Indian Institute of Technology Madras

Present

NPTEL

NATIONAL PROGRAMME ON TECHNOLOGY ENHANCED LEARNING

NUCLEAR REACTOR AND SAFETY

AN INTRODUCTORY COURSE

Module 05 Lecture 01

Safety Principles

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Good morning. In the last lecture we had a look at the different effects of radiation on human beings. We also saw that the natural background radiation itself was quite a reasonable amount, and we also saw how the doses of radiation are measured and how the limits are set. Finally, we also saw how to protect ourselves against the radiation by use of radiation shields.

Now having gone through some basics about radiation and nuclear reactor, let me just come to the safety principles that are followed in any nuclear establishment. As we saw in the first lecture that there are issues with every type of energy source.

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Introduction

- Any industrial activity has its positive and negative aspects. It yields some beneficial output but has some risk or harmful effects associated with it. Risk is the probability that a specified harmful effect will occur within a specified period. Operation of nuclear installations, usually have associated risks of various types. The environment may also suffer harm if radioactive materials are released, particularly under accident conditions. Consequently, it is necessary to limit the risks to site personnel, the public and the environment from the effects of ionizing radiation. These risks must be strictly controlled. This lecture dwells into the basic principles of safety followed for nuclear installations.

Similarly every industrial activity has its own positive and negative aspects. That is yields surely some beneficial output for example the energy sources give energy but they do have some harmful effect or some risk associated with that. For example if you take the nuclear establishments there the main issue is should there be an accident radioactive materials will be released. Hence, it becomes very necessary to limit the spread of radiation not only to the people working in the plant or the establishment whom we refer as occupational workers and the public and it should not get, you know, taken through the environment. So these essentially the risks must be controlled, kept in very low levels and in this lecture we will touch upon the safety principles that are followed in the design of the nuclear installations.

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Safety Objectives

- The safety principles are derived from the following Safety Objectives, as enunciated by the International Atomic Energy Agency (IAEA):
- **General Nuclear Safety Objective:** To protect individuals, society and the environment from harm by establishing and maintaining in nuclear installations effective defenses against radiological hazards. This General Nuclear Safety Objective is supported by two complementary Safety Objectives, one dealing with radiation protection and the other with technical aspects. They are interdependent: the technical aspects in conjunction with administrative and procedural measures provide protection from hazards due to ionizing radiation.

As I mentioned to you the Hiroshima, Nagasaki bombings were there in the very beginning. The growth of nuclear civilian nuclear program started later and the IAEA was itself established in the 1950s. It's called the International Atomic Energy Agency. So what are the objectives, safety objectives of any nuclear establishment? So the safety principles are the one which are derived from the following safety objectives as brought out by the International Atomic Energy Agency, and this followed threadbare by all the nuclear establishments. The first one is the nuclear safety objective. General nuclear safety objective. What does it mean? The objective is to protect the individuals, the society, and the environment from the harmful effects of the radiation by maintaining the nuclear installations in good condition and have enough barriers so that the radiation hazard doesn't reach the public. Along with the general nuclear safety objective, we have one deals with the radiation protection, and the other one deals with that technical safety. The radiation safety and the technical safety. Surely both are interdependent. The technical safety if it is assured maybe there may be no radiation release. Nevertheless, even under normal circumstances if at all there is any spillover of the radioactivity one has to take care. So that is where the radiation protection objective comes. These two along with some procedural or what we call as administrative measures are meant to provide protection from the hazards of the ionizing radiation.

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- **Radiation Protection Objective:** To ensure that in all operational states radiation exposure within the installation or due to any planned release of radioactive material from the installation is kept below prescribed limits and as low as reasonably achievable, and to ensure mitigation of the radiological consequences of any accidents.
- **Technical Safety Objective:** To take all reasonably practicable measures to prevent accidents in nuclear installations and to mitigate the consequences of any accidents that do occur; to ensure with a high level of confidence that, for all possible accidents taken into account in the design of the installation, including those of very low probability, any radiological consequences would be minor and below prescribed limits; and to ensure that the likelihood of accidents with serious radiological consequences is extremely low.

What is the radiation protection objective? It is very clear that in all the operation states of the reactor or establish of the -- or the installation exposure must be such that it is below the prescribed limits as so you saw the prescribed limits which are prescribed by the ICRP, International Commission on Radiation Protection. Not only that it could be a limit but still we would like to keep it as low as a reasonably achievable, and ensure that in case there is an accident, the radiological consequences can be mitigated. So that is the radiation protection objective. Then what are the technical safety objective?

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Again here this means measures or design measures which you take to see that any consequences of accidents are mitigated. Now that means what you need to do you have to foresee events which can occur in the plant in a very simple way. Now let me say that a primary coolant pump of a reactor fails, that means the reactor core will be not getting the coolant. It is not a good condition. So what I do as a technical person I provide one more pump as a standby pump so that even if this pump fails the other pump can take. Then there may be events which are a very low probability or there may be events of higher probability but in all situations the objective would be such that the accidents or the likelihood of accidents is kept extremely low so that people don't get the effect of the radiation.

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- Safety Objectives require that nuclear installations are designed and operated so as to keep all sources of radiation exposure under strict technical and administrative control. However, the Radiation Protection Objective does not preclude limited exposure of people or the release of legally authorized quantities of radioactive materials to the environment in operational states. Such exposures and releases, however, must be strictly controlled and must be in compliance with operational limits and radiation protection standards. To achieve the Safety Objectives, measures need to be taken to control radiation exposure in all operational states to levels as low as reasonably achievable and to minimize the likelihood of an accident that might lead to the loss of normal control of the source of radiation.

