**Chemical Process Safety**
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**Lecture 53**
**The Chernobyl Nuclear Disaster**
**(April 26, 1986)**

Welcome to another case study. In this particular module we are going to discuss the Chernobyl Nuclear Disaster which took place on April 26, 1987 and it is one of the worst nuclear disaster in the history because of the vulnerability, because of the disaster approach, although all nuclear (plant) power plants, they are relatively safe but this particular accident was one of the worst in the history of the nuclear power (plant) operations. So, let us have an introduction about this particular plant, the Chernobyl nuclear power plant is in the north of Ukraine and that is close to the Belarus border at around 120km from Kiev.

So, on April 26 1986 at around 1:00 am the subsequent to severe human error, the vapor explosion in reactor number 4 of that particular plant led to a release of huge amount of radioactive materials. So the accident occurred during an experiment to test a potential safety emergency core cooling feature. So you can see the proximity of other countries and cities of that particular plant in the figure given in this particular slide.

So the outcome of this particular accident was two workers died on the night of the same accident and 28 people died within a few weeks. 1,15,000 people were evacuated just for the time of incident and 2,20,000 people they relocated because of prolonged radioactivity at that particular arena and 6,000 acre, 6,000 cases they were reported for the thyroid cancer and a large area was contaminated because of the radio activity.

So, let us have a background of this particular accident. This Reactor Bolshoy Moshchnosti Kanalnyy - RBMK a Russian acronym translated roughly by means of a reactor of a high-power rich channel type. Now, this reactor cooled by water and a moderated by the graphite, this is the protocol of radioactive power plants.

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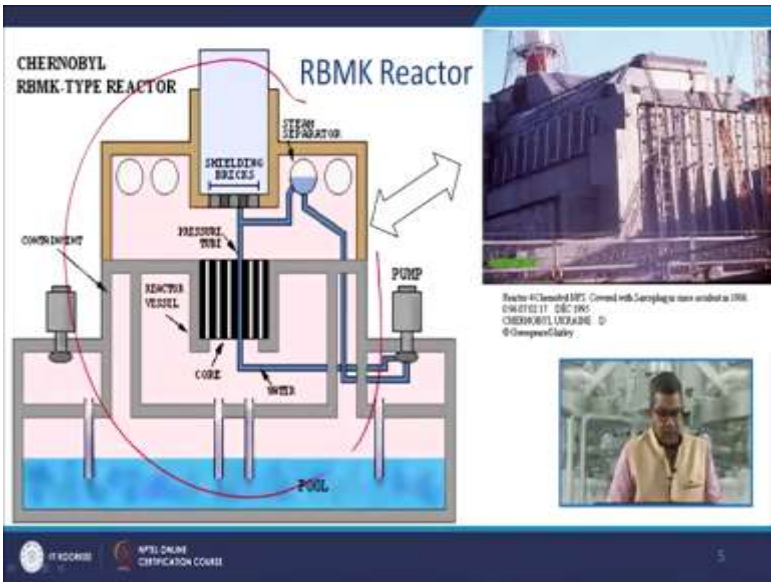


Now, this is the inside of this Chernobyl RBMK type of a reactor, they were having this main reactor with them and there are several containments, this is the main reaction vessel and the core and there was a water tubing inside with the shielding bricks and there was a separate steam separator through which the steam was separated with the pump and this is the actual photograph of (that) this reactor.

Now, the reactor plant scenario says that as the reaction occurs the uranium fuel becomes hot and the water pumped through the core in pressure tubes removes the heat from the fuel and the water is then subsequently boiled into steam and this steam turns on the turbines to generate the power and the water is (the) or steam is then cooled and then the entire cycle is repeated.

So, this was the total protocol of that particular process. Now, on 25th of April 1986, at 1 am the preparation of for the test was carried out at 1:47 pm there was a lowering of a reactor power halted at 1600 megawatts. So you can imagine that the capacity of that particular nuclear plant was so high, so at around 2 pm the ECCS was isolated and allow around 11:10 pm the power reduction resumed. So on 26th of April 1986, at midnight the operation shift changed and at around 12: 28 am the power level is now 500 megawatt and kept decreasing to 30 megawatt.

At 12:40 am the operator withdrew some of the control rods and 1:00 am in the early morning the power had rising to 200 megawatts and 1:03 am in the morning the connecting the fourth

main cooling pump to the left loop of the system 200 megawatt and around 1:07 am the connecting, they connected the fourth main cooling pump to the right of the loop system and this was a violation of nuclear operation protocol. So, they have committed a mistake that they have violated this protocol.

So on the same sequence at around 1:20 am there was increased feed water supply flow to the steam drums and remove more control rods again there was a violation of this protocol and at around 1:23 am the test was started and thereafter the automatic rod withdrawn from the core and two groups of the automatic control rods were back to the core.

So this is the sequential order of that particular incident and the same time the power kept increasing and then they sensed that there is something wrong in the system, so emergency button was pushed on and power was around 300 megawatt. So the same time the first exothermal thermal explosion took place and within 10-20 seconds the second explosion took place.

So this is the scenario after the thermal explosion and this is the actual photograph of the Chernobyl reactor and this is the photograph taken prior to the accident. So you can see that everything was normal at the moment. Now, these are the couple of photographs after the accident.

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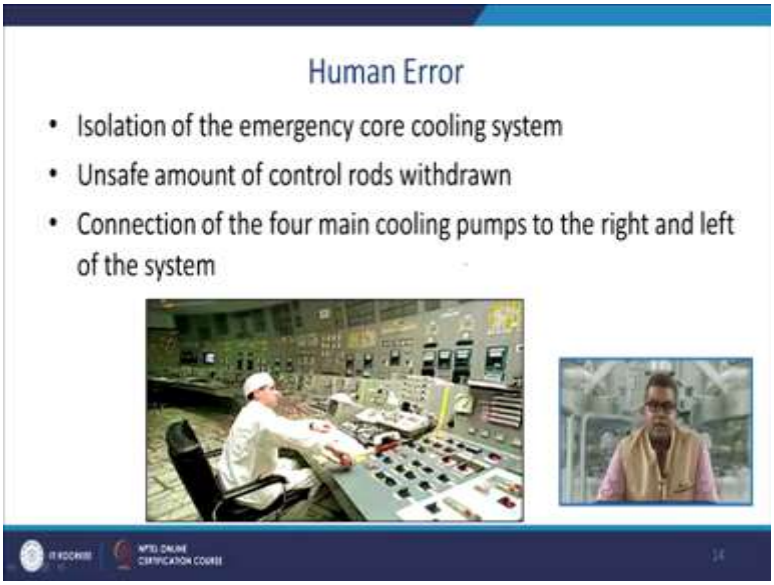

Now there was a human error attributed to this particular accident because of the isolation of emergency core cooling system there was unsafe amount of controlling rod withdrawn and the connection of four main cooling pumps to the right and the left of the system.

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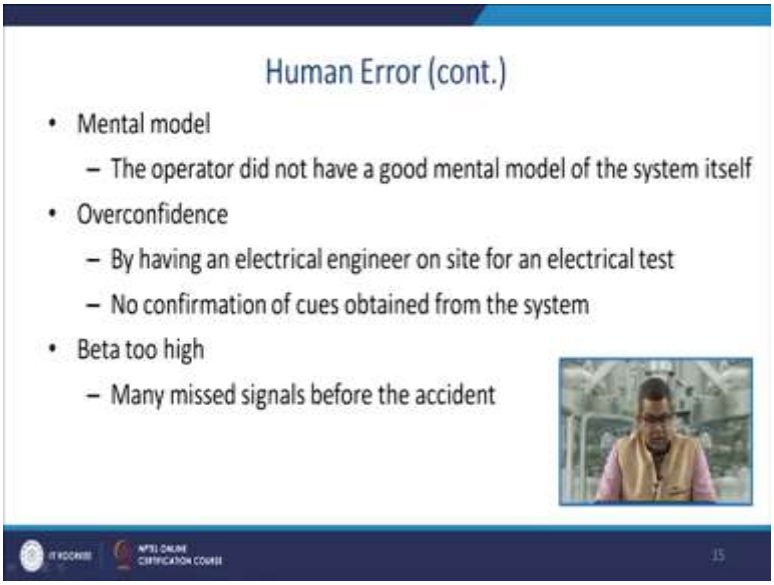


So they have suggested various things like mental model, the operator did not have a good mental model for the system itself maybe, he maybe not in a good mood etc. So the mental stability and the psychological factor usually come into the picture, then he might have an over confidence of the things, so by having an electrical engineer on site for the electrical test and there was no confirmation of cues obtained from the system. So this one again contributing factor in terms of human error, then the beta was to hide the things so many mystery signals before the accident. So some of the signals they overlooked in due course of time while carrying out that particular experiment.

