Islamic University Of technology (IUT)

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Nuclear Energy: Nuclear reactor, Waste management & Bangladesh Perspective

Submitted by:

Md. Asif Iqbal Tuhin (092451)

Fahim Shahriyar Tuhin (092447)

Md. Taousif Sarker (092404)

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Under the supervision of

Dr. Md. Shahidullah

Professor & Head of the Department

of

Electrical & Electronic Engineering

Islamic University of Technology (IUT)

Declaration

We do hereby declare that this book has not been submitted elsewhere for obtaining any degree or diploma or certificate

Countersigned

Signed

Dr.Md. Shahidullah

Md. Asif Iqbal Tuhin (092451)

Fahim Shahriyar tuhin (092447)

Md. Taousif Sarker (092404)

Preface:

Nuclear energy has been one of the most controversial topics since its first research testing in the early 20th century. This awesome power has been used for life-saving procedures and horrific destruction of human life alike. Nuclear energy is the energy that binds subatomic particles together against magnetic forces. When unleashed, nuclear energy presents one of the strongest energy forms man has ever known.

Nuclear energy is the world's largest source of emission-free energy. Nuclear power plants produce no controlled air pollutants, such as sulfur and particulates, or greenhouse gases. The use of nuclear energy in place of other energy sources helps to keep the air clean, preserve the Earth's climate, avoid ground-level ozone formation and prevent acid rain. Of all energy sources, nuclear energy has perhaps the lowest impact on the environment, including water, land, habitat, species, and air resources. Nuclear energy is the most eco-efficient of all energy sources because it produces the most electricity relative to its environmental impact.

Bangladesh began consideration of nuclear power in the 1960s, and with the Government approval of a national *Action Plan* in 2000, reinvigorated its efforts in recent years. The nuclear power plant would contribute to solving dire energy shortages and future increased demand for energy.

Acknowledgement:

We express our heartiest gratitude & indebtedness to our honorable and respectable teacher Dr. Md. Shahidullah, professor & head of the department of electrical & electronic engineering.IUT Dhaka for his continuous advises authentic supervision, cordial help closed guidance for the successful preparation and complete of our studies on Nuclear Power: Bangladesh perspective. His unalloyed kindness, sympathy and generously have tracked in our witness hearts.He is as like as a boon to us and we are all own to him forever.

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Md. Asif Iqbal Tuhin

Fahim Shahriyar Tuhin

Md. Taousif Sarker

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1.Introduction:

1.1 Nuclear power and its uses:

Nuclear power is energy which is produced with the use of a controlled nuclear reaction. Many nations use nuclear power plants to generate electricity for both civilian and military use, and some nations also utilize this type of energy to run parts of their naval fleets, especially submarines. Some people favor an expansion of nuclear power plants because this form of energy is considered cleaner than fossil fuels such as coal, although they come with a number of problems which must be addressed, including the safe disposal of radioactive waste products.

The process of generation nuclear power starts with the mining and processing of uranium and other radioactive elements. These elements are used to feed the reactor of a power plant, generating a reaction known as fission which creates intense heat, turning water in the plant into steam. The steam powers steam turbines, which generate electricity and feed the electricity into the electrical grid.

When nuclear energy is used to power something like a submarine, the reactor runs the engines, with the steam directly powering the engines. In both cases, the reactor requires careful supervision, because runaway nuclear reactions must be stopped as quickly as possible to prevent serious problems. Many nuclear power plants have extensive automated systems which help to identify potential trouble spots, and these systems can also re-route power, turn off parts of the plant, and perform other tasks which make the plant safer and cleaner.