So the safety objective needs that you must keep all sources of radiation exposure under control but it doesn't mean that there will be no radiation at all that should be clear our idea because when you work in a plant you do get some radiation effect but that radiation must be limited. So that's what the says the radiation protection objective does not preclude limited exposure of the people. Some authorized quantities need to be accepted. Again they must be controlled strictly. Here the control strictly comes so for example let us say a person is working in an area, radiation area and he has crossed the dosage limits. What we do? We take him out of the place where he is working and put another person so that this person is monitored outside. So this way either you can call it as an administrative control we do in the case of radiation workers. So normally the objective would be to see that the radiation which is received under all conditions; normal plant or any even conditions are within the limits prescribed by the ICRP.

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- Nevertheless, accidents can happen. Measures are therefore required to ensure that any **radiological consequence is mitigated**. Such measures include **on-site** accident management procedures and **off-site intervention measures** in order to mitigate radiation exposure after an accident has occurred. The greater the potential hazard from an uncontrolled release of radioactive material, the lower the likelihood needs to be of its occurrence.

However, nobody is infallible and accidents do happen. Okay so you did the enough care in the design to provide provisions such that accidents don't happen, but still accidents can happen. Accidents have happened. The Three Mile Island in USA. Chernobyl in Russia and the next was Fukushima recently. They have happened. So always we need to have a contingency plan to ensure that any radiological consequences in case of such accidents are mitigated. Now what are these measures. One is on-site accident management means on the site where the accident has happened. How do you manage? The people how do they – how do you limit the radiation and if radiation is more what you do? Do you transport them under the emergency condition if they are contaminated? We just cannot transport them anywhere. This is one situation, on the site. Other, for example, in the Fukushima case or the Chernobyl we had spread of activity to the environment. So the question arises off the site should I do anything? Is there need to evacuate the people so that they will get less of radioactivity? And here I would just like to add one point not the accident has happened and immediately the activity will spread like anything. It is not. It's a slow development. The spread of activity it is a function of so many weather parameters also. So in all directions it may not affect in some directions it may affect. So what we do we assess the weather conditions and accordingly area which area it is more likely and you have to do have some two to three hours time in which you can plan this and do the equation. Of course every equation needs the support of the infrastructure, the transport infrastructure around the place, everything. So these things are covered by the on-site emergency and off-site emergency planning which we will talk about later.

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Technical aspects of safety- Siting

- Potential sites need to be evaluated for manmade and natural factors that could adversely affect the safety of the installation. The effects the installation may have on the surrounding population and on the environment, such as the utilization of **land and water**, are evaluated. Relevant site related factors are into account in the design of the installation. An evaluation of all site related factors is made by the operating organization as part of the licensing application, and reviewed by the regulatory body. **Population density** and distribution over the lifetime of the installation are of particular importance and need to be evaluated periodically to ensure the continued feasibility of emergency plans. All aspects are evaluated for the **projected lifetime of the installation** and reevaluated as necessary to ensure the continued acceptability for safety of site related factors.

Now let us see what are the technical aspects of safety. What technical aspects you can look up. First and foremost thing even you cite a nuclear installation you see that whether that installation will be affected by the natural factors around that site. For example what affects the site conditions will may have on the plant. For example you let us take seismic place or seismic condition is there should I locate my plant there? Essentially the site has to be suitable. Then I may require water for using in the plant. Whether I have a source of water and whether the – any work on installation should not affect the water quality that is radiation should not get into the water. So this is again another factor to be considered. Then what else? The population density the population, how much of people are living there. The idea of the population density is very simple. As I said just before that we need to plan for evacuation in case of a large release of radioactivity into the environment. If the population density were high then I cannot evacuate all the people. It will take large amount of time. With that in mind the population density and distribution around the place are seen and these are planned in such a way that the population density must be reasonably low. Then one more thing whatever the site conditions are there today we must also look at whether any new industry or new, what you call let us say flats coming up are all going to come. So we have to look at the town plan whatever is being made long term plans around the site and then only decide on the site. For example, you take the place **Kalpakkam** we have a plant within a distance of about 16 kilometers you can't build any new flats after the plant had started. So any new thing gets – has to get clearance from the atomic energy establishment. So you just cannot grow.

So the site of the nuclear power plant or the nuclear installation is chosen with very very great care. Today in India where are the nuclear power plant sites practically they're spread out all over India but you might notice we have in the Tamil Nadu at Kalpakkam and Kudankulam. In

Karnataka we have at Kaiga. In Gujarat we have at Kakrapar. In Rajasthan we have in Kota then we have the Tarapur we have the atomic power plant. In all these cases basically the site conditions and water requirements which are huge these two are considered. Of course the water requirement even if it is a coal-fired plant remains similar because the condenser has got to be cooled in both cases.