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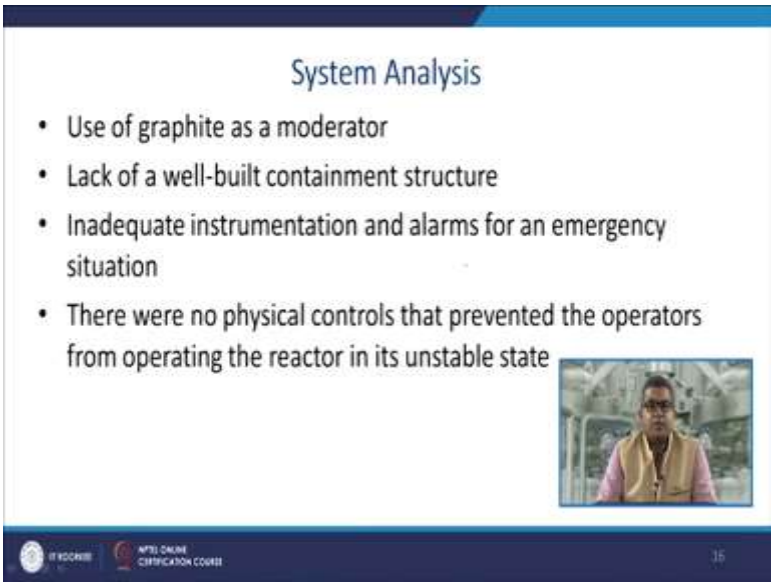


Then there was a system analysis for this particular accident, the use of the graphite as a moderator that was a well-known protocol for the nuclear power plant. There was a lack of a well-built containment structure, then there was inadequate instrumentation and alarms for an emergency situation and there was no physical control that prevented the operator from operating the reactor in its unstable (condition) state.

So usually whenever this type of thing occurs when this type of tests and other things are performed there may be several layers of safety operations. So if anyone fails like this in this particular case if the operator fails in that particular aspect, there may be certain other physical control which can prevent the further proceeding of that accident.

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So, let us have a look about the summary of the facts on April 26 1986, the Chernobyl nuclear power plant, the operator error caused an accident and a reactor explosion and this explosion releases around 190 tons of radioactive gases into the atmosphere and followed by the fire which lasted around 10 days and the if we talk about the people at stake, so 70 million people they lived in the contaminated area and 3 million were children and there was a wind inversion it or wind flowing at that point of time that carries radiation for very long distances. So the area in question was large enough compared to the other cases.

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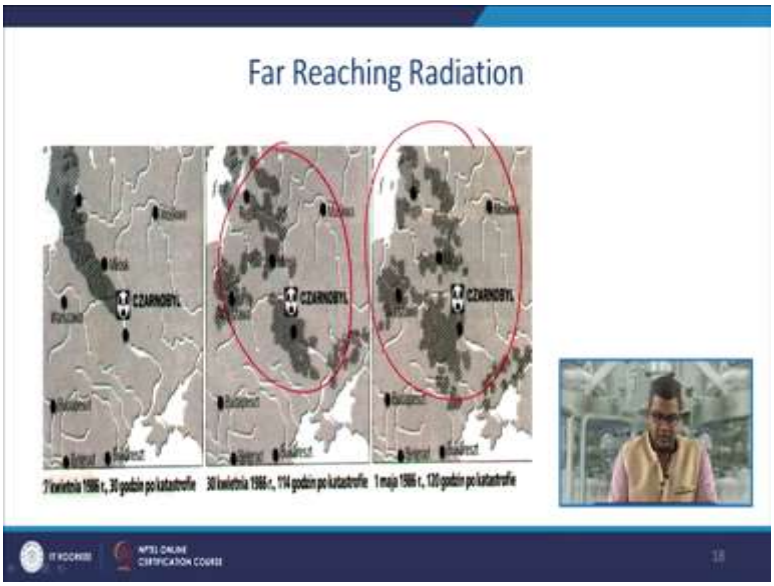


Now, you can see the Far-reaching of the radiation in this particular diagram here in the Chernobyl you can see that the wind inversion took place and are and it is spreaded to in so many areas like this.

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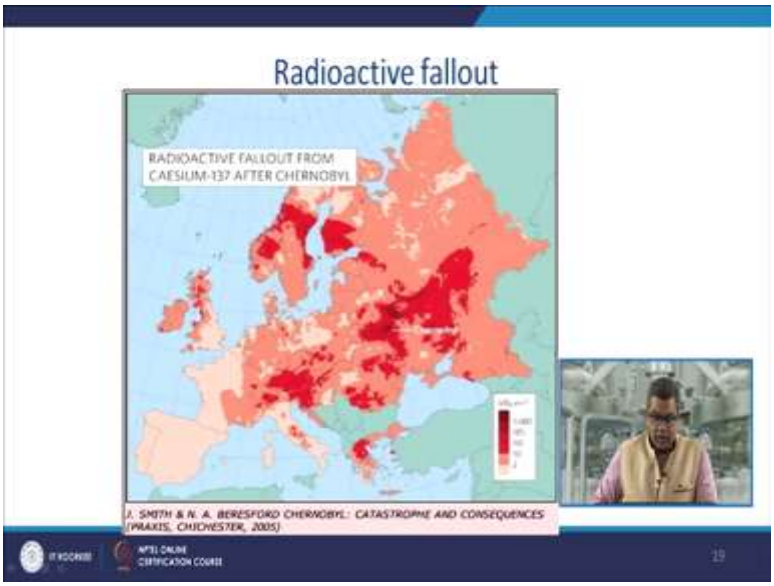


Now there was a radioactive fallout from cesium-137 that is after the Chernobyl reactor you can see that the red spots they represent the radioactive fallouts in this particular diagram.

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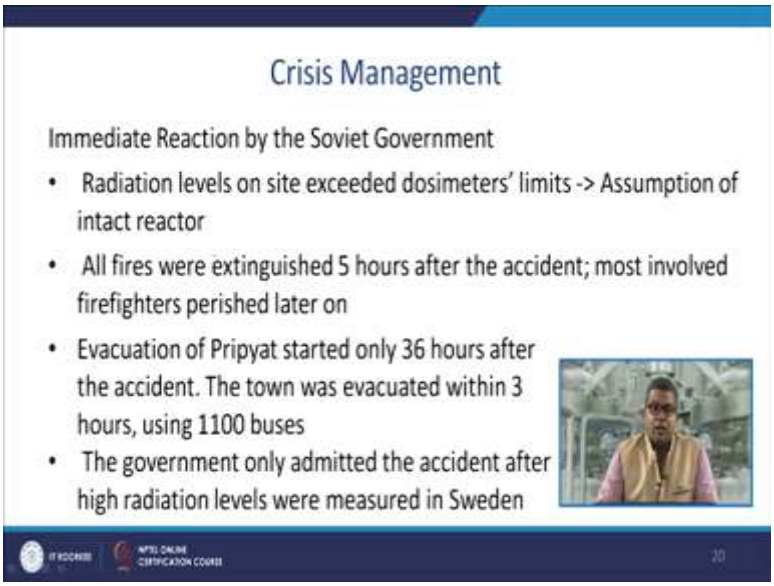


Now there was a Crisis Management at the point of time when the reaction took place so immediate reaction by the Soviet government it was earlier USSR, so the radiation level on site exceeded the dosimeters limit and assumptions of various intact reactor. So all fires were extinguished 5 hours after the accident, but most involved fire fighters they perished later on.

