Nuclear and Radiological Accidents. Negative consequences.

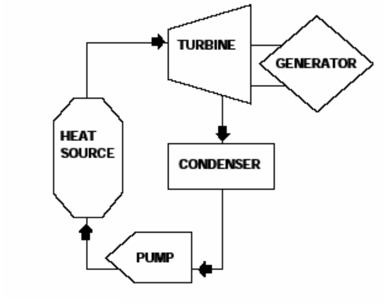
Nuclear Accident

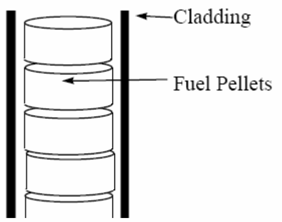
Introduction

A nuclear accident is one involving a device that uses a controlled chain reaction for some purpose. For example, a Nuclear Power Plant has nuclear fuel that through a self-sustaining and controlled chain reaction produces heat, turns turbines and produces electricity. Because of the energy involved in this process, there is potential for considerable radioactive material to be released and dispersed into the environment. Such a release would be due to a ‘nuclear accident’. Normally nuclear accidents with releases to the environment are very rare. However they have the potential to lead to widespread dispersion of radioactive material.

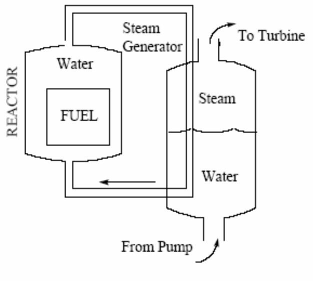
Nuclear power plant structure and operation

There are two main types of nuclear power reactors - *pressurized water reactors* (PWRs) and *boiling water reactors* (BWRs). In both types of reactors the reactor core is covered with water to allow the nuclear reaction to take place and to keep the core cool. A nuclear power plant is a facility at which energy released as a result of nuclear fission is converted to electrical energy under strictly regulated operating conditions. In a nuclear power plant, the heat source is the nuclear reactor, often called the reactor core. A heat source provides heat to generate steam. A *turbine* generator uses the energy of the steam to turn a turbine that generates electricity. The *pump* provides the force to circulate the water through the system. Nuclear power plants produce a great deal of heat through a nuclear chain reaction of fission of uranium-235 nuclear. The radionuclides produced by nuclear fission are called fission products. Fission products may be of a wide variety of elements and have very high radioactivity. The fission products include such hazardous radionuclide as iodine, caesium and strontium.





The nuclear fuel typically used in nuclear power plants consists of uranium in the form of uranium dioxide (UO_2). Uranium dioxide, a ceramic, is used because



like all ceramics, it can withstand very high temperatures. The uranium dioxide is fabricated into cylindrical *fuel pellets*. These pellets are stacked end-to-end to form a *fuel rod* that is encased in a metal tube called *fuel cladding*. Fuel cladding prevents radioactive fission products from escaping the fuel pellets into the reactor cooling water. The nuclear chain reaction rate may be regulated by *control rods*. Control rods absorb neutrons. When all of the control rods are inserted into the reactor core, it is called a *reactor shutdown*. The *reactor cooling water* removes the heat generated in the reactor. The system that contains the reactor cooling water is called the *primary coolant system*. Heat of primary coolant, which is radioactive, transferred to the non-radioactive secondary system. The secondary coolant is maintained at a much lower pressure so that as the heat is transferred, the secondary coolant flashes to steam. That steam is used to rotate the turbine, which generates electricity.

Most fission products are highly radioactive and will undergo radioactive decay. Most decay quickly and will be gone within several days. Some, however, remain in the nuclear fuel for many years, and must be contained to prevent injury to the public. Decay also produces heat, referred to as decay heat, which must be removed even after the reactor is shutdown. If the decay heat is not removed, it will result in reactor core melts and failures of the barriers designed to contain the fission products and possibly a radioactive release from the reactor.