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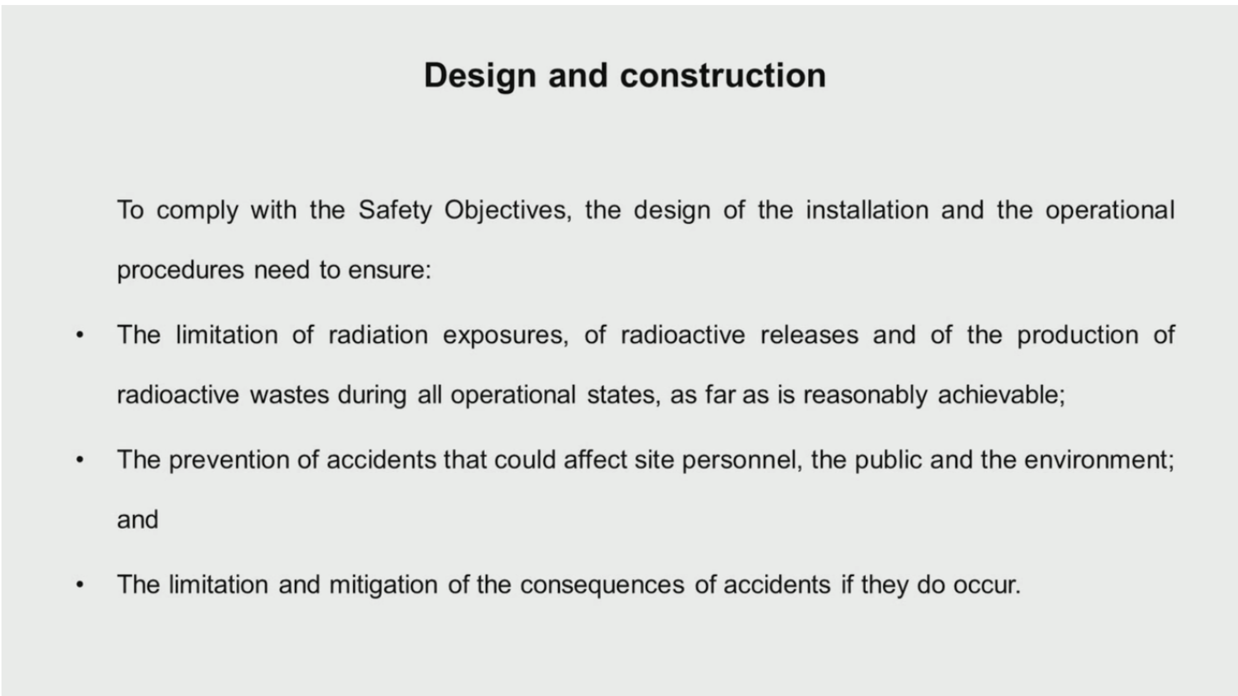

So the water requirement is a must. In the case of Kalpakkam we have used seawater for cooling the condensers of the Madras atomic power station. In the case of some of the plants where the river, where it's only a river water also we have taken the river water but in some cases in case you don't get the very close to the river or sea, we can employ cooling towers. In fact most of the nuclear plant photographs if you see in the net will have a cooling tower. One more thing you can notice all these nuclear power plants are situated away from the coal belt. That is Bihar because there is no point in building nuclear power plants very close to the coal belts because farthest you are from the coal belt your coal transportation cost becomes very high. So it would not be nice to build a coal-fired power plant which is very away from the coal mining area. So that's why we put up the thermal power stations close up to that and away from the distance long distances we have put the nuclear power plants.

Now we looked at the siting. Then the design. So the design of the installation we have to be very careful. We have to see what are all the conditions the plant will see under normal conditions or in the case of any failure. Let us say your motor trips, your motor fails, power fails what will happen? So I need to take care in the design that under these conditions what are all the loads, mechanical, or thermal etc. under no condition there should be a failure of the boundary and release of radioactivity.

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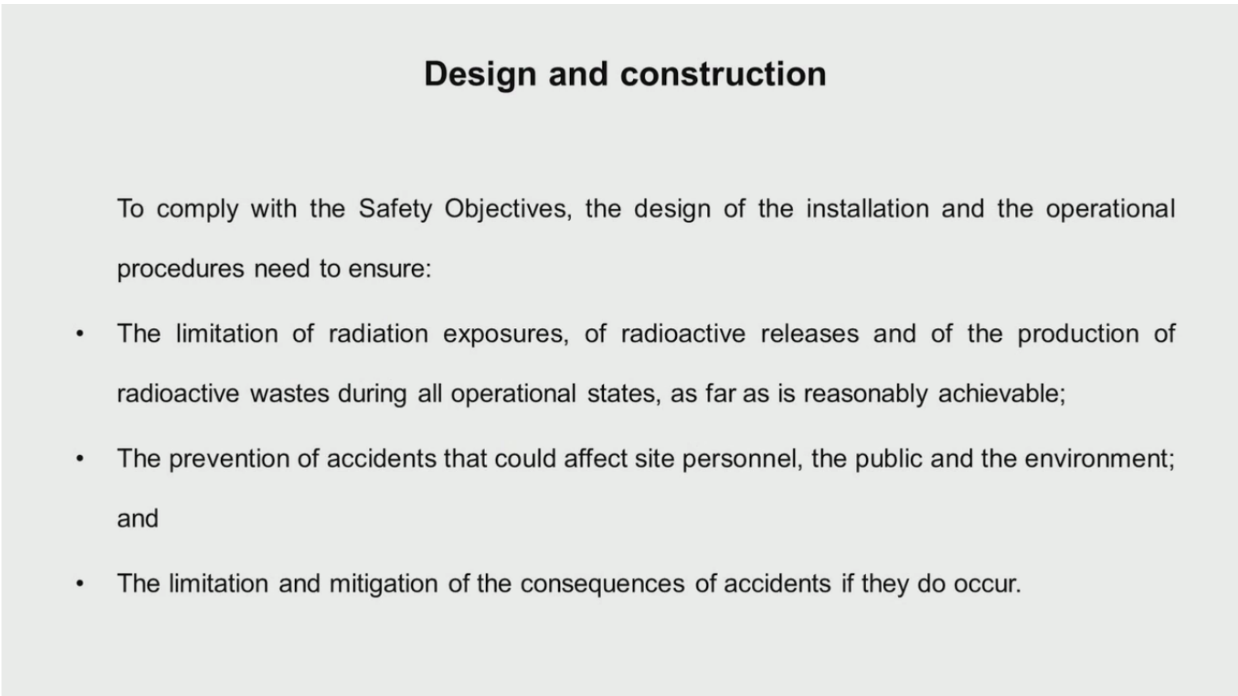

