiological monitoring system remote manual switch
RMW	reactor makeup water
RMWS	reactor makeup water storage
RMWST	reactor makeup water storage tank
RMWT	reactor makeup water tank
RNDT	reference nil ductility temperature
RO	reactor operator
RP	radiation protection reactor pressure
RPB	reactor pressure boundary
RPC	rotating pancake coil
RPI	relative position indication rod position indicator
RPIS	rod position indication system rod position information system
RPS	reactor protection system
RPT	recirculation pump trip
RPV	reactor pressure vessel
RRA	risk-reduction analysis/analyses
RRP	reactor recirculation pump
RRPI	relative rod position indication
RRS	reactor recirculation system reactor regulating system
RRW	risk reduction worth
RS	recirculation spray
RSA	remote shutdown area
RSCS	rod sequence control system
RSE	reserve shutdown equipment
RSO	radiation safety officer
RSP	remote shutdown panel
RSS	reactor shutdown system remote shutdown system reserve shutdown system
RSSF	retrievable surface storage facility
RSST	reserve station service transformer
RSW	raw service water
RT	reactor trip reference temperature
RTB	reactor trip breaker
RTCB	reactor trip circuit breaker
RTD	resistance temperature detector
RTM	reactor trip module
Rtndt	reference temperature nil ductility
RTP	rated thermal power
RTS	reactor trip system
RTT	reference transition temperature
RV	reactor vessel relief valve

RVIS	reactor vessel instrumentation system
RVLIS	reactor vessel level instrumentation system
RVLM	reactor vessel level monitoring
RVRLIS	reactor vessel refueling level indication system
RW	raw water river water
RWB	rod withdrawal block
RWC	reactor water cleanup
RWCS	reactor water cleanup system
RWCU	reactor water cleanup
RWL	reactor water level rod withdrawal limiter
RWM	rod worth minimizer
RWP	radiation work permit
RWS	radwaste system
RWSP	refueling water storage pool
RWST	refueling water storage tank

S

SA	service air
SAE	site area emergency
SALP	systematic assessment of licensee performance
SAMG	severe accident management guidelines
SAR	safety analysis report
SART	site access refresher training
SAS	service air system station air system
SAT	site access training spray additive tank startup auxiliary transformer station auxiliary transformer
SBCS	steam bypass control system
SBGT	standby gas treatment
SBGTS	standby gas treatment system
SBLC	standby liquid control
SBLOCA	small-break loss-of-coolant accident
SBO	station blackout
SBWR	simplified boiling-water reactor
SCAT	spray chemical addition tank
SCC	stress-corrosion cracking
scfh	standard cubic foot/feet per hour
scfm	standard cubic foot/feet per minute
SCHE	shutdown cooling heat exchanger
SCHES	shutdown cooling heat exchanger subsystem
SCI	secondary containment isolation
SCIV	secondary containment isolation valve
SCO	senior control (room) operator
SCPPCS	secondary containment purge and pressure control system
SCR	silicon-controlled rectifier
SCRO	senior control room operator
SCS	shutdown cooling system
SCSHX	shutdown cooling system heat exchanger

SCST	spray chemical storage tank
SCWHE	shutdown cooling water heat exchanger
SCWS	shutdown cooling water subsystem
SD	scram discharge shutdown
S/D	shutdown
SDBCS	steam dump bypass control system
SDC	shutdown cooling
SDCS	shutdown cooling system
SDG	standby diesel generator
SDHR	shutdown decay heat removal
SDHX	shutdown heat exchanger
SDM	shutdown margin
SDS	steam dump system
SDV	scram discharge volume steam dump valve
SDVIV	scram discharge volume instrument volume
SE	shift engineer significant event (NRC performance indicator)
SEN	Significant Event Notification (INPO)
SEP	site emergency plan standby electric power
SER	safety evaluation report significant event report
SET	- Special Evaluation Team
SFA	single-failure analysis/analyses spent fuel assembly standard fuel assembly
SFAS	safety features actuation signal
SFCS	spent fuel cooling system
SFP	spent fuel pit spent fuel pool
SFPC	spent fuel pool cooling
SFPCCS	spent fuel pool cooling and cleanup system
SFPCS	spent fuel pool cooling system
SFRCS	steam and feedwater rupture control system
SFS	steam and feedwater system
SFSP	spent fuel storage pool
SG	steam generator
S/G	steam generator
SGB	steam generator blowdown
SGBD	steam generator blowdown
SGBS	steam generator blowdown system
SGFP	steam generator feedwater pump
SGIS	safeguards initiation signal
SGTR	steam generator tube rupture
SGTS	standby gas treatment system
SGWLC	steam generator water level control
SHRS	shutdown heat removal system
SI	safety injection special instruction surveillance inspection surveillance instruction
SIAS	safety injection actuation signal
SIRWT	safety injection and refueling water tank