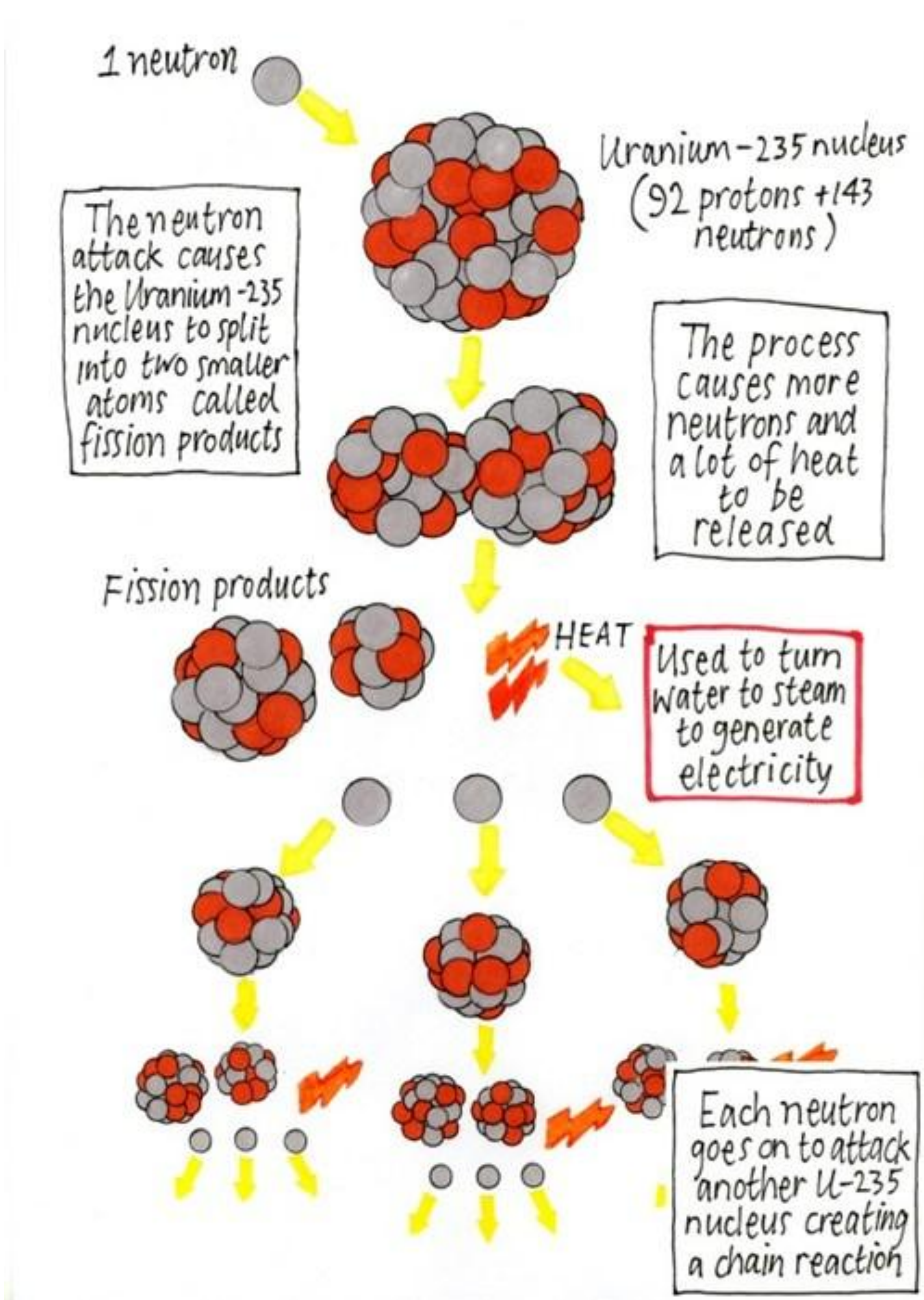
1.2 How nuclear power is produced

An atom of a particular element can have a different number of neutrons and this is called an isotope. For example most carbon (C) atoms have 6 protons and 6 neutrons and can be written as C-12, but some carbon atoms have 7 or 8 neutrons. These isotopes of carbon are written as C-13 and C-14 where the number represents the total number of protons and neutrons. These additional neutrons do not last forever and the loss of neutrons is called radioactive decay.

Uranium (U) atoms have 92 protons and between 141 and 146 neutrons making six different isotopes of Uranium. The isotope U-235 is the one used in generating nuclear energy. Uranium is a metal that is mined in different parts of the world (including Canada, Australia and

Kazakhstan) however most of the uranium found on Earth is U-238. Only a small amount of natural uranium (<1%) is U-235 which is needed in a nuclear reactor. U-238 is often made into plutonium (P)-239 which can also be used in a nuclear reactor.

At a nuclear power plant, neutrons smash into the nucleus of the uranium or plutonium atom which splits in half to produce two smaller nuclei, some more neutrons and heat. The neutrons released are able to collide with other uranium atoms causing a chain reaction.



1.3 Other uses of Nuclear Technology:

Nuclear Medicine :

Nuclear medicine uses radiation to allow doctors to make a quick, accurate diagnosis of the functioning of person's specific organs, or to treat them. Radiotherapy can be used to treat some medical conditions, especially cancer, using radiation to weaken or destroy particular targeted cells.

Tens of millions of patients are treated with nuclear medicine each year
Over 10,000 hospitals worldwide use radioisotopes in medicine, and about 90% of the procedures are for diagnosis. The most common radioisotope used in diagnosis is technetium-99, with some 30 million procedures per year, accounting for 80% of all nuclear medicine procedures worldwide.

Heat for Desalination :

Heat from nuclear reactors can be used directly, instead or as well as being used to generate electricity. This heat can be used for district heating, as process heat for industry or for desalination plants, used to make clean drinkable water from seawater.