Then the next step in the design we must consider okay should it fail how do I limit the consequences and how I mitigate the consequences. So one thing you see while being trying to be very safe in all nuclear establishments we always consider if that safety barrier fails. That is very very important. So because unless we – in spite of many postulates still some accidents have happened.

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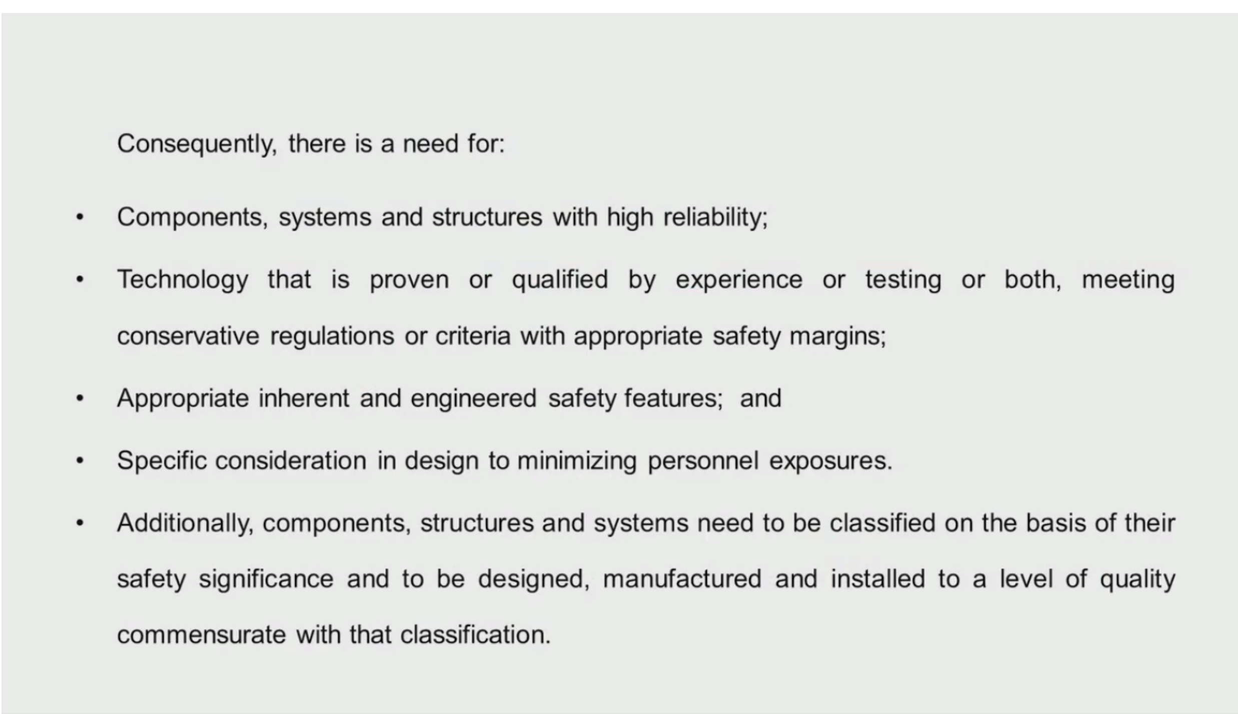

So what we need? Components of very high reliability. So the components must fail very rarely. So surely the quality of the design and the fabrication all had to be of the highest standard. So this also to some extent increases the cost of a nuclear power plant relative to the normal power plants, and the material which you use needs to be highly standardized and the quality assurance procedures need to be done at every stage. Then when I build up to a new power plant first is I must see whether it's a proven technology or at least it has been tested at some level and meets the criteria. However, in all cases technology, proven technology may not be available but based on the experience which we have had we can always integrate technologies which have been tested in parts into a power plant and then go ahead, of course, with caution at every step.

Here I would give you an example. This was regarding the fuel for the fast breeder test reactor at Kalpakkam. We were originally planning to have fuel, it is the fast reactor so it requires enriched fuel. So we were planning to have 70 percent of industry Uranium-235 and rest of that 30% was supposed to be plutonium-oxide. Now what happened? The enriched uranium was not available to us from abroad. So it put us on the defensive to look for what else. In some enriched uranium we went for plutonium which is available within the country. From our other like light water reactors. Then the question was with higher plutonium is there any difference in the behavior of the fuel. There were apprehensions that if you go for an oxide fuel with high content of plutonium, the properties which you expect may not exist because it was very highly sensitive to the oxygen by metal ratio. So whether one could really make it with very very perfect. So there are some doubts. We had some irradiation data but then there was a feeling that we could go with the carbide fuel. We might be able to get rid of this phenomenon, but we were not totally – carbide fuel has been irradiated in different reactors, in test reactors.

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Consequently, there is a need for:

- Components, systems and structures with high reliability;
- Technology that is proven or qualified by experience or testing or both, meeting conservative regulations or criteria with appropriate safety margins;
- Appropriate inherent and engineered safety features; and
- Specific consideration in design to minimizing personnel exposures.
- Additionally, components, structures and systems need to be classified on the basis of their safety significance and to be designed, manufactured and installed to a level of quality commensurate with that classification.