SIS	safety injection signal safety injection system
SIT	safety injection tank
SJAE	steam jet-air ejector
SL	safety limit
SLB	steamline break
SLC	standby liquid control
SLCS	standby liquid control system
SLI	steamline isolation
SLIV	steamline isolation valve
SMM	subcooling margin monitor
SNM	special nuclear material
SNUPPS	standardized nuclear unit power plant system
SO	supervising operator
SOE	sequence of events
SOL	senior operator license
SOM	shift operations manager
SOS	shift operations supervisor
SOV	solenoid-operated valve
SP	setpoint suppression pool surveillance procedure
SPC	standby pressure control suppression pool cooling
SPDS	safety parameter display system
SPGD	self-powered gamma detector
SPND	self-powered neutron detector
SR	safety related safety rod source range surveillance requirement
S/R	safety relief
SRD	self-reading dosimeter
SRFM	source range flux monitor
SRM	source range monitor
SRO	senior reactor operator
SRS	solid radwaste system
SRST	spent resin storage tank
SRT	spent resin tank
SRV	safety/relief valve
S/RV	safety/relief valve
SRWS	solid radioactive waste system
SSE	safe-shutdown earthquake
SSLPS	solid-state logic protection system
SSPI	safety system performance indicator
SSPS	solid-state protection system
SST	station service transformer
SSW	salt service water standby service water
SSWP	station service water pump
SSWS	standby service water system station service water system
STA	shift technical advisor
STE	shift technical engineer system test engineer

STP — special technical publication
standard temperature and pressure
surveillance test procedure
system test procedure

STS — Standard Technical Specification

S/U — startup

SUR — startup rate

SV — safety valve
solenoid valve
stop valve

Sv — sievert

SW — service water

SWCS — salt water cooling system

SWGR — switchgear

SWGTS — steam and waste gas treatment system

SWIS — service water intake structure

SWMS — solid waste management system

SWP — service water pump

SWPS — solid waste processing system

SWS — service water system
solid waste system

T

TAF — top of active fuel

TB — turbine building

TBCCW — turbine building closed cooling water

TBS — turbine bypass system

TBSCCW — turbine building secondary closed cooling water

TBSW — turbine building service water

TBV — turbine block valve
turbine building ventilation
turbine bypass valve

T/C — thermocouple

TCS — turbine control system

TCV — temperature control valve
turbine control valve

TD — time delay
turbine driven

TDAFP — turbine-driven auxiliary feedwater pump

TDAFW — turbine-driven auxiliary feedwater

TDAFWP — turbine-driven auxiliary feedwater pump

TDEFWP — turbine-driven emergency feedwater pump

TDH — total developed head
total dynamic head

TDP — turbine-driven pump

TDS — total dissolved solids

TE — temperature element

TEDE — total effective dose equivalent

TFC — thermal fatigue crack

TFS — turbine first stage

TG — turbine generator

T/G — turbine generator

TGB — turbine generator building

TGS — turbine generator system

TGSCC — transgranular stress-corrosion cracking

TGSS	turbine gland sealing system
TGV	turbine governor valve
T/H	thermal and hydraulic
TI	temperature indicator temporary instruction test instruction transport index
TID	total integrated dose
TIP	traversing in-core probe
TLD	thermoluminescence dosimeter
TLO	turbine lube oil
TLOFW	total loss of feedwater
TLOS	turbine lube oil system
TLOST	turbine lube oil storage tank
TM	technical manual temperature monitor
TP	test procedure
TPCDF	total plant core damage frequency
TPF	total peaking factor
TR	temperature recorder
TS	technical specification
TSC	technical support center
TSP	trisodium phosphate tube support plate
TSV	turbine stop valve
TSW	turbine service water
TT	temperature transmitter turbine trip
TTV	tenth thickness value