Space missions:

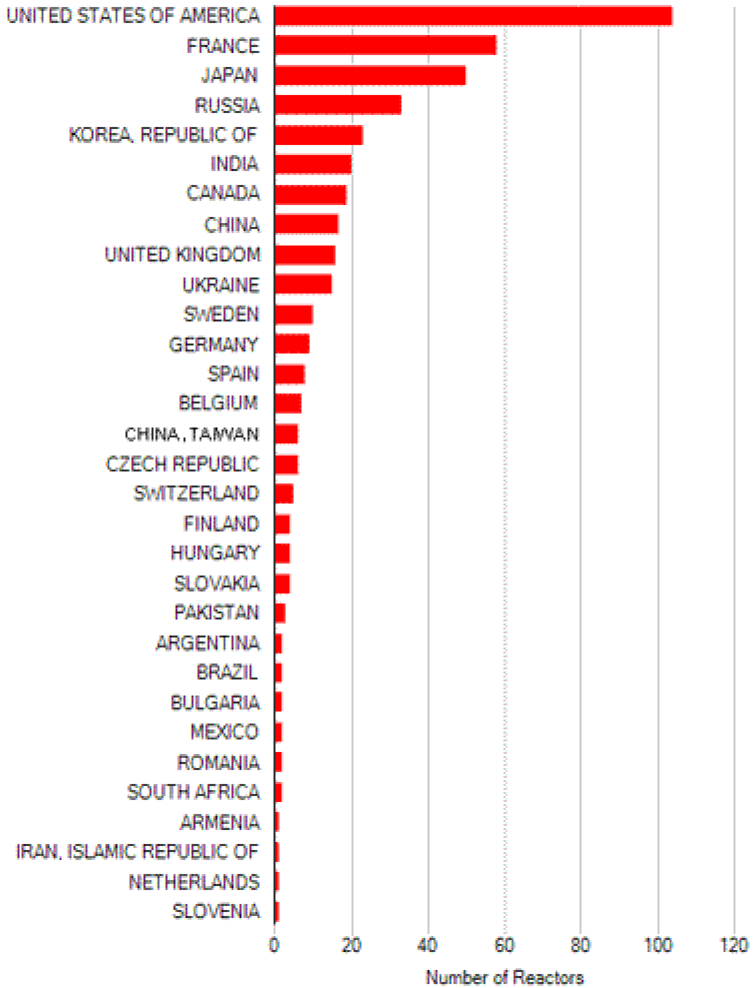
Radioisotope thermal generators are used in space missions. The heat generated by the decay of a radioactive source, often Plutonium-238, is used to generate electricity. The Voyager space probes, the Cassini mission to Saturn, the Galileo mission to Jupiter and the New Horizons mission to Pluto all are powered by RTGs. The Spirit and Opportunity Mars rovers have used a mix of solar panels for electricity and RTGs for heat. The latest Mars rover, Curiosity, is much bigger and uses RTGs for heat and electricity as solar panels would not be able to supply enough electricity.

In the future electricity or heat from nuclear power plants could be used to make hydrogen. Hydrogen can be used in fuel cells to power cars, or can be burnt to provide heat in place of gas, without producing emissions that would cause climate change.