So after some study and good amount of technical judgment, we went in for a 70% plutonium carbide, uranium carbide fuel and we went in steps. Every step of irradiation. We took out some of the pins tested them whether the property has changed or not. So that way we developed the technology itself in this process. So technology may be proven or qualified by experience. Then also we have to put in the design. Inherent features in the design. For example one inherent feature of a nuclear reactor if the temperature goes up, the reactivity should come down. That means the neutron population should come down. This sort of things can be done in the design, have to have some inherent. It is – I should say more intrinsic safety feature. Then we provide engineered safety feature. Engineered safety feature is what I explained to you some time back. Instead of one pump I have two pumps in the primary coolant circuit. I may have 200% pumps one in operation, one standby, or in the case of the steam power plant I can have 3X50% pumps with two operating on steam driven turbines and one operating on electricity. So all sorts of engineered safety features could be built in into the design. Then surely the consideration to minimize the personal exposures is a must. Now when you any reactor you have the main reactor core, then we move on to the heat exchangers, and then to the steam water system the main thing from safety point of view is our reactor core and we have to put the maximum quality assurance in that area. Now it just cannot be subjective so there needs to be a clear classification on the basis of the safety significance of every equipment, design, manufacturing as you say class one design, class two design, class one manufacturer, class two manufacture. Here when you move away let us say come to the stream water system any failure is not going to release in radioactivity. So you can accept certain failures but not on the reactor. So all these things of classification and corresponding qualifying or testing gives you a high level of reliability to the nuclear components.

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Since engineered systems may fail despite all careful precautions, it is a basic design concept to provide backup features so that either a function is performed by another system or another design feature mitigates the consequences associated with the failure of the system. Consequently, following design principles have been formulated:

- No single equipment failure or single maintenance action or any other single human action should disable a safety function;
- The possibility of failures due to a common cause should be minimized by diversity of equipment;
- Redundant systems should function independently of each other to achieve reliability; and
- Where practicable, design concepts should be used which place the installation in a safe state on failure of components or systems.

Again, I tell yes some engineered systems may fail. So always provide backup features. So what sort of design principles we consider in the design of nuclear establishments? No single equipment or single maintenance action or single human action should disable a safety function. So I repeat equipment failure we talked about a pump. It could be an instrumentation failure. Your thermocouple is reading your temperature. If it fails we can't take chances. So we provide some more thermocouples so that even if one of them fails I still get the temperature. So that the safety is not jeopardized. Then the other aspect so if a single equipment should not affect we always provide multiple equipments that is what is called as the redundancy, but that could be a common cause failure let us say like fire or there could be a common mode failure because of something wrong in the basic design. So we need to consider that probability also.

Then the third aspect is independence, that is there should be independence between the different redundant systems so that even if a common cause like fire is there all the redundant systems will not get affected. So these are the principles which we generally follow and in brief they are called as redundancy, diversity, and independence.

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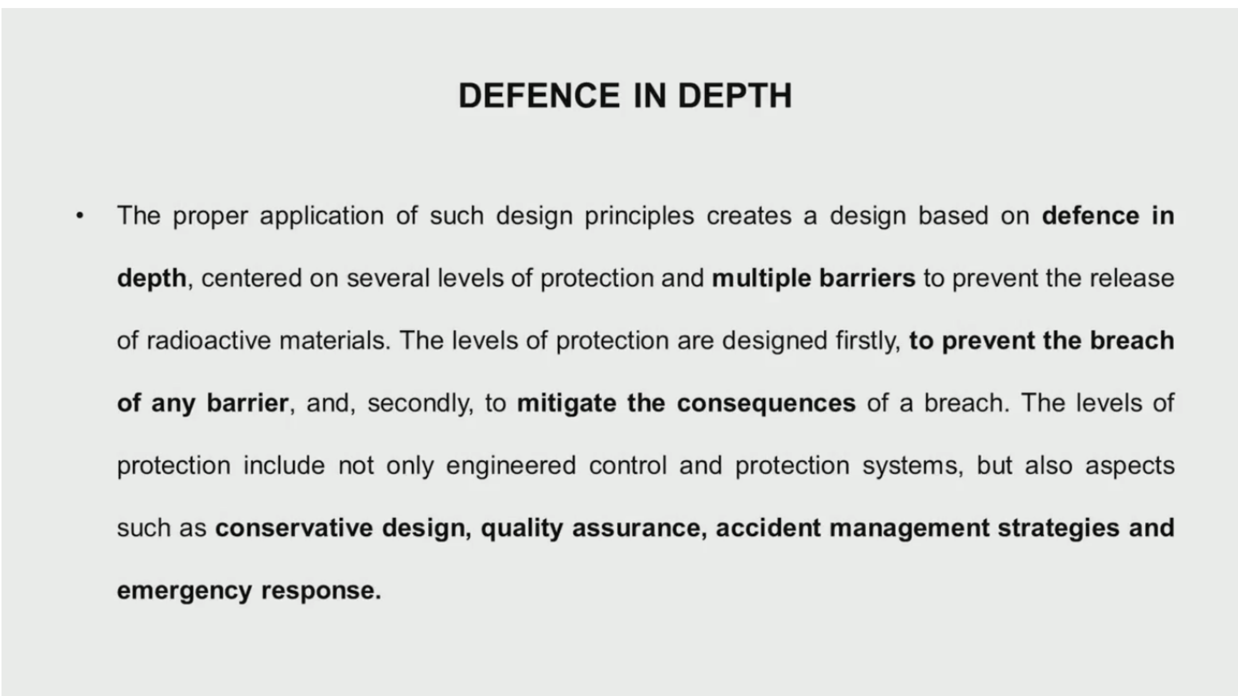