Now evacuation of prepared to start only 36 hours after the accident and thus the entire town was evacuated within 3 hours using 1100 buses. The government only admitted the accident after the high radiation levels were measured in Sweden. So you can imagine that the radiation fallout, they approached it to the Swedish arena. There were several other further developments in 86.

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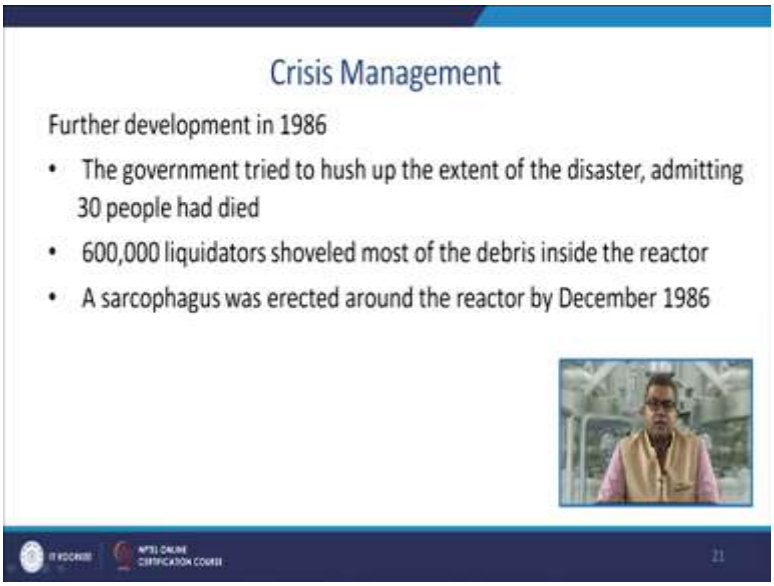


The government try to hush up with the extent of disaster admitting that 30 people they had died and 6 lakh liquidators shoveled most of the debris inside the reactor and a sarcophagus was erected around the reactor by the December 1986. So you can see that after this accident it took around 6-7 months to go ahead.

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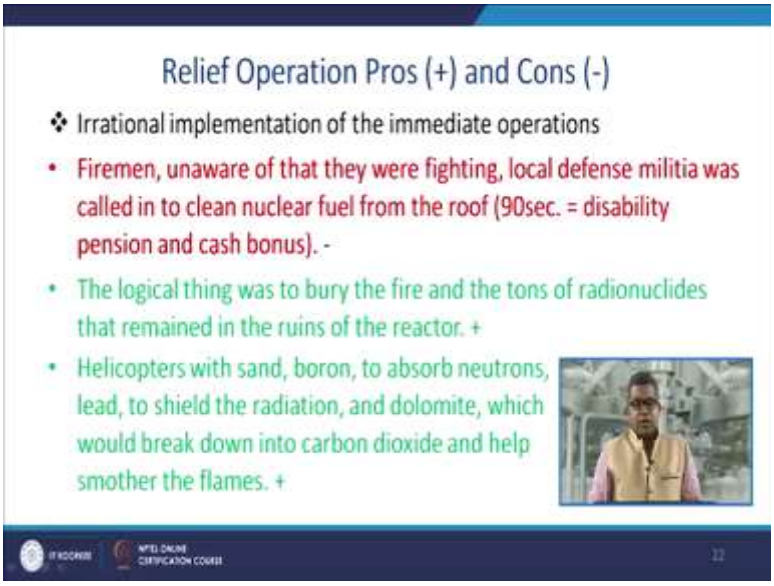


Now, there were certain relief operations were carried out and there were certain advantages and (advantages) disadvantages associated with, the irrational implementation of immediate

operations so the firemen they were unaware of that they were fighting, basically they were practically unaware that there is a radioactive contamination. The local defense militia was called to mean to clean the nuclear fuel from the roof and that is (97) 90 seconds is equal to Disability Pension in the various kind of cash bonus. So they were awarded for this type of compensation.

The logical thing was to bury the fire and the tons of radionuclide to that remained in the ruins of the reactor. So that was again issue, the helicopters with sand, boron to absorb the neutrons they led to shield the radiation and dolomite which would break down into the carbon dioxide and help some smoother the flame that was used at the time of relief operation.

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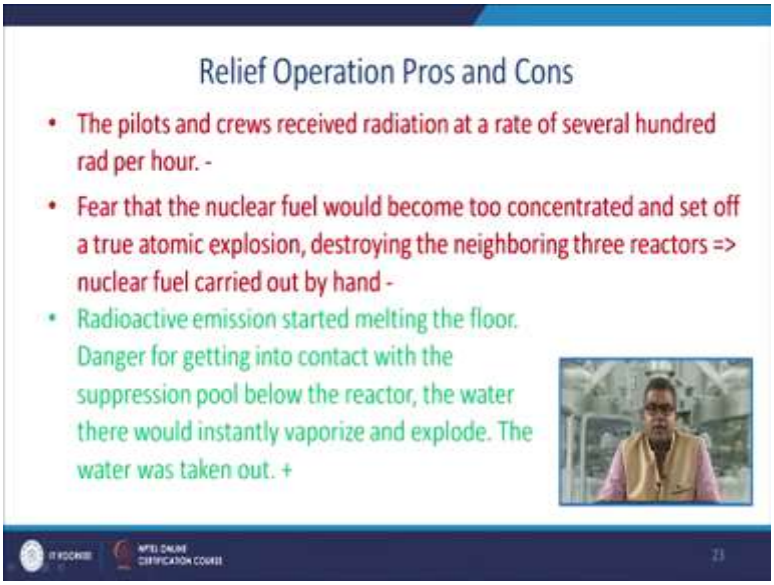


The pilots and the crews they received the radiation at a rate of several hundred radiations per hour. Now, fear that the nuclear fuel would become too concentrated and set of a true atomic explosion destroying the neighboring three reactors because (the) this thing may be propagated to the other reactors. So use nuclear fuel just was carried out by hand. So radioactive emission that is started melting the floor so you can imagine that how much gravity was it. Now danger for getting into the contact with the suppression of a pool below the reactor and the water there would instantly vaporize and explode, so the water was taken out. So that was again the pros of that particular accident.

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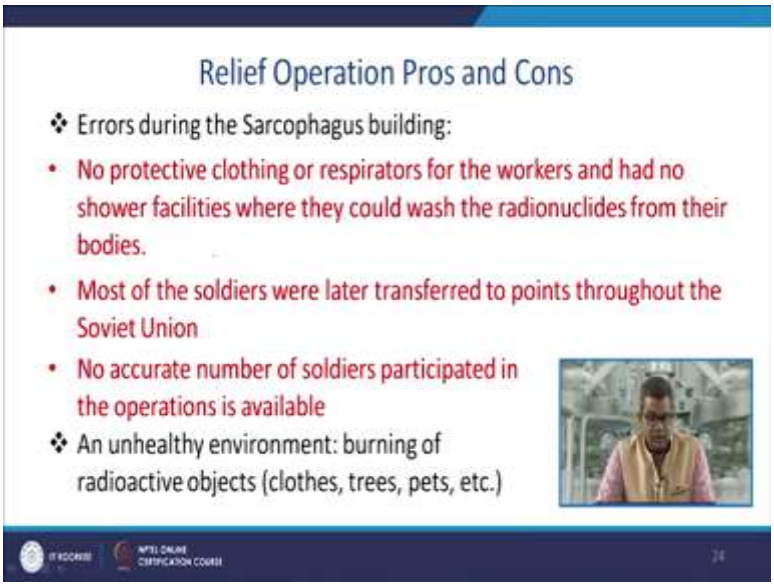


Now, there were several errors attributed to the sarcophagus building, there was no protective clothing or respirator for the workers and had no shower facility where they could have washed the radionuclide from their bodies and the most of the soldiers were later transferred to the point throughout the Soviet Union elsewhere Soviet Union and there was no accurate number of soldiers participated in the operation.