Nuclear plant safety

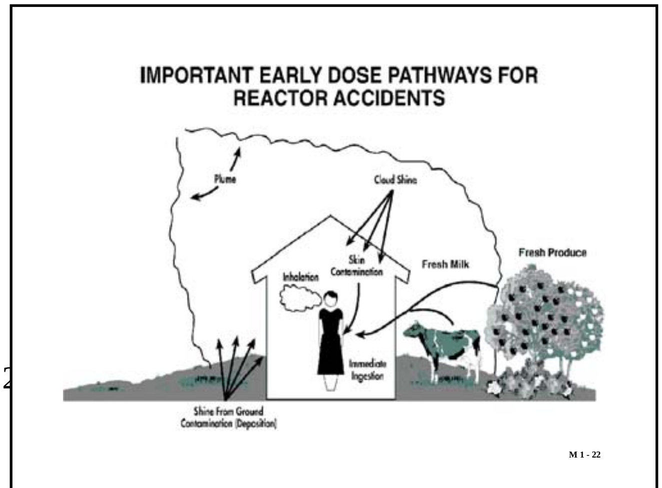
Nuclear power plants are designed with two principal safety objectives in mind. One is to contain radioactive fission products to prevent offsite health effects. The other is to ensure that heat generated by the reactor, including heat generated by the decay of fission products after reactor shutdown, is removed. Three barriers prevent the release of radioactive fission products from the reactor core to the environment: fuel cladding, reactor vessel and primary cooling system, and containment.

Fuel rods trap 99 percent of all fission products in the fuel pellets and the remaining 1 percent in the fuel cladding that encases the fuel rods. If the core is not sufficiently covered with water to provide cooling, it could overheat and cause a breakdown in the fuel cladding. Additional overheating could result in the release of the fission products in the fuel structure. Still more overheating could cause a fuel meltdown. Even if the fuel cladding were to fail, two more restraints prevent a release to the atmosphere. The reactor core is located within a *reactor vessel* that has walls of steel up to 30 centimetres thick. The large pipes of the *primary coolant system* also contain the reactor cooling water and radioactive materials present. The *containment building* is the third barrier between the radioactive products and the environment. It is a building that generally is made of high-density, reinforced concrete as much as two metres thick. The containment building is built to withstand severe accidents and natural and technological hazards. Even if the first two barriers are damaged, the containment building should prevent the significant release of most fission products to the environment.

Pathways of exposure

The radiation dose received by the public during the first hours or days of a nuclear reactor accident (*early phase*) comes mostly from five sources:

1) external gamma radiation from the radioactive cloud or plume, released from damaged reactor, so called cloud shine,



2) external gamma radiation from radioactive material deposited from radioactive cloud on the ground, trees, buildings, called ground shine,

3) inhaling radioactive material in the plume,

4) external alpha, beta and gamma radiation from radioactive material deposited on the skin,

5) eating contaminated food, milk and water.

During a release the dose from cloud shine, ground shine, skin contamination and inhalation are the most important. After the plume has passed, the dose from ground shine and eating of contaminated food, milk and water become most important. Dose from external gamma, skin contamination and inhalation can be prevented or reduced by what are referred to as urgent protective measures. These are protective measures that must be implemented urgently or immediately and include sheltering, evacuation, and thyroid blocking. Dose from ingestion can be reduced by restricting immediate consumption of locally produced food.

The principal pathways for exposure of the public during the *intermediate phase* (after the source and releases have been brought under control) are expected to be exposure of the whole body to external gamma radiation from deposited radioactive materials (ground shine). Exposure may also occur from contamination of skin and clothes and ingestion of radioactively contaminated food and water.

During the *late phase,* exposure may ensue following external radiation from ground deposition, inhalation of radioactive material resuspended in air, and ingestion of radioactively contaminated food and water.

Examples of nuclear accidents

The worst commercial accident in the United States occurred at the **Three Mile Island** nuclear station in 1979. As a result of equipment failures and operator error, a valve that was stuck open allowed coolant water that covered the reactor core to escape from the reactor system for over two hours. This radioactive water, nearly a million gallons, ended up on the basement floors of the containment building and auxiliary buildings. The loss of coolant water in the reactor core continued to the point that the fuel was no longer submerged in water. Without the cooling provided by the water, the cladding and some of the fuel pellets melted. Large quantities of radioactive material were released into the containment building. The containment building performed, as designed and radioactive releases to the atmosphere were small. The releases resulted from leakage of the radioactive water that was carried outside the containment building.
See more *http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html/*

On 26 April 1986, the most serious accident in the history of the nuclear industry occurred at Unit 4 of the **Chernobyl** nuclear power plant in the former Ukrainian Republic of the Union of Soviet Socialist Republics, near the common borders of Belarus, the Russian Federation and Ukraine.