U

UAT	unit auxiliary transformer
UDS	ultimate damage state
UFSAR	updated final safety analysis report
UHI	upper-head injection
UHS	ultimate heat sink
UHV	ultrahigh voltage
ULD	unit load demand
UO	unit operator
UPS	uninterruptible power supply
USI	unresolved safety issue
UT	ultrasonic test ultrasonic testing
UV	undervoltage

V

V%	volume percent
Vac	volts alternating current
VAR	volt amperes reactive
VCT	volume control tank
Vdc	volts direct current

W

w%	weight percent
WABA	wet annular burnable assembly
WAPA	wet annular poison assembly

WB	whole body
WG	waste gas
WGC	waste gas compressor
WGDS	waste gas disposal system
WGDT	waste gas decay tank
WGS	waste gas system
WHT	waste holdup tank
WMS	waste management system
WOG	Westinghouse Owners Group
WP	work procedure
WPS	waste processing system
WR	wide range
WTF	waste treatment facility
WTP	water treatment plant
WW	well water
WWS	well water system
WWTF	waste water treatment facility

Typical

Boiling Water &

Pressurized Water

Reactor Plant Data

Appendix C

BOILING WATER REACTOR NUMBERS

Reactor

Coolant	Water
Moderator	Water
Core Coolant Flow Rate	264,000 gallons per minute
Feedwater Inlet Temperature	383°F
Steam Outlet Temperature	543°F
Steam Capacity	13,464,000 pounds mass per hour
Heat Output	11,915,000,000 BTUs per hour

Reactor Vessel

Material	Carbon steel clad with stainless steel
Height	73.5 feet
Weight	750 tons
Inside Diameter	20.9 feet
Wall Thickness	4 to 9 inches
Design Temperature	575°F
Design Pressure	1,250 pounds force per square inch

Fuel Rods

Material	Uranium dioxide
Enrichment	0.71 to 4.91 percent by weight
Number of Fuel Pellets	32,000,000
Total Weight, Uranium	132.2 metric tons
Cladding	Zirconium alloy
Cladding Thickness	0.030 inches
Length of Fuel Rod	14.66 feet
Number of Fuel Rods	60,356
Fuel Pellet Length	0.275 inches
Fuel Pellet Diameter	0.424 inches

Control Blades

Material	Stainless steel tubing
Neutron Absorber	Boron carbide
Blade Length	14.4 feet
Blade Width	9.75 inches
Number	185

Containment

Material	Reinforced concrete
Height	161 feet
Wall Thickness	6.0 feet
Lining Thickness	0.25 inch
Volume	519,450 cubic feet
Design Pressure	53 pounds force per square inch

PRESSURIZED WATER REACTOR NUMBERS

Reactor Coolant System

Coolant	Water
Moderator	Water
Core Coolant Flow Rate	138,400,000 pounds mass per hour
Vessel Inlet Temperature	557.5°F
Vessel Outlet Temperature	618.5°F
Heat Output of Core	11,642,000,000 BTUs per hour
Cold Leg Piping	27.5 inches inside diameter
Cold Leg Piping	2.69 inches nominal wall thickness
Reactor Coolant Pump Suction Piping	31 inches inside diameter
Reactor Coolant Pump Suction Piping	2.99 inches nominal wall thickness
Hot Leg Piping	29 inches inside diameter
Hot Leg Piping	2.84 inches nominal wall thickness