So there is no data available as on date to find out that how many soldiers those who have participated in that particular rescue operation. An unhealthy environment, that is the burning of radioactive object like cloth, tree, pets, etc, because the immediate measures they follow a protocol to burn all kind of radioactive contaminated objects that may include the cloths, various vegetation, animals, etc. So they decided to burn it out off but that particular environment, that particular activity be made the entire environment unhealthy.

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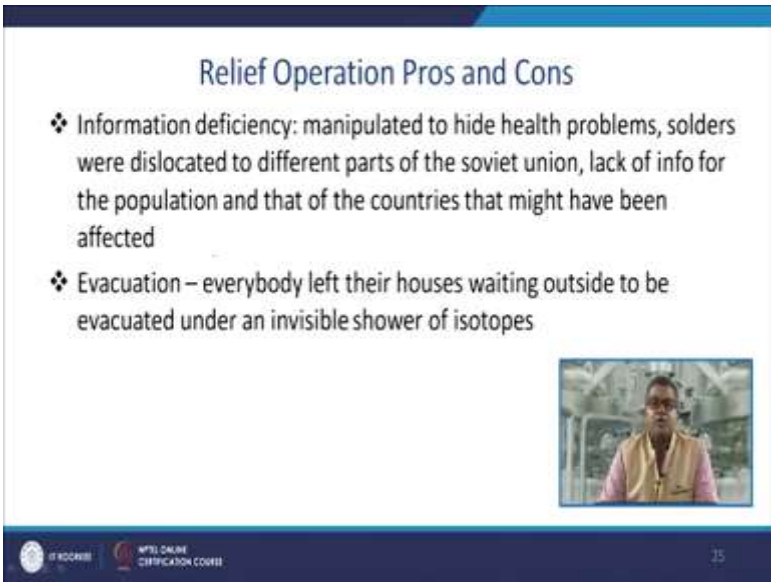


Now, information there was an information deficiency, they manipulated to hide the health problem. Soldiers were dislocated to different parts of the Soviet Union there was a lack of information for the population and that of the countries that might have been affected. So the no proper information was provided either by the Soviet Union or other authorities to the neighboring countries or other stakeholders. So evacuations, so everybody left their houses waiting outside to be evacuated under an invisible shower of Isotopes. So again nearby people they were not been sensitized about the gravity of that particular accident and the gravity of the operation been carried out at the Chernobyl nuclear facility.

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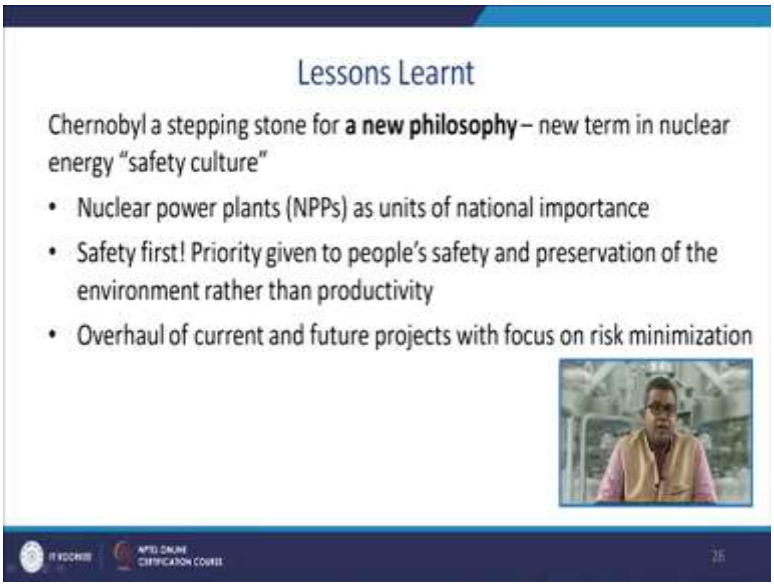


So, let us have a look about the various lessons learned from this particular accident. The Chernobyl is stepping stone for a new philosophy that is new terms in the nuclear energy safety culture. So the nuclear power plant sometimes referred as NPP is the as unit of national importance so in each country they have given the national importance and the safety first, they are just following the concept of safety first, so priority given to the people safety and the environment and rather than the productivity, so they have synchronized the things in the aspect that people safety is the first and then the environment and the productivity is the least one.

The overhaul of current and the future projects with the focus on risk minimization being carried out by various countries including India so that they can avoid the reoccurrence of such type of accident because this particular accident may have a long-term impact to the arena in question.

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Now, let us have a look about the direct casualty, so 5.5 million people still live in the contaminated area, 31 people died in 3 months of a radiation poisoning, 134 emergency workers they suffered from acute radiation sickness, 25,000 the rescued worker died since then the disease caused by the radiation, the cancer affects the many others and increase the chances of a birth defect, miscarriage and as and other genetic diseases. So these things they are having the long-term impact and sometimes may not contribute towards the statistical analysis of direct casualties. Now, there are several other indirect casualties because of the time frame that the things are again catalogued by various authorities.

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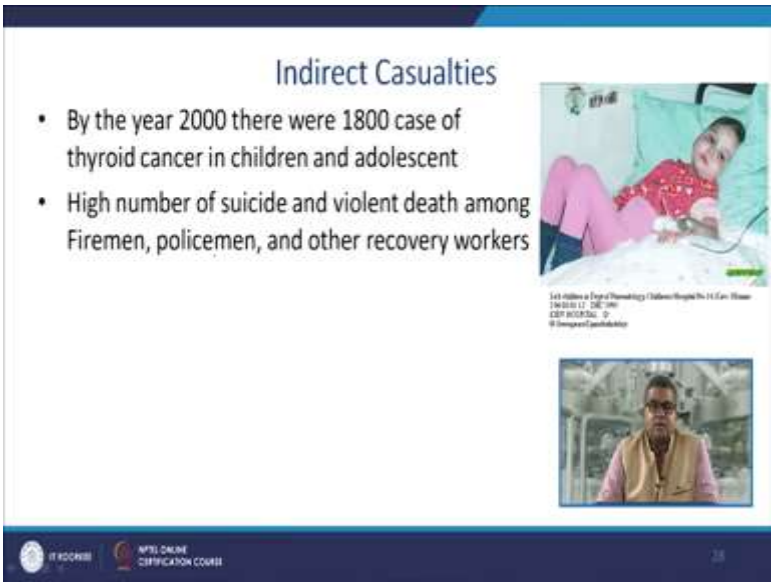


So by year 2000 there were 1800 cases of thyroid cancers, cancer in children and others there are high number of suicide and a violent death among the firemen, policemen and other recovery workers may be attributed to some psychological fact because they might have suffering from other radioactive diseases etc. Now, there was a serial environmental impact.

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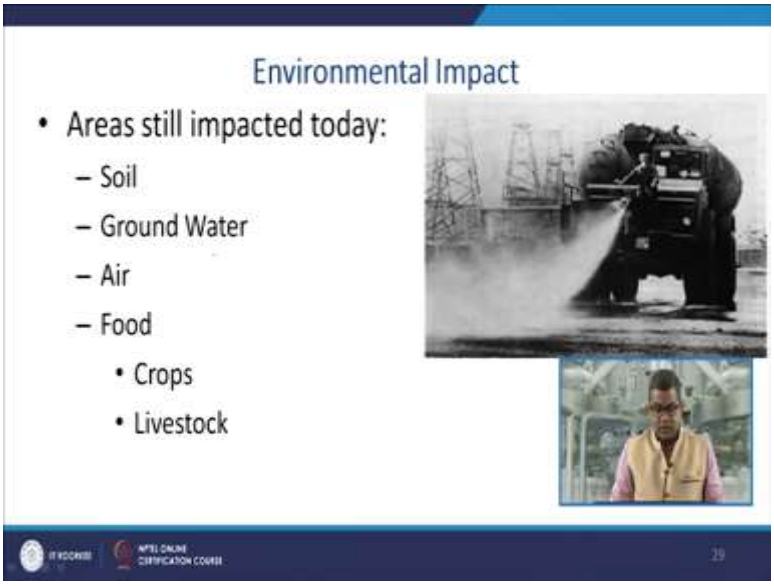


So, let us have a look about the area and arena those who are still impacted today, they are the soil, the ground water, air, food, crop and other livestock. So these are the various areas where

those who are affected by this radioactive contamination and is still in a generalized manner these are the major area (whose) which are affected in case of any chemical disaster took place anywhere in the world.