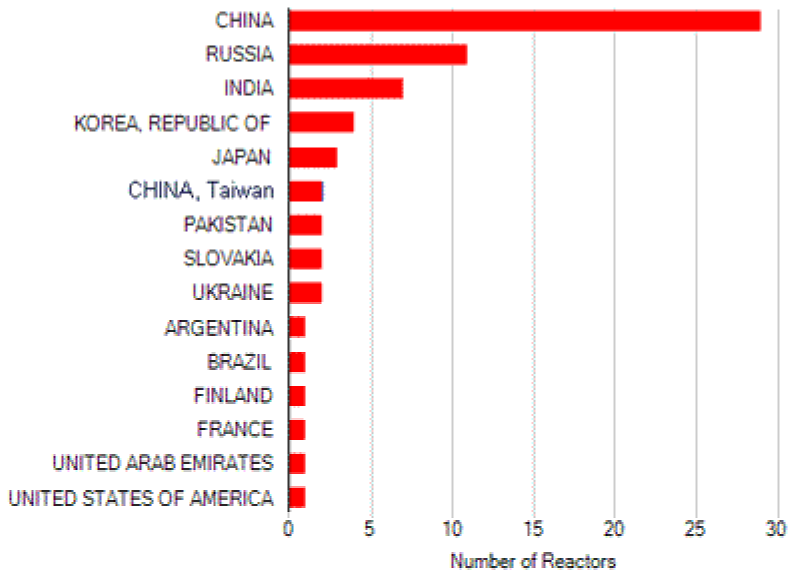
1.4 Nuclear Power in the World today

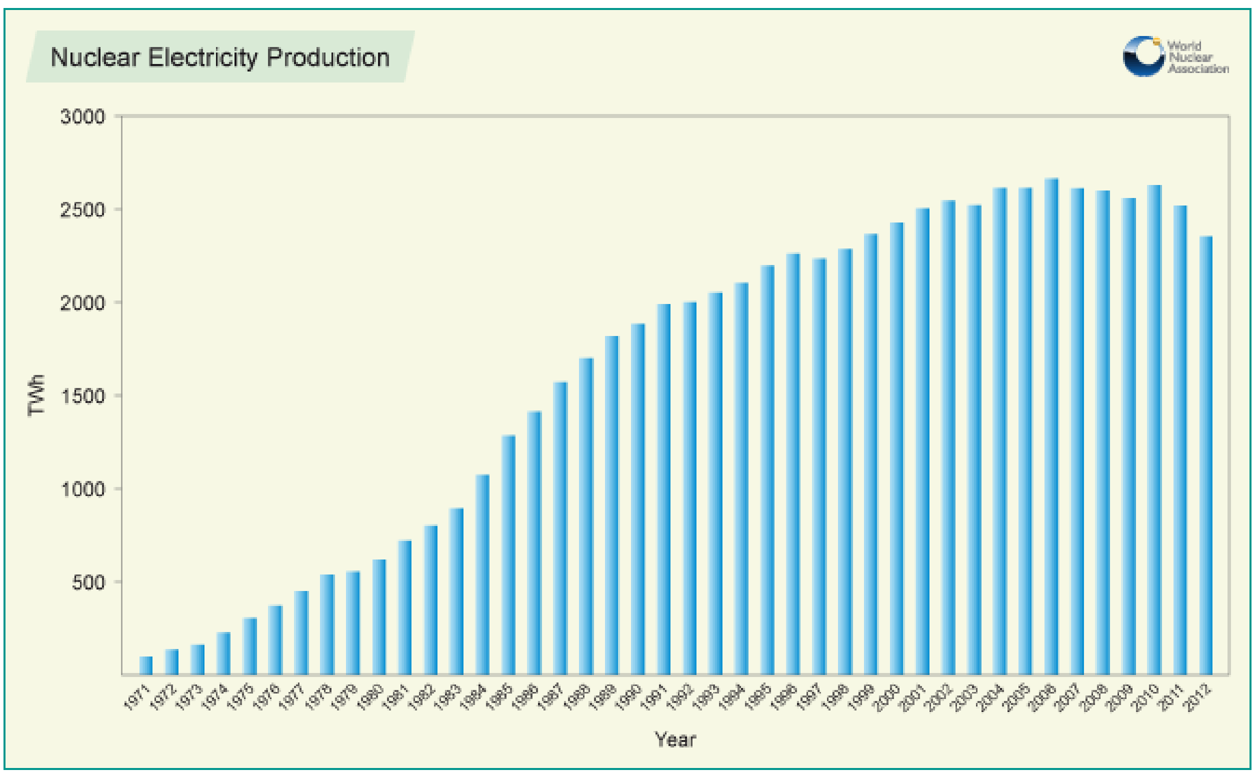
- The first commercial nuclear power stations started operation in the 1950s.
- There are now over 430 commercial nuclear power reactors operating in 31 countries, with 372,000 MWe of total capacity.
- They provide about 13.5% of the world's electricity as continuous, reliable base-load power, and their efficiency is increasing.
- 56 countries operate a total of about 240 research reactors and a further 180 nuclear reactors power some 150 ships and submarines.

Nuclear power plants world-wide, in operation and under construction:



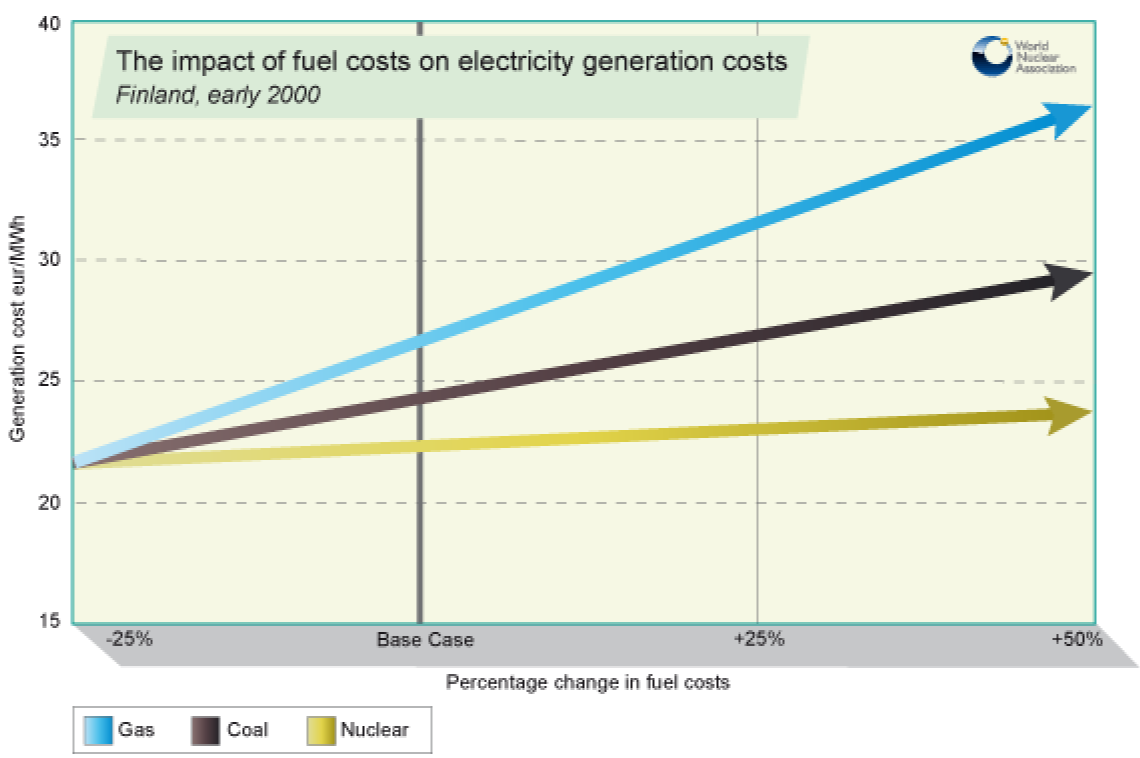
Number of reactors in operation, worldwide:

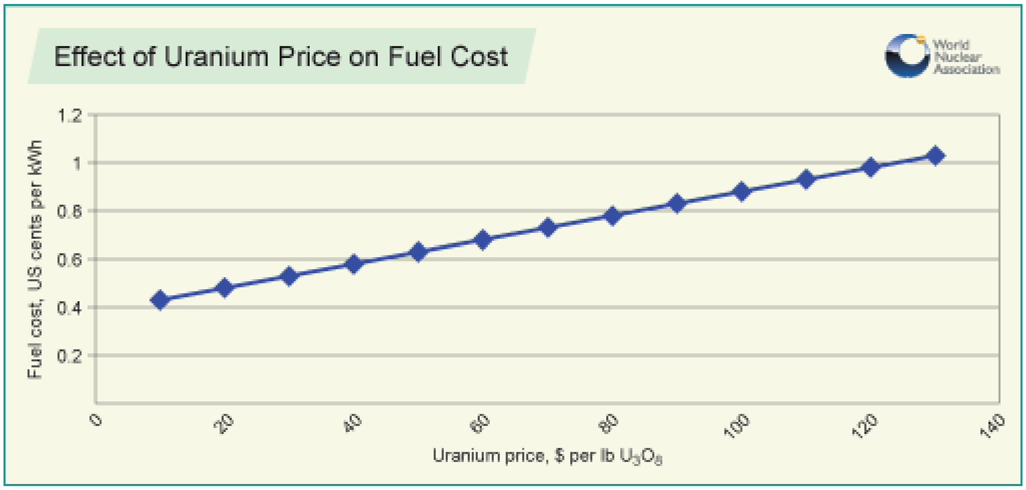




1.5 How much does a Nuclear Plant cost?

Costs for nuclear power plants are driven primarily by the upfront cost of capital associated with construction. While a natural gas power plant could be constructed for as little as $850/kW, recent estimates put construction of a nuclear power plant at $4000/kW. This estimate means a 1 GW plant should cost about $4 billion if financed by a lump upfront payment. In practice, however, it is much more expensive to construct nuclear power stations because there are significant uncertainties associated with their construction times. Because construction of a new nuclear power plant represents a significant cost it must be financed as an investment and requires interest payments over the life of a loan. The rate of interest (discount rate) represents uncertainty in whether the plant will be able to service payments on its loan. The construction of a new nuclear power plant involves risk in construction delays, public opposition, and changes in the regulatory environment, all of which could lead to significant cost overruns and adversely affect the profitability of a project. Modeling a nuclear power plant as an annuity costing an initial $4 billion with a 40 year life and interest rate of 11% (corresponding to approximately 50-50 debt/equity split) results in a total cost of more than $17 billion over the life of the loan. The point is that an attempt to fund construction of a new nuclear power station is squeezed from both sides: they are inherently more expensive to manufacture and also have a much higher cost of capital than fossil-fuel power plants. In reality construction costs could be even worse; recent examples in the United States have priced from $5 to $12 billion per 1.1 GW reactor over the relatively short construction time span. Even though the fuel costs of a nuclear plant are fairly low, these upfront costs associated with construction and financing tend to dominate the ultimate cost of nuclear power and make it significantly more expensive than fossil fuel power.





1.6 Emerging Nuclear Energy Countries:

- Over 45 countries are actively considering embarking upon nuclear power programs.
- These range from sophisticated economies to developing nations.
- The front runners after Iran are UAE, Turkey, Vietnam, Belarus, Poland and Jordan.

Nuclear power is under serious consideration in over 45 countries which do not currently have it (in a few, consideration is not necessarily at government level). For countries listed immediately below in bold, nuclear power prospects are more fully dealt with in specific country papers:

- In Europe: Italy, Albania, Serbia, Croatia, Portugal, Norway, **Poland,** Belarus, Estonia, Latvia, Ireland, Turkey.
- In the Middle East and North Africa: Iran, Gulf states including **UAE,** Qatar & Kuwait, Yemen, Israel, Syria, Egypt, Tunisia, Libya, Algeria, Morocco, Sudan.
- In west, central and southern Africa: Nigeria, Ghana, Senegal, Kenya, Uganda, Namibia.
- In South America: Chile, Ecuador, Venezuela.
- In central and southern Asia: Azerbaijan, Georgia, Mongolia, Bangladesh, Sri Lanka
- In SE Asia: Indonesia, Philippines, Vietnam, Thailand, Malaysia, Singapore, Australia, Newzealand.
- In east Asia: North Korea

Despite the large number of these emerging countries, they are not expected to contribute very much to the expansion of nuclear capacity in the foreseeable future – the main growth will come in countries where the technology is already well established. However, in the longer term, the trend to urbanization in less-developed countries will greatly increase the demand for electricity, and especially that supplied by base-load plants such as nuclear. The pattern of energy demand in these countries will become more like that of Europe, North America and Japan.