Reactor Vessel

Material	Low alloy steel, stainless steel clad
Number of Closure Studs	54
Height	44.6 feet
Inside Diameter	14.4 feet
Wall Thickness	5.5 to 8.5 inches
Design Temperature	650°F
Design Pressure	2,485 pounds force per square inch

Fuel Pellets

Material	Uranium dioxide
Enrichment	2.1 to 4.2 percent by weight
Number of Fuel Pellets	13,808,000
Total Weight, Uranium	222,739 pounds mass
Diameter of Pellet	0.3225 inches
Length of Pellet	0.530 inches

Fuel Rods

Material	Zirconium alloy
Thickness	0.0225 inches
Weight (total in core)	50,913 pounds mass
Length	12 feet
Number in Core	50,952 (193 fuel assembly plant)
Total Length in Core	115.8 miles

Rod Cluster Control Assemblies (RCCA)

Absorber Material	Silver - Indium - Cadmium
Composition	80% - 15% - 5%
Absorber Rodlet Diameter	0.341 inches
Number of Rodlets per RCCA	24
Number of RCCAs in Core	53

PWR NUMBERS (cont)

Pressurizer

Volume	1,800 cubic feet
Power of Electrical Heaters	1,800 kilowatts
Inside Diameter	84 inches

Reactor Coolant Pump

Flow Rate	93,000 gallons per minute
Speed	1,200 revolutions per minute
Design Head	300 feet of water
Height	27.5 feet
Weight	193,000 pounds mass
Horsepower Rating	7,000 horsepower

Steam Generator

Height	67.75 feet
Outside Diameter	175.75 inches
Number of U-Tubes	3,388
Heat Transfer Area	55,000 square feet
Steam Flow	4,500,000 pounds mass per hour
Moisture Content of Steam	< 0.25% by weight

Containment

Material	Reinforced concrete
Height	205 feet
Diameter	140 feet
Vertical Wall Thickness	4.0 feet
Dome Thickness	3.0 feet
Base Mat Thickness	10.0 feet
Lining Thickness	0.25 inches
Volume	2,500,000 cubic feet
Design Pressure	60 pounds force per square inch
Design Temperature	320°F

GENERAL PLANT DATA

Electrical Generator

Speed	1,800 revolutions per minute
Voltage	24,000 volts
Cooling for Stator	Water
Cooling for Rotor	Hydrogen
Capacity	1,050,000,000 watts (1,050 Mw)

Main Condenser

Material	Stainless steel or titanium tubing
Number of Tubes	81,500
Tubing Length (total)	616 miles
Condensing Surface Area	880,000 square feet
Cooling Water Flow	448,000 gallons per minute

Cooling Tower

Type	Natural draft, evaporative
Height	540 feet
Base Diameter	415 feet
Top Diameter	301 feet
Water Flow	448,000 gallons per minute
Evaporation Rate	20,000 gallons per minute

CHAPTER 1

1. For an electrical generator to generate electricity, three things are required. List these three items required to generate electricity.

   a. ______________________________
   b. ______________________________
   c. ______________________________

2. The device used to turn the electrical generator in most commercial nuclear power plants is a ________________.

3. The major types of light water reactors in the United States that are used for the commercial production of electricity are ____________________ and ______________________.

4. After the steam passes through the low pressure turbines, it is converted back into water in the ______________________.

5. The component that may be used to reduce the temperature of the circulating water prior to discharging from the plant is the ______________________________.

CHAPTER 2

1. The nucleus of an atom contains one or more ________________, which have a ________________ charge, and zero or more ______________, which have ______________ charge.

2. The number of electrons will be _________ the number of protons.

3. Electrons have a _____________ charge.

4. Two atoms with the same number of protons, but with a different number of neutrons, are called ________________.

5. The source of heat is the ______________ process.

6. There are three major processes that neutrons can undergo in the reactor. One is to cause fission, which is desirable. The other two are ____________________ and ____________________________.

7. The neutron poison that can be controlled by the operator in both a boiling water reactor and a pressurized water reactor is the __________________________.