Now the application of such principles, design principles takes you into depth of the design. So why we do this application of such sort of principles we are looking at providing defense as much as possible. Now what are the defense mechanisms? Let us take from the radioactive release point of view. As I said we must mitigate the consequences in case of a release. You must have multiple barriers. So first effort would be surely to prevent the breach or failure of any barrier, but in case it fails mitigate the consequences and you provide this how, conservative design, quality assurance, accident management, and emergency response; all aspects. So this in brief is called as the defense in depth approach.

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The design also needs to take account of the performance capabilities of the operating and maintenance personnel. Attention to human factors ensures that the installation is tolerant of human error. Among the appropriate elements in minimizing human error is the systematic application of ergonomic principles to:

- Engineered systems;
- The provision of automatic control, protection and alarm systems;
- The elimination of human actions that jeopardize safety;
- The clear presentation of data; and
- Reliable communication within the installation.

Now one of the factors which comes in any operation is the performance of the human beings or the operators and the maintenance people shortly [Indiscernible] [00:32:53]. So human factors are very important. Human error can lead to problems. So as much as possible we have to engineer the system design in such a way that there is provision for automatic control. There is automatic control and protection and also provide alarms so that it can give support to the operator to tell okay the event is becoming it can even be a great event. Alarm so take care. And this also requires that the available data to the operator is clear so you must have visualization must be clear it could be in the form of graphs or it could be in the form of what you call other things which indicate to him that okay so and so conditions are there this has happened plus all these things together with communication measures within the installation. In fact in one of the later chapters when I explained an accident how it happened because of a lack of communication, lack of reliable communication it happened. So this is also very important that throughout the plant the communication system must be working and in good condition.

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- A **comprehensive safety analysis** of the behaviour of the installation must include an assessment of a wide spectrum of events to ensure that accidents, including those of low probability, can be effectively dealt with and their consequences mitigated by means of installed safety systems, sound procedures and accident management. The responsibility for ensuring that the safety of the design is acceptable lies with the **operating organization**. The task of producing a safe design lies with the **design organization**. However, a group responsible for safety assessment, and separate from those carrying out the design, needs to provide **an independent verification** that all safety requirements and objectives have been met. Moreover, the operating organization must ensure that there is appropriate liaison with the design group in order to ensure that the design meets the operating staff's requirements and is consistent with anticipated operating procedures.

Then having done all this in the plant design and let us say train the operators and maintenance people also with all the things you do your comprehensive safety analysis and it includes the operation under different conditions including instance of low probability or high probability, and how in case whether if there is a failure does it need a mitigating feature or not. So this responsibility is with the operating organization. Then the safety analysis which is done has to be assessed by experts. So normally what we do the Atomic Energy Regulatory Board sets up a project design safety committee for each reactor and they have do an independent verification whether all the safety requirements and objectives have been met. Then the operating group and the design group must be in close liaison with each other so that the designer must be able to meet the operating staffs requirement under any operating conditions. For example what he calls the ergonomics. The placing of the switches and safety you know, switches basically it should be such that it should not lead to your spurious action by the operator at the same time in case of an emergency he should be able to approach it without any difficulty.

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- Construction of an installation can start only after the operating organization has satisfied itself that the main safety issues have been resolved and the regulatory body has satisfied itself of the adequacy of the safety analysis submitted and the adequacy of the proposed arrangements, procedures and quality assurance programmes to implement the design throughout construction. In this regard, the responsibility for ensuring that the construction is acceptable lies with the operating organization.

Now construction. Design is we have chosen the site. Then the design is over. The safety analysis has been done. Then comes the construction and construction can be done only after the regulatory authority or in our country it is the Atomic Energy Regulatory Board satisfies itself that the adequacy of the safety analysis is there for that particular site and when all the quality assurance measures have been taken care, then only the license is given for start-up construction.

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Commissioning

- The purpose of commissioning is to demonstrate that the design specifications of the installation have been met and that the completed installation is satisfactory for service. The operating organization is responsible for the preparation and **documentation of the commissioning programme** with the full participation of the design organization. The programme needs to provide for the **sequential testing** of elements of systems and completed systems and of the correct functioning of **interrelated systems** in a progressive manner. The installation needs to be proven for **all foreseeable operational states**. The commissioning programme, including relevant limits and conditions, must be approved in advance by the regulatory body. The regulatory body must satisfy itself that the safety analysis is valid for the commissioning programme and for continued operations.

Next step is the commissioning. Commissioning means each and every system or subsystem you first commission them in independently and then after all the systems have been commissioned, you put them together and see. So the responsibility of this is with the operating organization. So in the commissioning program you have to provide for sequential testing, maybe the fluid is not flowing but still you could do a dry test. You could repeat the testing of the equipment under when the flow is there and when the temperatures are going up you do the testing at each and every condition which is different and you also see the behavior of the one system on the other interrelated systems, how it is effecting, is it as you have foreseen in the safety analysis or the design and most important in commissioning is the documentation. Right from the procedure for commissioning to the commissioning results and whether the commissioning test results are in consonance with the predictions if it is not so one has to be clear and its regulatory authority has to be satisfied if it is not so why it is not so and it is acceptable both these things need. So this is what is that because now till now it was in a theoretical stage, analysis stage, now when you are going to the practical we have to see that there is a good you know agreement between the actual condition at site. So the safety analysis also must ensure that what are all the commissioning tests which we are going to do must be known so if they are different from the operating condition they also need to have been looked into by the designer when he does the safety analysis. For example there could be some events which could happen during commissioning when all the systems are not there so such sort of events have to be thought of by the designer.