The Chernobyl accident was the result of an inherently unsafe reactor design combined with serious deficiencies in “safety culture”. Additionally, the operators were not informed of design weaknesses and did not comply with all operational procedures. The combination of these factors provoked the worst nuclear accident in which the reactor was totally destroyed within a few seconds.

Major releases of radionuclides from the Chernobyl reactor continued for ten days following the explosion on April 26. These included radioactive gases, condensed aerosols and fuel particles.

The total release of radioactive material was about 14 EBq, including 1.8 EBq of ^{131}I, 0.085 EBq of ^{137}Cs, 0.01 EBq of ^{90}Sr and 0.003 EBq of plutonium isotopes. Radioactive noble gases contributed about 50% of the total activity released.

More than 200,000 square kilometers of Europe was contaminated with levels of ^{137}Cs above 37 kBq/m^2. Much of this area was within the three most affected countries, Belarus, Russia and Ukraine. The level of deposition was extremely varied and was enhanced in areas where it was raining while the contaminated air masses passed. Most of the strontium and plutonium was deposited within 100 km of the destroyed reactor due to their larger particle sizes.

Many of the more significant radionuclides had short physical half-lives. Thus, most of the radionuclides released in the accident have long since decayed away. The releases of radioactive iodine caused greatest concern immediately after the accident. After the first year the main radiological impact has been determined by the deposition of caesium isotopes and this will continue for decades to come; deposits of ^{90}Sr are also of longer term concern but of much less significance than caesium isotopes. Over the longer term (hundreds to thousands of years) the plutonium isotopes and americium-241 will remain, although at levels not radiologically significant outside of 30 km zone.

The deposition in urban areas in the nearest (about 3 km) city of Pripyat and surrounding settlements could have given rise to substantial external exposure. However, this was, to a large extent, averted by the evacuation of residents. The deposition of radioactive material in other inhabited areas has resulted in the continuing exposure of the population, albeit at much reduced levels compared to the immediate aftermath of the accident.

In most settlements outside the 30 km zone the dose rate has essentially returned to the background level before the accident. The territories contaminated as a result of the accident have been intensively monitored and studied for two decades and the behavior of the main residual contaminants, ^{137}Cs and ^{90}Sr, is well understood.

A wide range of effective countermeasures has been established and implemented by the respective Governments to maintain radiation exposures and contamination levels below national standards.

The health consequences of the Chernobyl accident are of a multifaceted nature and are related to both direct radiation exposure and to a combination of many non-radiation factors. The nature and magnitude of the health consequences remains the subject of continuing debate among the scientific community, the public, policy makers, non-governmental organizations and within the media. This debate will inevitably continue but, increasingly, a common understanding is emerging on the effects of the accident.

Acute radiation syndrome (ARS) was diagnosed in 134 emergency workers exposed from 1 to 16 Gy of whole-body irradiation. Twenty eight patients died within three months after exposure. During the following years, nineteen more ARS survivors died due to various causes; however their deaths were not necessarily directly attributable to radiation exposure. Among the general population exposed to the Chernobyl radioactive fallout, however, the radiation doses were much lower than among the emergency workers, and ARS and associated fatalities did not occur.

See more http://www.tesec-int.org/Chernobyl.htm

Radiological Accident

Introduction

Radiological accidents are initiating by the lost radiation sources, accidents during transportation of radioactive sources or materials, equipment or human errors in radiation sources operation.

Sources, often called "sealed sources," are usually small metal containers in which a small amount of a radioactive material is sealed. They are frequently used in industrial gauges (e.g., moisture and density gauges).

If these gauges or other radiation-containing equipment is disposed of improperly or sent for recycling as scrap metal, the sealed source may be 'lost' and end up in a metal recycling facility or in the possession of someone who is not licensed to handle the source. They are one of the most frequently reported radioactive contaminants in shipments received by scrap metal facilities.

If a steel mill melts a source, it contaminates the entire batch of metal, the processing equipment, and the facility. More importantly, it can result in the exposure of workers or users to radiation.

There have also been incidents in which unsuspecting people find these sources, and not knowing what they are, keep them or even open them and suffer serious exposures. Some satellites use radioactive materials as a power source during long space flights. During the launch or re-entry of satellites there is the potential for an accident that would disperse radioactive materials.

Equipment failure

Equipment failure is one possible type of accident, recently at Bialystok in Poland the electronics associated with a particle accelerator used for the treatment of cancer suffered a malfunction. This then led to the overexposure of at least one patient. While the initial failure was the simple failure of a semiconductor diode, it set in motion a series of events which led to a radiation injury.