8. The water that flows through the core performs two major functions. One is to remove the ___________ from the core. The other is to _________________ neutrons.

9. The rapid insertion of the control rods in order to rapidly shut down the fission chain is called a __________________.

10. Even after the reactor has been shut down, there is heat being generated inside the core. This heat is called _______________.

11. When a fission occurs, the resulting nuclei are called __________________.

CHAPTER 3

1. The components inside the boiling water reactor vessel used to remove moisture from the steam prior to the steam exiting the vessel are called the ____________ and ____________________________.

2. The components located in the reactor vessel that are used to increase the core flow, but do not have any moving parts, are called the ________________.

3. The system that removes impurities from the reactor coolant system is called the ______________________________.

4. The systems used to provide water to the reactor vessel during accident conditions are called the ____________________.

5. To remove decay heat from the reactor immediately after shutdown, _________ will be sent to the main condenser.

6. After some amount of time, the method that will be used to remove heat from the core will utilize a pump and a heat exchanger. This system is called the ______________________________.

7. In the event the reactor cannot be shutdown by the control rods, the ______________________________ system can be used.

8. The large quantity of water that can be used to supply some of the emergency core cooling system pumps is called the ______________________________.

9. The reactor vessel is located in the ______________________________.

CHAPTER 4

1. The component that maintains the proper pressure on the reactor coolant system is the ____________________________.

2. A primary loop is made up of a ______________________________, a ______________________________, and the interconnecting piping.

3. The __________________________ provides the amount of forced flow needed to remove the heat generated by the reactor core.

4. Instead of generating steam in the reactor vessel, as in the boiling water reactor, the steam is formed in the ______________ in a pressurized water reactor.

5. To reduce the pressure and temperature inside the containment after an accident, the ____________________________ system is used.

6. The primary system of a pressurized water reactor is located inside the ___________.

7. The hot leg of the primary loop goes from the _______________ to the _______________.

8. The cold leg of the primary loop goes from the _______________ to the _______________.

9. To increase pressure, the pressurizer utilizes __________________________.

10. The large tank of borated water used as the suction supply of the emergency core cooling system pumps is the _________.

11. The component of the emergency core cooling systems which does not require electrical power to inject water into the reactor coolant system is the ______________________.

12. The cooling water system which removes the heat from the reactor coolant flowing through the residual heat removal system heat exchanger is the ______________.

13. In a pressurized water reactor, the operator can control not only the control rods, but also the amount of __________ dissolved in the reactor coolant to help control the fission process.

14. The charging pumps in the ___________ system are also used as the __________ pumps in the emergency core cooling system.

15. To purify the coolant, the chemical and volume control system utilizes ________ and ____________________________.

16. The source of water for the auxiliary feedwater system is the _____________.

17. The two major systems that comprise the secondary systems on a pressurized water reactor are the ____________________ system and the _____________ system.

18. The ____________ in the steam generator separates the potentially radioactive reactor coolant system from the secondary water.

CHAPTER 5

1. The particles and/or energy emitted by an atom when it decays is called ________.

2. Radioactivity is measured in units of ______________________________.

3. The process of forming charged particles is called _________________________.

4. The largest ionizing radiation is the _____________________________.

5. The _____________________________ has the highest penetrating distance of the ionizing radiations.

6. __________ radiation is considered to be an external hazard, but mainly to the skin and lens of the eye.

7. The best shielding material for ________ radiation is materials that contain hydrogen.

8. The __________ is the amount of biological damage caused by one RAD of gamma radiation.

9. To convert a dose of RAD into REM, multiply the RAD by a ______________.

10. DOSE = (DOSE RATE) X (________)

11. Radioactive material where it should not be is called _______________________.

CHAPTER 6

1. Radiation damage to body cells falls under two major categories of effects. These two major categories are _________________ effects and _________________ effects.

2. The most sensitive organs in the body to radiation damage are the _____________.

3. High (acute) doses of radiation tend to _____________ cells, while low doses tend to _______________ or _________ them.