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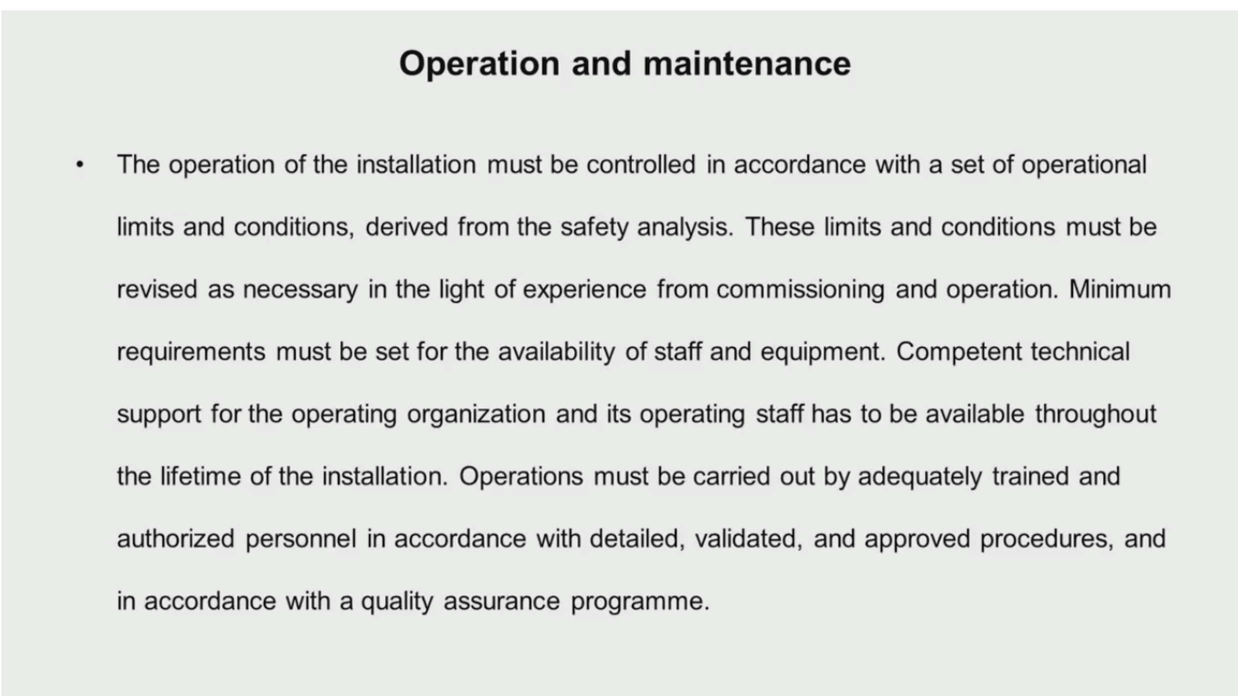

Then operation and maintenance. Of course, here you have a rule book called as the technical specifications of operation which tells you what are all the limits within which it should be operated. Of course, automatic control is there but still it tells you what are all the limits so that the operator knows okay at this level alarm will come but at certain level he needs to act. All those things are clearly given as an input and these limits and conditions may be revised depending on your experience of the commissioning. Initially you may put something but you may find that the margins are so low and still safety is not jeopardized you may increase the margins and put higher limits but of course one more thing of this competent technical the minimum staff requirements is specified. If the minimum staff requirement is not there you should not operate. So then the technical support to the [Indiscernible] [00:41:18] staff has to be available throughout the plant operation from the design side and the people in the operation and maintenance need to be trained adequately so that they are well aware of the procedures which are given and follow the quality assurance objectives of the program.

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- The installation must be regularly inspected, tested, and maintained in accordance with approved procedures to ensure that components, structures, and systems continue to be available and to operate as intended, and meet the design objectives and requirements of the safety analysis. Modifications to the installation must be controlled in accordance with approved procedures. Where modifications alter the operational limits and conditions, there needs to be a safety analysis to justify the new limits and conditions. Operating procedures must provide staff with instructions for responding to anticipated operational occurrences. Procedures are also needed to manage, accidents that could lead to severe consequences. The principal objectives of such procedures are to restore prime safety functions, to facilitate long term recovery from an accident, and to mitigate its radiological consequences.

So what it says the installation must be also regularly inspected even though the operation has started and maintained and we must see that all the components are available at all the time but based on the experience you may need a modification to the design. This modification needs to be studied in very well detail. It should not result in some earlier objective which has been met in not being met. So any modification has to be thoroughly studied. The safety analysis to be repeated and then only the clearance for the modification has to be given. In fact, modifications are quite difficult in an operating power plant. And once safety analysis is completed then you have to give the new limits of operation and conditions for the modified circuit. Then the operating procedures one is under normal operating conditions; how to start the reactor, how to shut down the reactor, how to commit or put on one system, how to bring in another system. All those things are there. It also should give how the operator needs to respond for in case of any operational occurrences and how he should manage. So something like special procedures in case of events needs to be given to the operator specifically during power failure where a large number of components can fail and more so sometimes station blackout where on-site power and off-site power also is lost we need to give the operator what he should do.