A related cause of accidents is failure of control software, as in the cases involving the Therac-25 medical radiotherapy equipment: the elimination of a hardware safety interlock in a new design model exposed a previously undetected bug in the control software, which could lead to patients receiving massive overdoses under a specific set of conditions.

Human error

Human error has been responsible for some accidents, such as when a person miscalculated the activity of a teletherapy source. This then led to patients being given the wrong dose of gamma rays. In the case of radiotherapy accidents, an underexposure is as much an accident as an overexposure as the patients may not get the full benefit of the prescribed treatment. Also, humans have made errors while attempting to service plants and equipment which has resulted in overdoses of radiation.

Lost source

Lost source accidents are ones in which a radioactive source is lost, stolen or abandoned. The source then might cause harm to humans or the environment. For example, the event in Lilo, where sources were left behind by the Soviet army. Another case occurred at Yanango where a radiography source was lost. The most known example of this type of event is the Goiânia accident which occurred in Brazil.

Examples of radiological accidents

Some examples of radiological accident presented from “*Radiation accidents and other events causing radiation casualties--tabulated data*” compiled by Wm. Robert Johnston, last updated 17 February 2008.

This is a listing (incomplete) of radiation accidents and other events (e.g. intentional acts) that resulted in acute radiation exposures to humans sufficient to cause casualties. For sources and for details on specific events see individual pages at Database of Radiological Incidents and Related Events or follow links in table.

Date: 12-29 September 1987
Location: Goiania, Goias, Brazil
Type of event: accidental dispersal of lost radiography source
Description:

A radiotherapy unit had been abandoned in a clinic, which was being demolished. The unit had a source consisted of 1375 curies of cesium-137 in the form of cesium chloride salt, sealed within two nested stainless steel containers to form a 5-cm diameter capsule. Two individuals, R.A. and W.P., dismantled the unit and extracted the source, taking it to the home of R.A. Both began vomiting on 13 September; W.P. sought medical treatment on 15 September and was advised to stay home. R.A. opened the source outside his home on 18 September. The unit material was sold to a junkyard owned by D.F., who noticed a blue glow from the source container that night; he and his wife M.F. examined the material closely, also inviting a number of people to view the capsule. On 21 September the source material was removed and distributed among several people, some of whom spread it on their skin. Also that day M.F. became ill and was cared for by her mother M.A., who took contamination to her home on leaving on 23 September. Around 23 September junkyard employees I.S. and A.S. were exposed while further dismantling parts of the unit. D.F.'s brother I.F. took some source material home on 24 September and set it on a table during a meal; several family members, including his 6-year-old daughter L.F., handled the material while eating. On 25 September D.F. sold some unit components to a second junkyard.

With many people ill by 28 September, M.F., assisted by G.S., took the material along with some components recovered from the second junkyard and transported it on a bus to a hospital where she placed it on the desk of Dr. P.M. and stated it was "killing her family." Doctors initially suspected a tropical disease, but one suspected radiation injury. The morning of 29 September a medical physicist, W. F., was contacted; his arrival was delayed because he doubted the readings of his first radiation monitor, but arrived in time to prevent the fire department from throwing the source into a river. The afternoon of 29 September the authorities were alerted and began response, including identification of contaminated areas and treatment of injured people in facilities set up in the city's Olympic stadium. About 112,800 people were examined at the stadium of whom 129 were found to be contaminated; 20 were hospitalized.

By 3 October some injured people had been sent to Rio de Janeiro for treatment, while others were treated in a special wing of the Goiania General Hospital. Four people died in the acute phase: M.F. and L. F. died 23 October, with respective doses of 570 and 600 rad, respectively; I.S. died 27 October (dose 450 rad); A.S. died 28 October (dose 530 rad). A fifth person, D. F. (dose 700 rad) was hospitalized in May 1994 and subsequently died of liver failure related to his radiation injury. Others exposed included M.A. (430 rad), G.S. (300 rad), and Dr. P.M. (130 rad). W.P. suffered

radiation injury to his hand, and R.A. and W.P. both suffered radiation sickness. In addition to the five who died, 23 suffered localized radiation burns, several requiring amputation of fingers. The 23 injured survivors included 9 showing bone marrow depression of whom 3 displayed acute radiation sickness. During hospitalization many patients suffered depression and other emotional problems.
Consequences: 5 fatalities, 20 injuries.
References:
Brandao-Mello, C. E., R. Farina, A. Rodrigues de Oliveira, M. P. Curado, J. F. Filho, and Q. C. B. Santos, May 2000, "Medical follow-up of the radiation accident with 137-Cs in Goiania--an update (1990-1994)," in *Restoration of Environments Affected by Residues from Radiological Accidents: Approaches to Decision Making*, IAEA (Vienna, Austria), pp. 240-243, on line at *IAEA* [http://www-pub.iaea.org/MTCD/publications/PDF/te_1131_prn.pdf].