Some of the above countries can be classified according to how far their nuclear programs or plans have progressed:

- Power reactors under construction: UAE (Iran reactor has started up and been grid-connected)
- Contracts signed, legal and regulatory infrastructure well-developed: Lithuania, Turkey, Belarus.
- Committed plans, legal and regulatory infrastructure developing: Vietnam, Jordan, Poland, Bangladesh.
- Well-developed plans but commitment pending: Thailand, Indonesia, Egypt, Kazakhstan, Saudi Arabia, Chile; or commitment stalled: Italy.
- Developing plans: Israel, Nigeria, Malaysia, Morocco, Kuwait.
- Discussion as serious policy option: Namibia, Kenya, Mongolia, Philippines, Singapore, Albania, Serbia, Croatia, Estonia & Latvia, Libya, Algeria, Azerbaijan, Sri Lanka, Tunisia, Syria, Qatar, Sudan, Venezuela.
- Officially not a policy option at present: Australia, New Zealand, Portugal, Norway, Ireland, Kuwait.

Bangladesh status:

- Bangladesh plans to have two 1000 MWe Russian nuclear power reactors in operation from 2020.
- This is to meet rapidly-increasing demand and reduce dependence on natural gas.

Bangladesh produced 38 billion KWh gross in 2009 from some 6.1 GWe of plant, giving per capita consumption of 250 kWh/yr. About 88% of electricity comes from natural gas. Electricitydemand is rising rapidly, with peak demand 7.5 GWe, and the government aims to increase capacity to at least 7 GWe by 2014, meanwhile importing some 250 MWe from India. New small coal-fired plants are envisaged for 2 GWe of that, and for 3 GWe more by 2016. However, about half the population remains without electricity, and the other half experience frequent power cuts. Some 5.0% of government expenditure is being allocated to 'power and energy'. The capacity target for 2021 is 20 GWe.

1.7 NPP in Bangladesh

Building a nuclear power plant in the west of the country was proposed in 1961. Since then a number of reports have affirmed the technical and economic feasibility. The Rooppur site in Pabna district about 200 km north of Dhaka was selected in 1963 and land was acquired. The government gave formal approval for a succession of plant proposals, then after independence a 125 MWe nuclear power plant proposal was approved in 1980 but not built.

With growth in demand and grid capacity since then, a much larger plant looked feasible, and the government in 1999 expressed its firm commitment to build this Rooppur plant. In 2001 it adopted a national Nuclear Power Action Plan and in 2005 it signed a nuclear cooperation agreement with China.

In 2007 the Bangladesh Atomic Energy Commission (BAEC) proposed two 500 MWe nuclear reactors for Rooppur by 2015, quoting likely costs of US$ 0.9-1.2 billion for a 600 MWe unit and US$ 1.5-2.0 billion for 1000 MWe. In April 2008 the government reiterated its intention to work with China in building the Rooppur plant and China offered funding for the project. The International Atomic Energy Agency (IAEA) approved a Technical Assistance Project for Rooppur Nuclear Power Plant to be initiated between 2009 and 2011, and it then appeared that an 1100 MWe plant was envisaged.

Russia, China and South Korea had earlier offered financial and technical help to establish nuclear power, and in March 2009 Russia made a formal proposal to build a nuclear power plant in the country. In May 2009 a bilateral nuclear cooperation agreement was signed with Russia. In April 2009 the government approved the Russian proposal to build a 1000 MWe AES-92 nuclear plant at Rooppur for about $2 billion, and a year later this had become two such reactors by 2017. A nuclear energy bill was introduced into parliament in May 2012, with work to begin in 2013, and setting up a Bangladesh Atomic Energy Regulatory Authority. Parliament was told that 5000 MWe of nuclear capacity was envisagedby 2030, and a second plant would be built in the south onceRooppur is operating.

In May 2010 an intergovernmental agreement was signed with Russia, providing a legal basis for nuclear cooperation in areas such as siting, design, construction and operation of power and research nuclear reactors, water desalination plants, and elementary particle accelerators. Other areas covered included fuel supply and wastes – Russia will manage wastes and decommissioning. An agreement with Rosatom was signed in February 2011 for two 1000 MWe-class reactors to be built at Rooppur for the Bangladesh Atomic Energy Commission (BAEC). In line with standard Russian practice this includes fuel supply and return of used fuel to Russia. Another intergovernmental agreement was signed in November 2011 for the project tobe built by AtomStroyExport (which in mid-2012 was merged with Nizhny Novgorod Atomenergoproekt, NIAEP). In June 2013, NIAEP-AtomStroyExport signed a contract with BAEC to prepare documentation related to investment in construction and environmental impact assessment for the plant, as well as providing for necessary engineering studies. NIAEP-ASE said that this represented a transition to long-term cooperation.