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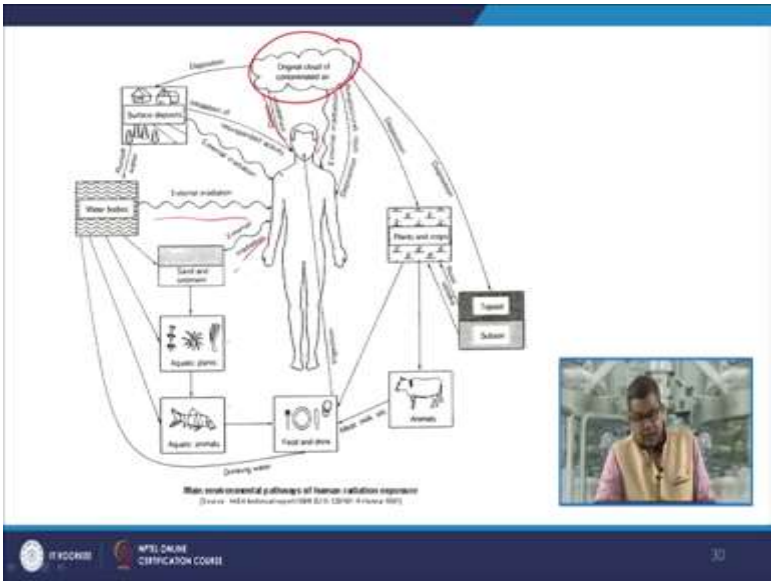

Now, here you can see (the) there are main environmental pathway of human radiation, so as we discussed in the previous modules about the industrializing, there are four routes of entry of any contaminants to the body structure. So you can see that in this particular figure there are the original cloud of contaminated air and this may directly go into the body either through inhalation, either through the dermal absorption.

Now, you can see that there may be certain water bodies or externally radiation may took place, external radiation made through to take place through skin, maybe they are attributed to the sand, aquatic plant, aquatic animals, etc. So as far as the human intervention is concerned, these are all those four routes of entry to for radioactive material to the human body they took place in this fashion. Apart from this the food and drink, animal, plant crops etc. So these are the various routes through which these radioactive material got contaminated.

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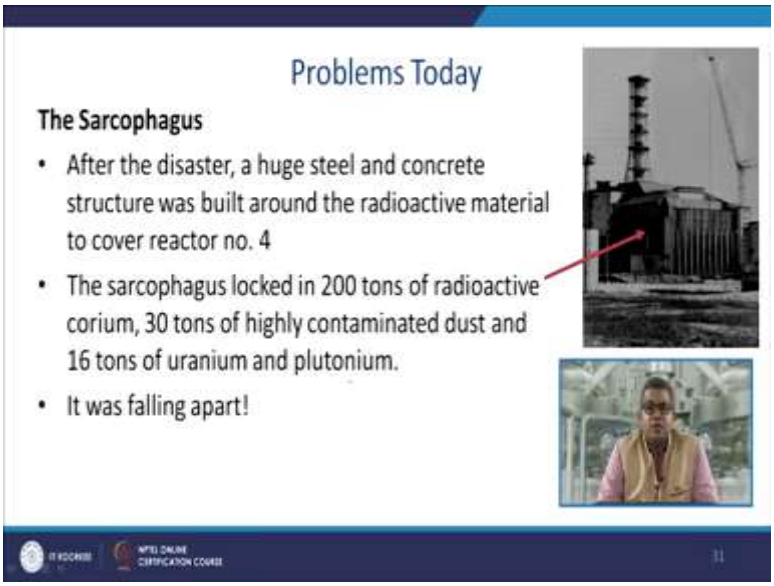


Now let us have a discussion about the problems today. The sarcophagus, the after the disaster a huge steel and a concrete structure was built around the radioactive material to cover the problematic reactor number 4 and the sarcophagus logged in 200 tons of a radioactive corium, 30 ton of highly contaminated dust and 16 tons of uranium and plutonium. So it was falling apart.

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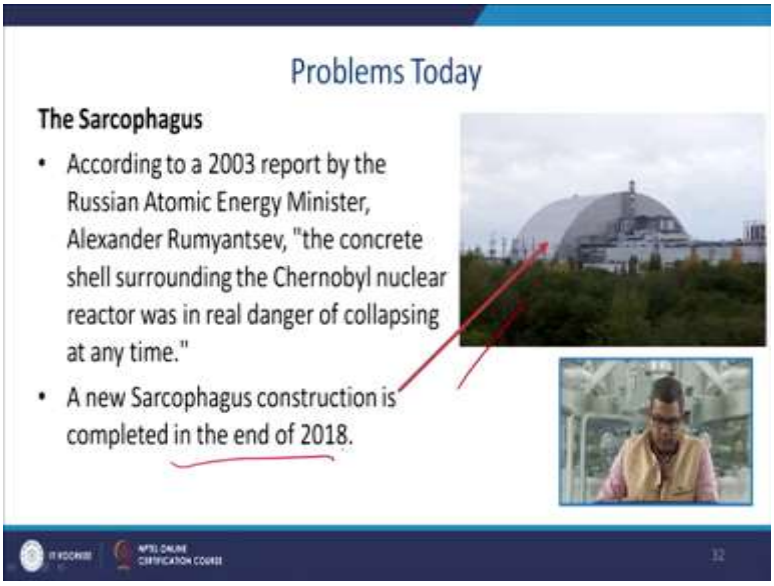


Now, you can see that this, the new sarcophagus construction, this was completed in the end of 2018. So according to 2003 report by the Russian Atomic Energy Minister the concrete shell

surrounding the Chernobyl nuclear reactor was in real danger of collapsing at any time. So a new sarcophagus was constructed and it was completed and the end of 2018.

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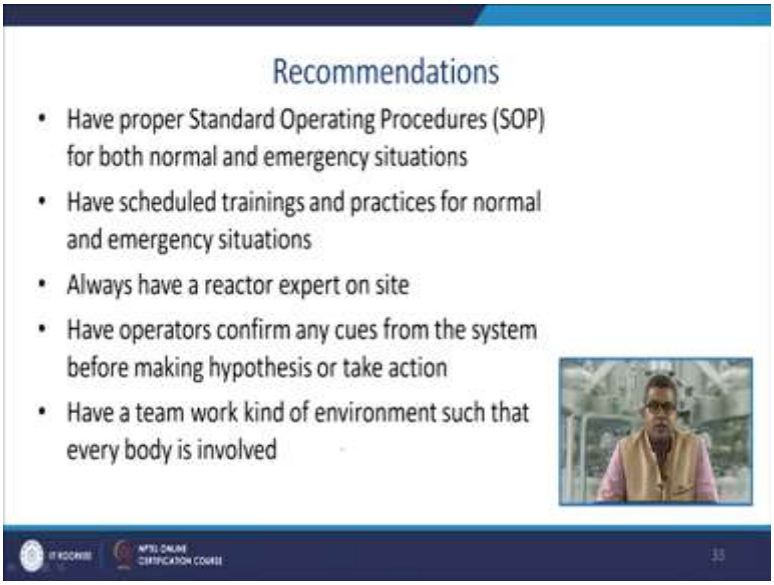


Now, there are several recommendations attributed to this nuclear disaster. Now, first and foremost recommendation that have a proper standard operating procedure or a protocol for both normal and emergency situation. Now, you can have a scheduled training and a practices for normal and emergency situation. You must have a always a reactor expert on site. So you have operators to confirm any cues from the system before making hypothesis or take action. Must have our teamwork kind of environment such that everybody is involved. Now, this type of thing attributed to the proper safety training which we had discussed in first modules.