Date: 5 February 1989
Location: Delmed Company, San Salvador, El Salvador
Type of event: accident at industrial irradiator
Description:
An accident occurred during repairs at an medical sterilizer irradiation facility with a cobalt-60 source. One component of the radiation source fell out of the source rack, leaving it exposed in the irradiation room at a time when radiation monitors were disabled. Several workers entering the room received radiation exposures. One person received an 800 rem dose, causing death, and two others received severe injury from radiation, one receiving 290-370 rem.
Consequences: 1 fatality, 2 injuries.

Date: August 2000-24 March 2001
Location: Instituto Oncologico Nacional, Panama City, Panama
Type of event: radiotherapy accident
Description:
In August 2000 a modification to the computerized treatment planning system used to calculate shielding blocks during radiotherapy treatments. Unknown to the operators, the change resulted in overexposures to patients. Development of symptoms in treated patients led to discovery of the error on 24 March 2001, after 28 patients had been overexposed. Five patients died due to overexposure, one died in December 2000 of cancer unrelated to treatment, and two died by 2001 (one on 19 October 2000, 2 weeks after treatment) of undetermined causes. Of the radiation-related deaths, dates were as follows: 6 March, about 3 weeks after treatment; 28 March, about 7 weeks after treatment; 7 May, about 13 weeks after treatment; 19 May, about 10 weeks after treatment; 20 May, about 12 weeks after treatment; Most of the other 20 patients displayed injuries, mostly involving radiation injury to the bowel. By 23 May 2002, 17 patients had died, with 13 of the deaths caused by rectal complications and 14 deaths total linked to radiation exposure. By August 2003, 21 patients total had died with 17 of the deaths attributed to radiation exposure. For all deaths, times between exposure and death were 35, 47, 69, 115, 116, 117, 172, 277, 292, 292, 319, 321, 326, 345, 363, 386, 439, 650, 691, 782, and 836 days.
Consequences: 17 deaths, 11 injuries.

Date: 19 March 1984
Location: Casablanca (Mohammedia), Morocco
Type of event: lost radiography source
Description:
A 16.3-curie iridium-192 industrial radiography source was lost and taken home by a laborer. The laborer had laid the source on a table in the family bedroom, and it was in the house for possibly a

few weeks. Exposure to radiation caused the deaths of 8 family members, including 4 children and their parents within a few days of each other, about 45 days after exposure. Three other people received significant exposures. Diagnosis of radiation exposure was only made 80 days after initial exposure.
Consequences: 8 fatalities, 3 injuries.
References:
Biau, Alain, 2001, "Radiation protection of the workers in industrial radiography: the point of view of the regulatory body in France," on line, *European ALARA Network* [http://ean.cepn.asso.fr/pdf/program5/session%201/5_biau.PDF].

Date: 5 October 1982
Location: Baku, Azerbaidjan, USSR
Type of event: irradiation from orphaned source
Description:
A cesium-137 source was carried by an individual in a clothes pocket, exposing several individuals. Five people suffered radiation burns and died; at least one other person suffered acute radiation sickness, and 12 others were exposed.
Consequences: 5 deaths, 13 injuries.
References:
Ilyin, L. A., V. Yu. Soloviev, A. E. Baranov, A. K. Guskova, N. M. Nadezhina, and I. A. Gusev, May 2004, "Early medical consequences of radiation incidents in the former URRS territory," 11th International Congress of IRPA, on line, *IRPA* [http://irpa11.irpa.net/pdfs/7c20.pdf].