In February 2012 the Ministry of Science and Technology signed an agreement with Russia's Rostechnadzor related to regulation and safety "and the provision of advisory support to the Bangladesh Nuclear Regulatory Commission on regulation, licensing and supervision". Staff will be trained in Russia.

An intergovernmental agreement for provision of a $500 million Russian loan to finance engineering surveys on the site, project development and personnel training was signed in

January 2013. A future loan of about $1.5 billion is expected for the nuclear build proper. In August 2012 a financing agreement was negotiated under which Bangladesh would borrow $500 million for a 2-year technical and economic study together with design, documentation and training, at not less than 4,5% interest rates, which subsequently because 3%. Russia will then provide a second loan of over $1.5 billion for 90% of the first unit's construction. The agreement was signed in January 2013. The $500 million loan will be repaid in 12 years with five years grace period, and the final construction cost will be repaid in 28 years with 10 years grace period. The IAEA continues its close involvement with the project.

Site works are due to start in January 2014, and construction of the first unit is expected from 2015, with operation soon after 2020.

2. Nuclear Reactor

2.1 Basic infrastructure required for NPP

1. National position
2. Nuclear safety
3. Management
4. Funding and Financing
5. Legislative framework
6. Safeguards
7. Regulatory framework
8. Radiation protection
9. Electrical grid
10. Human resource development
11. Stakeholder involvement
12. Site and supporting facilities
13. Environmental protection
14. Emergency planning
15. Security and physical protection
16. Nuclear fuel cycle
17. Radioactive waste
18. Industrial involvement
19. Procurement

- The issue of safety and security in siting, designing, construction and operation phases of Rooppur NPP will be given top priority. The selection of nuclear technology is crucial because this NPP project site was selected earlier, the essential characteristics at present, such as site geology and hydro-geology; seismicity; site preparation; excavation; internal and external access routes; emergency preparedness; construction laydown and storage areas; service utilities; administration and technical support buildings – all these will be re-assessed.

- Authorization or siting license from Bangladesh Atomic Energy Regulatory Authority has to be taken. It is mandatory.
- Initiatives have been taken for the development of technical and economic feasibility evaluation for the NPP location.
- The assessment of Rooppur NPP environmental impacthas been undertaken.
- Bangladesh has decided to involve the NPP design institute of the vendor country in site characterization of Rooppur NPP so that nuclear reactors must be complimented with the latest safety codes for severe accident prevention and capable of tolerating severe man-made or natural events like flood, earthquakes etc.
- It is proposed that in order to build and operate the Rooppur NPP, Bangladesh needs to establish a project organization that could function independent of any political and regulatory establishments.
- Initiatives for capacity building in national academic and research infrastructure in the field of nuclear science and technology have been taken with Dhaka University and some other private universities establishing departments of nuclear engineering. DU started the nuclear engineering courses from this year. These capacity building initiatives will enhance the development of technical competence of regulatory authority personnels, engineers so that there are abundance of trained hands by the time Rooppur NPP is erected.
- According to a 1997 UN resolution and IAEA's multilateral approach to nuclear fuel cycle, no new countries joining the nuclear club with NPPs will be encouraged to handle uranium. Therefore, we have a pact that Bangladesh will have to return the uranium fuel rods which will be leased as fuel for power generation. If we even think of adopting the technology of nuclear fuel cycle, this program will be stopped. So stealing of uranium is out of the question.
- The spent fuel will be taken back to Russia and the recycling will be done there. As per the agreement, the Russian authority would take the responsibility of nuclear waste management taking away all the waste to Russia by a specialized ship.
- After Fukushima disaster, it has been ordered to the nuclear industry to build NPPs with robust design that can ensure safety, security, and which will provide physical protection to the environment and to the public. We are looking at a generation 3+/Third Generation Plus reactor which will ensure to not allow transmission of radiation beyond 800 meters.
- Rooppur NPP will have pressurised water reactors (PWR), the generation-III type

discussed above, with extra safety features - the core of a PWR consists of slightly enriched uranium as fuel, and water as both moderator and coolant, a combination that makes the void coefficient negative. A negative feedback stabilises a system. If voids are formed in the core for any rise in power level, the negative void coefficient will bring the power down. No power surge, like the one in Chernobyl unit 4, is possible in a PWR making it inherently safe.

- The reactor at Rooppur will be built with containment buildings. It is possible to build multiple containments around reactors as extra precaution.

- PWR incorporates multiple barriers to prevent the release of radioactivity in to the atmosphere.

a. The first barrier is the ceramic fuel pellet where nuclear fissions take place and energy is released. The pellet retains most of the fission products, the main source of radioactivity.

b. The second barrier is a sealed metal tube called the cladding that contains the fuel pellets. The cladding retains any gaseous radioactive material that may leak out of the fuel pellets.

c. The third barrier is the closed primary cooling water system that circulates through the core and carries the heat to the steam generator. The cooling system will contain any radioactivity that may leak out of the cladding.

d. The fourth and last barrier is the containment building designed to contain any radioactivity that may leak out of the primary cooling system through any accidental rupture.