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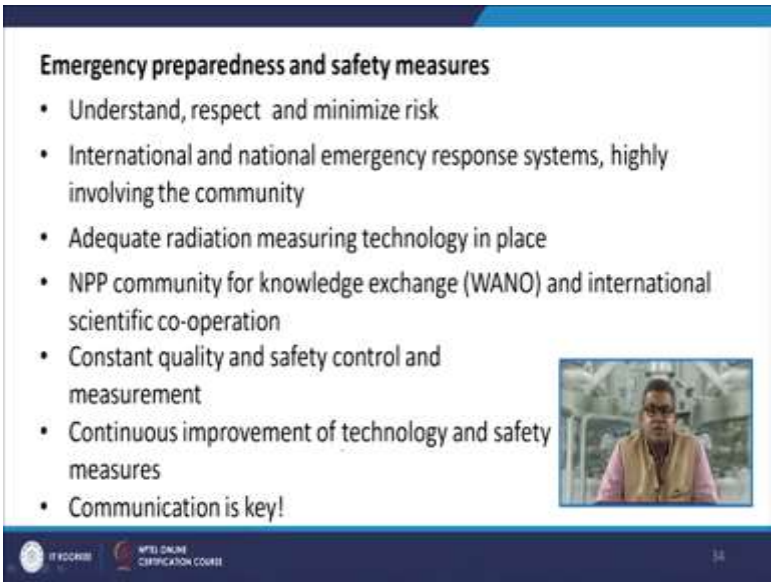


Now, there is a certain emergency protocols and safety measures so you must understand and respect and minimize the risk. There are several International and National Emergency systems because as we mentioned in this the previous slide that the first time the radioactivity of that particular Chernobyl leak was detected by the Sweden so you cannot overlook the importance of international responders.

So you have to take into the consideration for this highly involving community. Now adequate radiation measuring technology should be in place, the nuclear power plant community for the knowledge exchange and international scientific cooperation that is become must. There is a, there must be a constant quality and its safety control measurement and a continuous improvement of technology and safety measurement measures.

So, now the last point in this particular slide is the key, that communication is the key and like in every accident there was a communication gap between the plant officials and the local authorities. So indeed in that is Chernobyl disaster there was a communication gap between the local authorities because it was the duty of the authorities to train the nearby people. Now, there are other health consequences and a lesson from the medical responders. So from hermetic nuclear reactor more than 400 radioactive isotopes they were released into the biosphere, so about 40 of them are the potentially hazardous to the human.

Now, this fallout may be deposited into the clothing, skin, and then may enter into the body through the route which we have already discussed. There are certain gases materials or particulate matter that may be inhaled, subsequently absorbed through the deposition in the respiratory track. There may be certain radioactive material that falls on into the food and into the water supply or that is transferred from hand to mouth, may be ingested.

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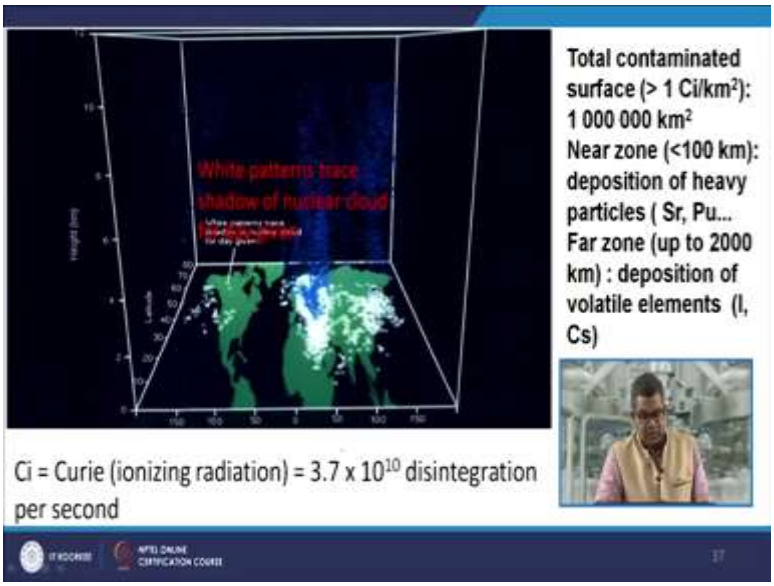


Now, this you can analyze that the you can see that the white pattern traces in that in this particular figure, shadow of the nuclear cloud for a day given, so you can see that how much gravity is there for the nuclear disasters. Now, we cannot overlook the importance of various half-life and activity of various new radioactive nuclei and the people must be aware about this one.

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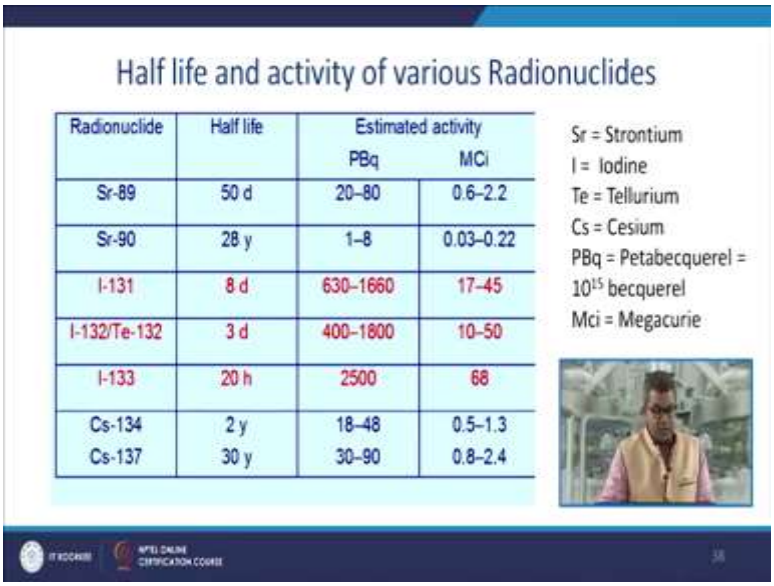


So in this particular table we have enlisted the various radio nuclei those who are involved in the nuclear power production and their respective half-life and their respective activity, so you can have a look and you can analyze that how gravities that for those radionuclide.

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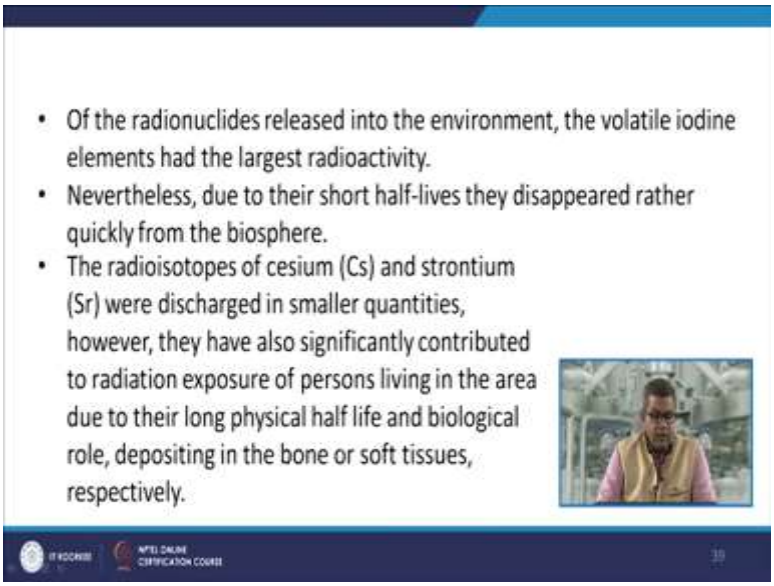


So, of the radionuclides released into the environment the volatile iodine is element had to be the (large) largest radioactive. So nevertheless due to their short half-life, they disappeared rather quickly from the biosphere. So the radio isotope or of cesium and strontium were discharged in a

smaller quantity. However, they have also significantly contributed to the radiation exposure of person living in the area due to their long physical half-life and the biological role depositing in bones or the soft tissues of the human body respectively.