Date: 11 March 2006
Location: Fleurus, Belgium
Type of event: accident with industrial irradiator
Description:
A worker received an accidental radiation exposure at a facility for irradiation of medical devices. The facility uses a cobalt-60 source in an exposure cell but stowed in a pool when personnel are present, using a safety interlock system. On 11 March the employee noticed a radiation monitor alarm was activated with no irradiation in progress and the cell door open. He reset the alarm and entered the cell for 20 seconds to close the cell door. The worker was not carrying a Geiger counter as required by company procedures. He suffered nausea and vomiting soon afterward but made no connection to the irradiator. Several weeks later he suffered massive hair loss and went to a doctor, when it was determined he suffered an exposure of 420 rem; this estimate was subsequently revised to 440-480 rem. The individual was admitted to a French hospital for treatment of radiation sickness on 31 March. Primary cause of the accident has been suggested to be a failure of the hydraulic control system that raises and lowers the source from safe storage in its pool.
Consequences: 1 injury.
References:
FANC, 12 April 2006, "Information file: Sterigenics," *FANC*, on line [http://fanc.fgov.be/FANC/en/sterigenics_2006_04_11_dossier1.htm].

Negative consequences of nuclear or radiological accidents. Intervention levels.

Negative consequences of nuclear or radiological accidents

The main negative consequences of nuclear or radiological accidents are following:

- Consequences for health: deterministic effects and stochastic effects
- Psychological
- Environmental
- Economic
- Social

Consequences for health. There are basically two types of physical health effect related to radiation exposure. The first is called a *deterministic effect*. These effects occur relatively soon (within days to weeks) after an exposure to a high dose at a high dose rate. Essentially the damage to the tissue from the radiation is so extensive that the body does not have time to regenerate new tissue, and so the effect becomes visible with many of the features of a thermal burn, but usually much deeper and long-lasting. Deterministic effects often appear localized on the body depending on the radiation exposure pattern and the level of penetration of the radiation. The higher the radiation dose the more severe is the damage to the tissue and the sooner the onset of symptoms (at very high doses the effects can appear within hours). However at low doses and dose rates these effects do not occur at all - there appears to be a dose threshold below which one is ‘safe’ from these effects. This has an important bearing on the goals of emergency response - namely to try to keep the doses received below the threshold for deterministic effects. Deterministic effects need specialized medical treatment to overcome and aid patient recovery, although any paramedic treatment is usually relatively straightforward.

The second type of health effect that can be caused by radiation is a so-called *stochastic effect*, such as cancer or hereditary effects in any future offspring. These types of effects are characterised by their late appearance after exposure (several years up to decades), and critically that their occurrence is not certain. The radiation may cause some damage to the cells of the body which is not visible but changes the functioning of those cells. These changes may manifest themselves at a much later date as a cancer for example. Notice that we say ‘may’ occur, there is no certainty of occurrence. For stochastic effects, we find that the chance or probability of an effect increases the higher the radiation dose. So at low doses there is a very low chance of cancer developing - at very high doses, there is a higher chance of cancer. However it appears that there is no ‘safe’ dose, or dose threshold below which cancers do not occur. Also it apprears that it is the cumulative dose that influences the chance of cancer development and not the dose rate (at least not strongly).

Are the cancers induced by radiation different from those induced by other hazards (e.g. chemicals, biological agents, naturally from one’s genetic make-up etc.) ? The answer appears to be no - they are indistinguishable, unlike a deterministic effect, which can readily be attributed specifically to radiation. This means that the only way these effects can be detected is by studying cancer statistics for a population, using careful cancer and dose registration. This graph for example shows an increase in the risk of thyroid cancer among 5-yr olds as they age following a radiation dose to their thyroids. At young ages, there is a significant increase over the normal rate of thyroid cancer, but as they grow older, it becomes more difficult to be able to attribute a cancer specifically to radiation exposure.

This also means that the radiation-induced cancers are treated in exactly the same way as non-radiation-induced similar cancers, needing no specialist treatment.

Nuclear and radiological accidents have consequences other than just the direct physical effects on humans. *Psychological health effects* will always accompany a nuclear or radiological accident whether or not it has resulted in persons receiving significant radiation exposure. Some protective actions taken during Chernobyl to reduce the radiological health risks, such as relocation and resettlement, did more harm than good because of the resulting psychological health effects brought on by stress and anxiety. Psychological health effects must be considered when determining protective actions. To minimize the potential for longer-term stress in affected population groups, it is essential to resist pressure to introduce protective measures for political reasons that are well below those justified on radiological grounds.