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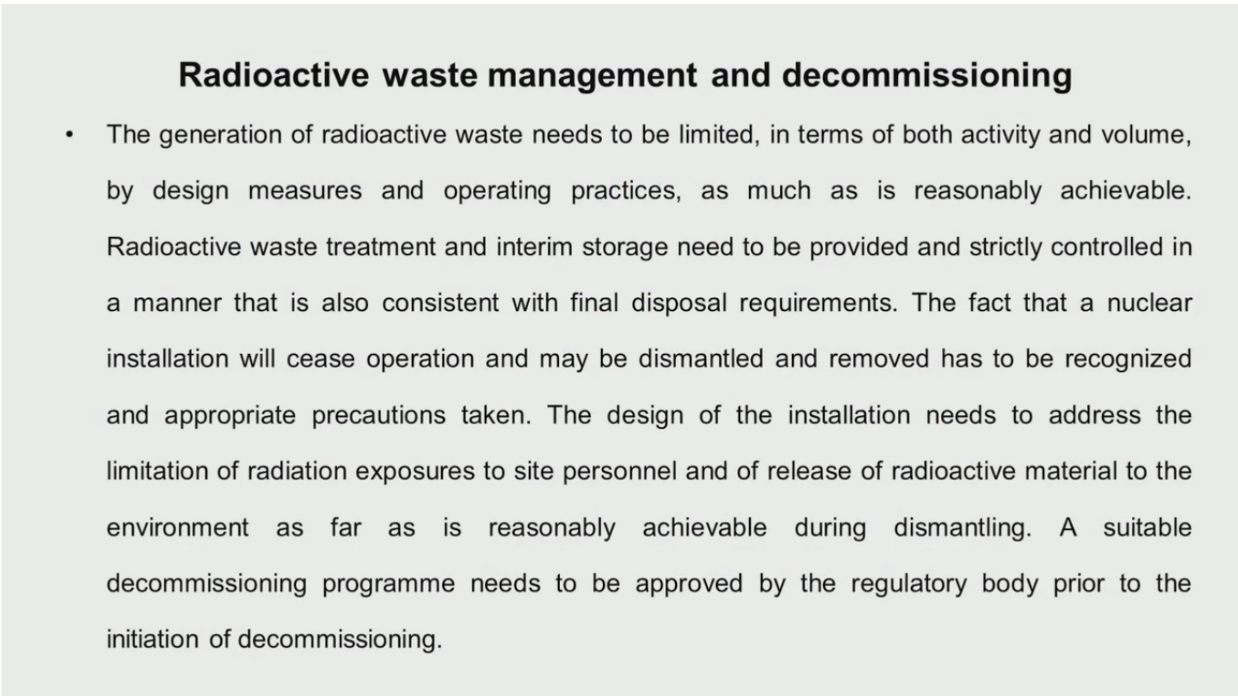

Then having said all this let us say the plant has operated, the plant during its operation if it is a reprocessing facility there would be a regeneration of radioactive wastes and we have to have the operating practices to see that this radioactive waste is treated and stored before finally disposing it off because the radioactive initially is hot because having lot of activity and temperature is also high. It needs to be kept cooled for a certain time in interim storage before being disposed. Then let us say a nuclear installation has operated and after some years you feel that it does lose its life little. There's no – it's not economical to or safe to operate this installation, then you have to decommission it. So the decommissioning approach how you are going to dismantle the equipment, how you are going to because some of – many of them are active. These things also needs to be recognized even at the design stage so that you are able to dismantle. As I said at the design stage you must consider how the maintenance will be done. That is the layout of the components will be such maintenance should be possible. Then also at a later stage when you want to decommission how to approach. So the procedure steps at least in a very very framework must be clear how we are going to do. So that needs to be looked at in the design stage itself. Then of course like a commissioning program, decommissioning program has to be put up. Of course, after clearance be the regulatory body we need to go for.

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Defence in Depth

Nuclear reactors have two specific characteristics that differentiate them from other energy production plants:

- These reactors accumulate a large quantity of radioactive products from which staff must be protected and the large scale dispersal of which to the environment would constitute a major accident.
- Significant energy release (Decay Heat) continues for a very long time, even after reactor shutdown,
- Correct cooling of the fuel and fuel cladding is therefore essential to avoid fuel clad failure.

Now what are the most important characteristics? Two important specific characteristics of nuclear reactors relative to the coal-fired plants. what are they? Now first is they produce large quantity of radioactive products. So that need then to be such that the staff and the environment are protected. Then the other aspect is that decay heat even though your fission reactions have stopped, the fission products still are decaying and continue to generate heat which is called as a residual heat or they also called as a decay heat, and this heat needs to be removed. In fact, the spent fuel, the fuel which has been in the reactor for and got that enough warm up when you take it out it is still has heat. It is kept in spent fuel bay with cooling. So the correct cooling or cooling of the reactor core or cooling of the spent fuel ponds is essential so that the clad should not fail because if we don't remove the heat the clad temperature will go up, the clad will fail and the fission products will come out, activity will come out into the environment.

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DECAY HEAT QUANTITIES

- Energy continues to be generated in the fuel even after a reactor shutdown. The radioactive products deriving from fission release a certain amount of energy in order to reach a stable state.

Time After Shutdown	% of Initial Power
1 second	17
1 minute	5
1 hour	1.5
1 day	0.5
1 week	0.3
1 month	0.15

Just to give you an idea of the...

[Audio Ends Abruptly at 00:47:36]

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