So, there was about 10 times more radio cesium released then the radio strontium. So the more volatile cesium isotopes formed radioactive aerosols and contaminated a significant large area over thousand kilometers than the strontium isotope. So that was the one of the reason why this radioactive cloud traveled across to the other European country like Sweden etc.

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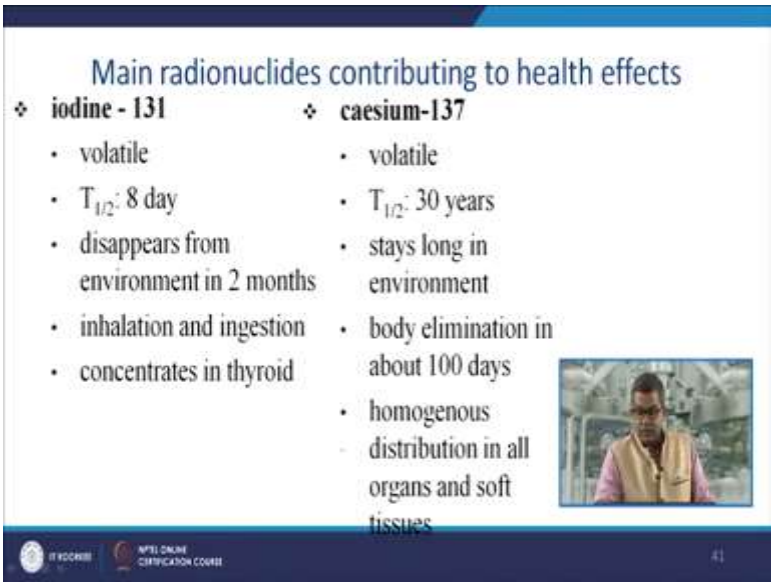


Now, there are (major) main radionuclides contributing to the health effect, like iodine-131 that these are volatile in nature, they are having the half-life of 8 days and they disappeared from the environment in just 2 months and inhalation and ingestion may caused various problems, they (concentrated) concentrates in thyroid, so may create the thyroid cancer etc. There is the caesium-137, this is volatile in nature, they having the half-life of 30 years compared to the iodine-131 (which is) which was having 8 days.

Now, they stay is a long in the environment and body eliminates this about caesium-137 in about 100 days. This is homogeneous in nature and distribution in all organs and all soft tissues, so this is the main problem with the cesium. Now other biological effect of exposure to this ionizing radiation that is the deterministic effect occurs when the dose is above given threshold that is the

characteristic of any kind of the given effect, the severity increases with the dose and many cells die or have a function altered like various example fibrosis, marrow depletion, cataract etc.

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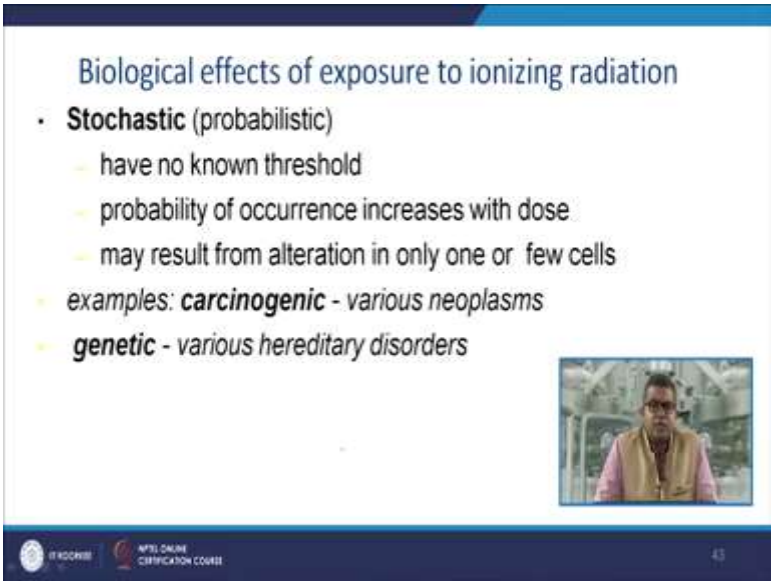


There are certain (stoch) stochastic or the probabilistic things they have no known threshold. The probability of the occurrence increases limit the dose and this may result for from alteration in only one or a few cells, like some sort of carcinogens, like the various neoplasms, genetic disorders, various hereditary problems may occur in due course of time. So with a disaster from a large radio logically contaminated explosion, most of the victims they suffered conventional trauma complicated by the radiation and internal radiological contamination. So, this would also be the case in the terrorists use is terrorists used of radiation dispersal explosive devices.

So most of the casualties would have conventional injuries resulting from the chemical explosion and fire, other would receive the injuries during the rescue attempts because the radioactive particles or radioactive materials clouds may get deposited to their cloths or skin etc. So very few casualties would have in a pure radiation injury so a nuclear detonation would yield a similar casualty distribution but on a very vastly larger scale. Usually cataracts it was developed in 13 patients by in 2001 among the confirmed by the ARS cases.

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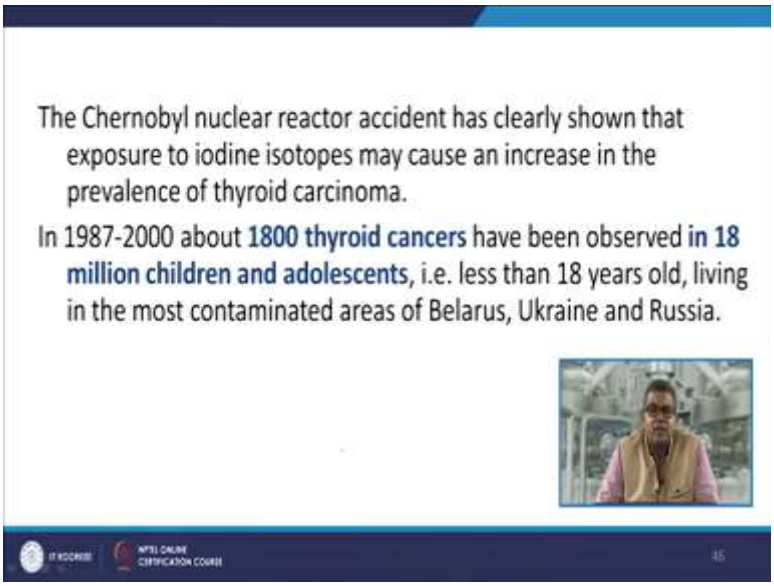


So the Chernobyl reactor accident has clearly shown that the exposure to iodine isotopes may cause an increase in the prevalence of thyroid carcinoma. So in between 1987 to 2000 about 1800 thyroid cancers have been observed in 18 million children that is less than 18 years old living in the most contaminated area of Belarus, Ukraine or Russia, those who are involved in that particular type of nuclear radiation.

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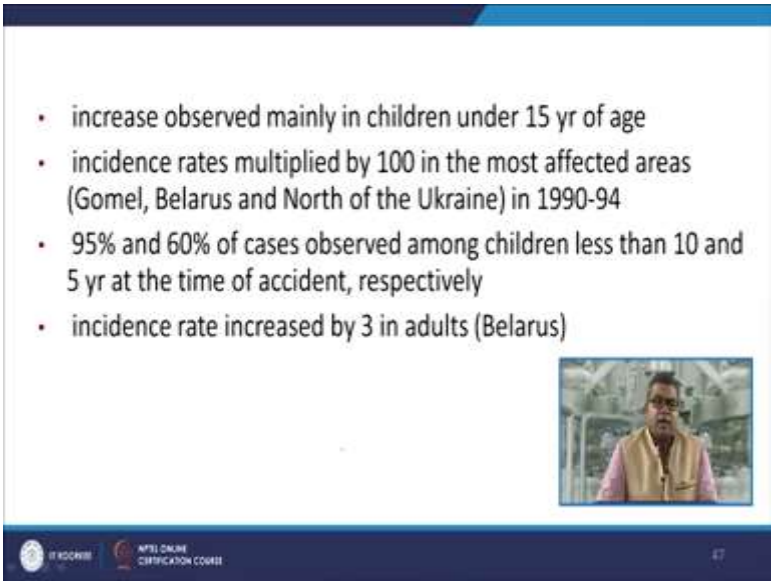

Now (increased) increase observed mainly in the children under 15 years of age and incidence rate multiplied by 100 in the most affected areas of Belarus and northern part of Ukraine in 1992 to 1994. 95 percent and a 60 percent of cases observed among the children less than 10 and 5 years at the time of accident respectively. So the incident rate increased by 3 in adults in especially in Belarus.