Every accident involving radiation has led to anxiety and distress among the people who have been - or who think they have been - exposed to radiation. These effects in the case of the Chernobyl accident have been serious and long-lasting, despite the radiation exposure to most people being relatively mild. They include severe clinical depression and symptoms of stress, including high blood pressure and cardiovascular problems, and development of alcoholism and drug addiction as a reaction to the stress.

When land, water or air become contaminated with radioactive material, there is concern about the *environmental effects*. Normally radiation does not affect the ecosystem unless the levels are very high, although it can damage individual plants and animals. More problematic are the impact of countermeasures on the environment - countermeasures that were taken to protect man. Moreover when the environment becomes contaminated with radioactive material no matter whether the levels are very small, there is concern among the population continuing to live there. Finally environmental processes, such as wind and rivers can transport radioactive material from one place to another, which raises further concerns.

Any countermeasures taken to address health or environmental impact will have associated costs, whether they be the direct cost of the countermeasure itself, or the lost *economic* output from formally productive areas. Together with health and environmental impact the *social* consequences associated with the accident and any countermeasures employed, it is clear that the consequences are often more than just the direct health consequences alone.

These basic obligations can be expressed in terms of these practical objectives for emergency response. Note that in one way or another they address the management of the accident consequences we have just identified with the aim of reducing the negative impact of the accident - yet recognizing that this must be done under the constraints of politics and economics.

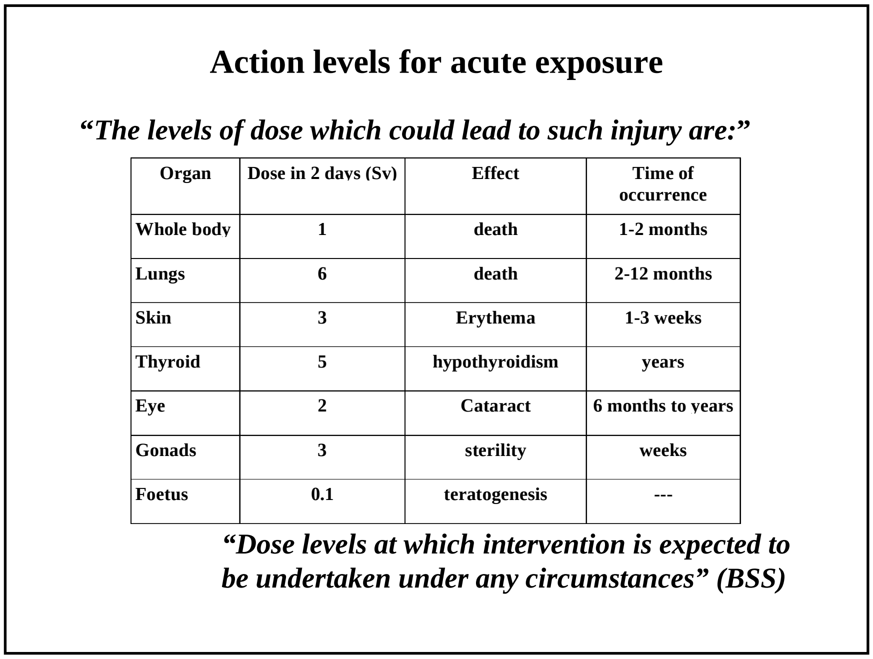
Intervention levels

The International Commission on Radiological Protection in its ICRP 63 publication recognized that radiation dose was the measure of hazard for deterministic effects and its recommendations on dose thresholds were taken into account in the development of the International Basic Safety Standards (BSS).

BSS encompasses the main objective - to prevent deterministic effects, i.e. early death and morbidity, by keeping doses below the thresholds for such effects. However because models on which dose estimates are based are notoriously inaccurate, it is therefore recommended that protective actions be implemented when assessed future doses reach some substantial fraction of the deterministic thresholds, or when there is a not insignificant risk that these dose thresholds may be exceeded, if action is not taken immediately. This is wrapped up in the Requirement of the International Basic Safety Standards that at levels of projected dose likely to lead to serious injury, protective actions or intervention will be expected to be undertaken under any circumstances

What are those levels?