4. LD 50/60 is defined as ______________ _______________________.

5. The three major categories of effects of exposure to low doses of radiation are __________, __________, and __________.

6. Genetic effects are effects on ________________________ ________________________.

7. The primary result of somatic effects is _______________________________.

8. In-utero effects are effects on ________________________ ________________________.

CHAPTER 7

1. Because of the consequences of a release of ___________________, the plant is designed with multiple barriers to the environment.

2. The three barriers are _______________, ________________________________, and ________________________________.

3. The major source of occupational exposure is ___________________.

CHAPTER 8

1. The sources of natural background radiation are _______________________, _________________________________, and _________________________________.

2. The average person in the United States receives approximately ______________ per year exposure.

CHAPTER 9

1. NRC Dose Limits are found in __________________________.

2. The occupational dose limits are:
   ________________ (whole body),
   ________________ (hands & feet),
   ________________ (skin)
   ________________ (lens of the eye)
   ________________ (single organ).

3. To minimize the dose from external radiation, one must minimize the ______________ of exposure.

4. A source of radiation, measured at a distance of 2 feet, gives a reading of 400 mrem/hour. The dose at 10 feet would be __________ mrem/hr.

5. Shielding needs to be _______________ to minimize exposure.

6. _____________ is a good shield for neutron or gamma radiation.

CHAPTER 10

1. The major portion of high level waste is made up of ______________________.

2. Low level waste can be in the form of _________, __________, or __________.

ANSWERS

CHAPTER 1

1. a. A conductor
   b. A magnetic field
   c. Relative motion between the two

2. Steam driven turbine

3. Boiling water reactors and Pressurized water reactors.

4. Main condenser

5. Cooling tower

CHAPTER 2

1. Protons
   Positive
   Neutrons
   No

2. Equal to

3. Negative

4. Isotopes

5. Fission

6. Absorption by poisons
   Leak out of the core

7. Control Rods

8. Heat
   Thermalize

9. Scram or trip

10. Decay heat

11. Fission Products

CHAPTER 3

1. Swirl vane separators
   Steam dryer

2. Jet pumps

3. Reactor Water cleanup system

4. Emergency core cooling systems

5. Steam

6. Residual Heat Removal System

7. Standby liquid control system

8. Suppression pool

9. Drywell (primary containment)

CHAPTER 4

1. Pressurizer

2. Reactor Coolant pumps
   Steam Generator

3. Reactor Coolant Pump

4. Steam Generator

5. Containment Spray

6. Containment

7. Reactor vessel outlet
   Steam generator inlet

8. Reactor coolant pump outlet
   Reactor vessel inlet

9. Electrical heaters

10. Refueling water storage tank

11. Cold leg accumulators

12. Component Cooling Water System

13. Soluble boron

14. Chemical & Volume Control System
    High Head injection

15. Filters
    Demineralizers

16. Condensate storage tank

17. Main Steam
    Condensate/feedwater

18. Tubes

CHAPTER 5

1. Radiation

2. Curies

3. Ionization

4. Alpha particle

5. Gamma Ray

6. Beta

7. Neutron

8. REM

9. Quality factor

10. TIME

11. Contamination

CHAPTER 6

1. Direct effects
   Indirect effects

2. Blood forming organs

3. Kill
   Damage or change

4. Lethal dose at which 50% of those exposed will die within 60 days.

5. Genetic, Somatic, and In-utero

6. The offspring of the person exposed

7. Cancer

8. An embryo/fetus exposed to radiation.

CHAPTER 7

1. Fission products

2. Fuel clad, reactor coolant system, and containment

3. Corrosion and activation products.

CHAPTER 8

1. Cosmic Radiation
   Terrestrial Radiation
   Internal Radiation

2. 360 mrem/year

CHAPTER 9

1. 10 CFR 20

2. 5 rem/year
   50 rem/year
   50 rem/year
   15 rem/year
   50 rem/year

3. Time

4. 16 mrem/hour

5. Maximized

6. Water

CHAPTER 10

1. Spent fuel (fission products)

2. Solids, liquids, or gases