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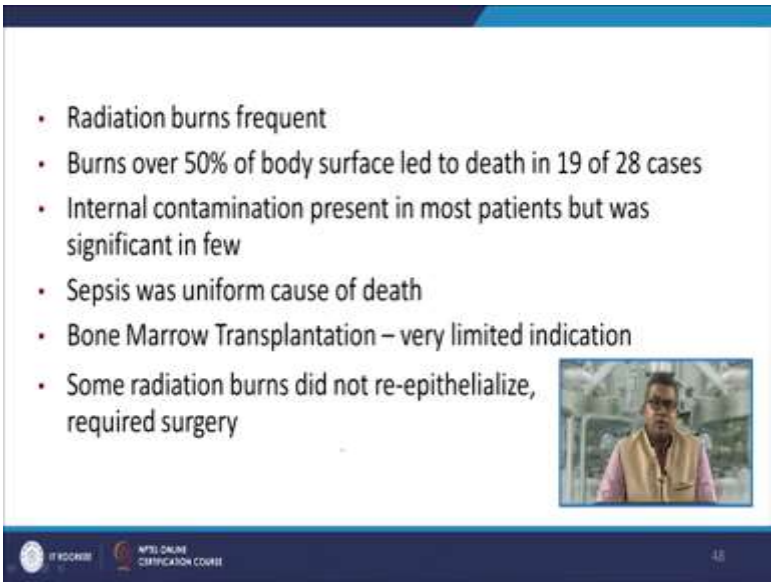


Now let us have a some other (feature) facts about the radiation, radiation burns frequent, the burns over 50 percent of the body surface led to death in 19 of 28 cases. The internal contamination this present in most patient, but was significant in very few. The sepsis was uniform cause of death. Bone marrow transplantation very limited indication of remedy. Some radiation burns did not re-epithelialize require surgery.

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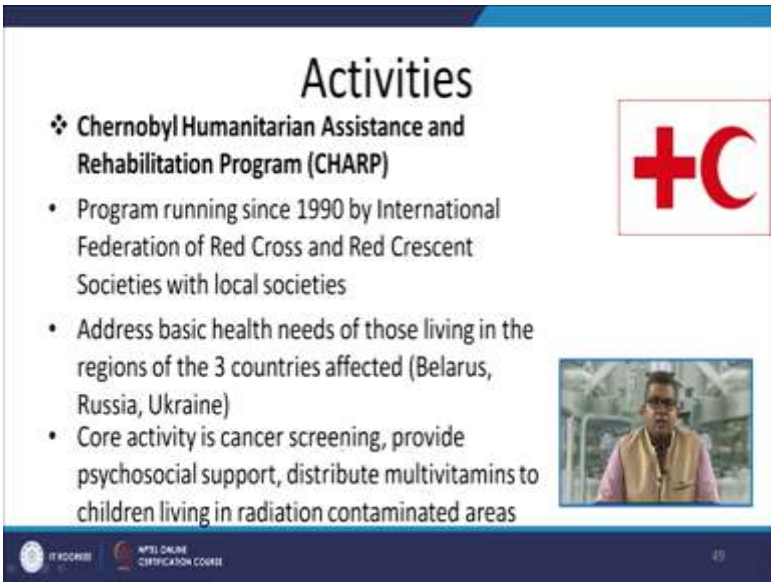


Now, there are certain activities involved in the Chernobyl humanitarian assistance and rehabilitation program that is called CHARP. Now, the program runs since 1990 by the International Federation of Red Cross and Red Crescent Society with the local societies. Now, this address basic health needs of those living in the regions for three countries, those who are affected may live like Belarus, Ukraine and Russia. The core activity is a cancer screening provide the psychological support distribute the multivitamin to the children live in the radiation contaminated area.

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Now another recovery program was developed by United Nation Development Program, UNDP in 2001 that is called the Chernobyl Recovery and Development Program, CRDP. Now, the aim of that particular program was to return the normal life by providing support to the government of Ukraine for elaboration and implementation of development oriented situation for the region. Another, aim was to mitigate the long-term social, economic and environmental consequences and to create the more favorable living condition to promote the sustainable human development in the affected region. So that was the main aim of the CRDP program.

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Apart from this, International Atomic Energy Agency IAEA, they have created and they have employed safeguard system which is among the most advanced for any safeguarded nuclear facility and that is implemented to all the countries those who are having the nuclear power facilities. They have remotely monitored on-site inspection and seals to ensure that non-diversion of any kind of nuclear material.

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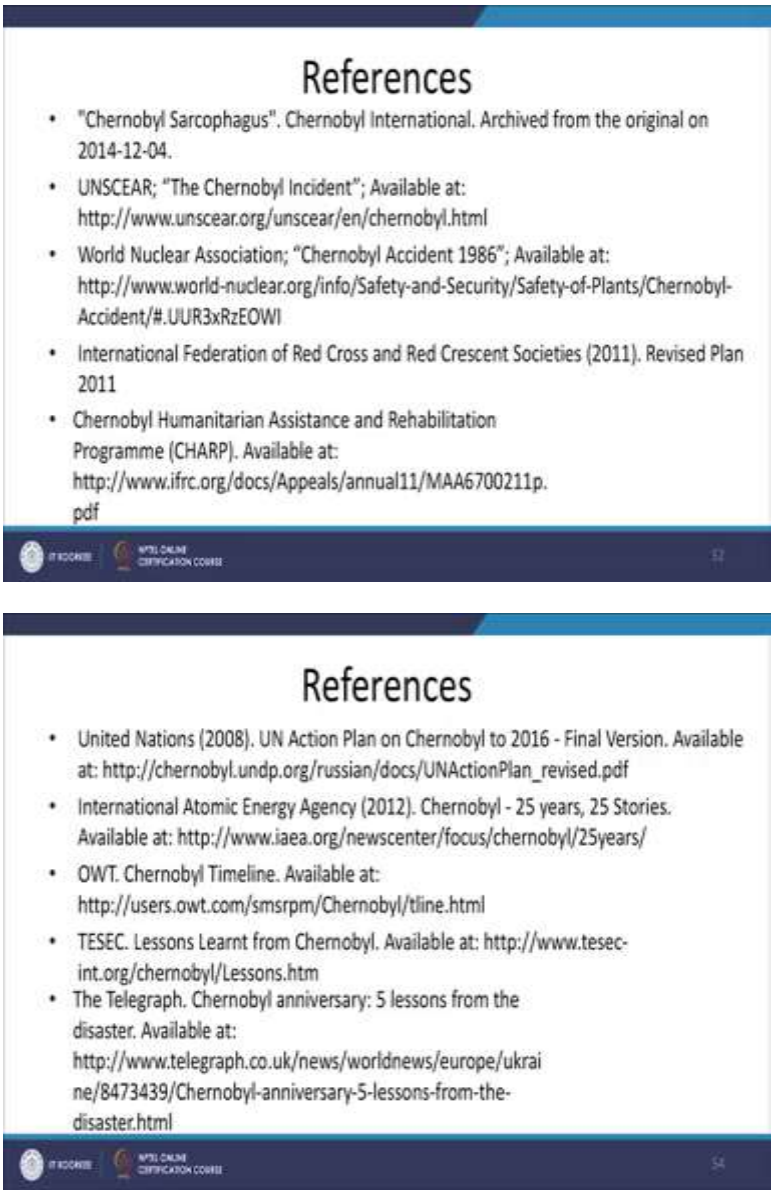


So, in this particular module we have discussed about the nuclear disaster with a case study of Chernobyl, and if you wish to have a further reading then we have enlisted different references for your convenience. Thank you very much!