The levels at which intervention is expected to be undertake under any circumstances are following:



Action levels for acute exposure

"The levels of dose which could lead to such injury are:"

Organ	Dose in 2 days (Sv)	Effect	Time of occurrence
Whole body	1	death	1-2 months
Lungs	6	death	2-12 months
Skin	3	Erythema	1-3 weeks
Thyroid	5	hypothyroidism	years
Eye	2	Cataract	6 months to years
Gonads	3	sterility	weeks
Foetus	0.1	teratogenesis	---

"Dose levels at which intervention is expected to be undertaken under any circumstances" (BSS)

They are specific to each organ, and they are expressed in terms of the dose received in a 2 day period. 1 Sv is taken as the whole body dose threshold for serious deterministic effects. With the exception of the foetus the other thresholds are higher, so for uniform radiation fields the whole body is critical.

Returning to criteria for intervention, another objective of emergency response is to reduce as much as possible the additional radiation-induced stochastic effects (e.g. cancers) in the population.

However we should take into account that natural background radiation (from cosmic rays, terrestrial gamma rays, radon etc.) provides on average individual dose of 2.4 mSv per year, and this can range from about 1 to about 10 mSv per year in and within different countries around the world. So on average we each receive some 170 mSv radiation dose from natural background in our lifetimes (assuming 70 year mean life expectancy), and this typically ranges from about 70 to 700 mSv. So after an accident, we must recognise that it is impossible to reduce the total dose to zero - the accident will increase the lifetime dose and associated risk of cancer.

While an intervention, such as food controls, sheltering or evauation, may have benefits in reducing the dose and therefore in reducing the associated risks, intervention also has penalties. These penalties include the risk of side effects (e.g. reducing the nutrition in the diet if key foods that are already scarce, are banned), increased doses to emergency workers (e.g. to the police in carrying out an evacuation), economic costs and socio-psychological penalties.

So it is clear that for each protective action that might be considered, there is a tradeoff between the penalties of taking the action and the benefits of reducing radiation exposure. This suggests that the level at which protective actions are taken be optimized. For example, the risks associated with evacuation include road accidents and possibly death, and the cost includes the interruption of economic activities and the emotional troubles associated with having a large number of people stay in emergency shelters. The question is what level of dose saved will evacuation be worthwhile - this level is called the *Intervention level.*

The recommendations of the ICRP were considered in the drafting and adoption of the Basic Obligations for Intervention as required in the BSS.

Here there is a requirement that intervention should be taken when it is justified; that the intervention should be optimized to produce the maximum net benefit given prevailing conditions;

and that intervention shall be considered when the averted dose is expected to exceed prescribed intervention levels. The optimization should in principle take into consideration social and economic factors in the country where they apply. For example, in some countries or regions, evacuation may be difficult at best of times due to the lack of means of transportation or high population density.

However there are strong reasons to adopt the guideline values in the Basic Safety Standards to ensure international harmonization and credibility of national authorities.

Based on a generic optimization analysis, generic intervention levels have been adopted by BSS. It is worthwhile noticing that the new guidance does not contain upper and lower limits like those in the ICRP publications. This is in part a result of the Chernobyl experience where the exact interpretation of these upper and lower limits by different organizations led to delays in the implementation of the protective action, and to mistrust among the affected populations. These drawbacks with the two-tier approach - led to the adoption of a set of generic intervention levels for each protective action in the BSS.

Generic intervention levels

➢ **10 mSv dose avertable in 2 days**	***Shelter***
➢ **50 mSv dose avertable in 1 week**	***Evacuate***
➢ **100 mSv avertable thyroid dose**	***Iodine Prophylaxis***
➢ **30 mSv in first 30 days or 10 mSv in next 30 days**	***Relocate***
➢ **1 Sv lifetime**	***Resettle***
➢ **Generic Action Levels for foodstuffs**	***Control food***

Basic Safety Standards

The intervention levels are expressed in terms of the dose averted for each action, except for foodstuffs where they are expressed in terms of the activity concentration of key radionuclides in the foodstuff.

Psychological factors can also affect the implementation of protective measures. The compliance with imposed food restrictions was alarmingly low in some areas directly affected by Chernobyl. This was in part because of a lack of information early in the event and conflicting information later. The severity of these psychological effects will depend, in part, on whether people have confidence that the authorities are competent and trustworthy, and have taken prompt and effective action to control radiation doses. In those areas near the plant, information on accidents and protective actions should be provided to the public as part of a routine education programme. At the time of an accident, be honest and provide clear, simple advice based on internationally endorsed guidance to the public. Efforts should be made to provide consistent advice and assessment to the public and media, and to correct false information. Every effort must be made to maintain public trust.