- Prime Minister Sheikh Hasina, while observing a nuclear power plant model during the inaugural ceremony of a two-day international conference on nuclear power last month, said that during the bilateral consultation, she had requested Russian President Vladimir Putin for providing Bangladesh the safest and the latest reactors and has received his assurance in this regard.

Meanwhile, as Bangladesh is opting nuclear power generation, many countries have decided a nuclear phase-out. A nuclear power phase-out is the discontinuation of usage of nuclear power for energy production. Often initiated because of concerns about nuclear power, phase-outs usually include shutting down nuclear power plants gradually and looking towards renewable energy and other fuels.

Austria was the first country to begin a phase-out (in 1978) and has been followed by Sweden (1980), Italy (1987), Belgium (1999), and Germany (2000). Austria and Spain have gone as far as to enact laws not to build new nuclear power stations

2.2 Types of Nuclear Reactor

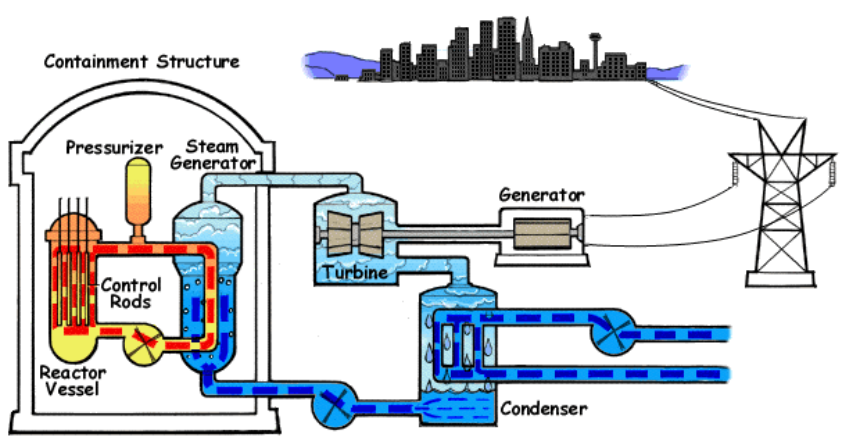
2.2.1 PRESSURISED WATER REACTOR (PWR)

Basic Structure

- ❑ Primary ckt (cooling) & secondary ckt (steam generator)
- ❑ Nuclear vessel (fission chain reaction in primary ckt)
- ❑ Hot primary coolant is pumped into heat exchanger (steam generator)
- ❑ Steam generator contains thousands of tubes (1.9cm dia)
- ❑ Heat transfer is done without mixing of two fluids

Moderator

- ❑ Light water is used
- ❑ Fast fission neutrons are to be slowed down to sustain chain reaction
- ❑ Neutrons undergo multiple collisions with light water and lose speed



Coolant

- ❑ Light water is used
- ❑ Temperature is about 275^oC at the bottom of the core
- ❑ Temperature rises around 315^oC at the upper part of the core

- ❑ The water (coolant) remains liquid due to high pressure (15.5 MPa) in primary ckt

Fuel

UO_2(uranium di oxide)

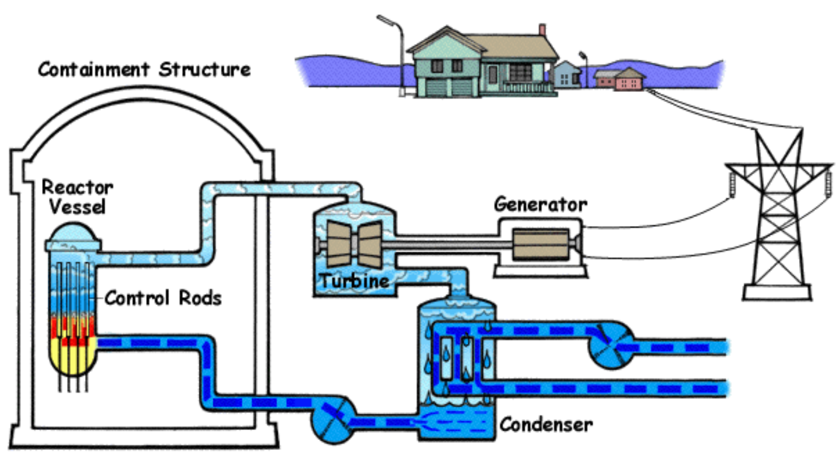
2.2.2 BOILING WATER REACTOR (BWR)

Basic Structure

- Almost same, but the main difference is in BWR (here is no steam generator).
- The water used here is kept under low pressure (7.6 MPa).
- In BWR reactor core heats up the water, which turns into steam and drive the steam turbine.

Coolant & Moderator

- De-mineralized water
- It is used as it drives the turbine.
- Otherwise There will be erosion due to chemical reaction

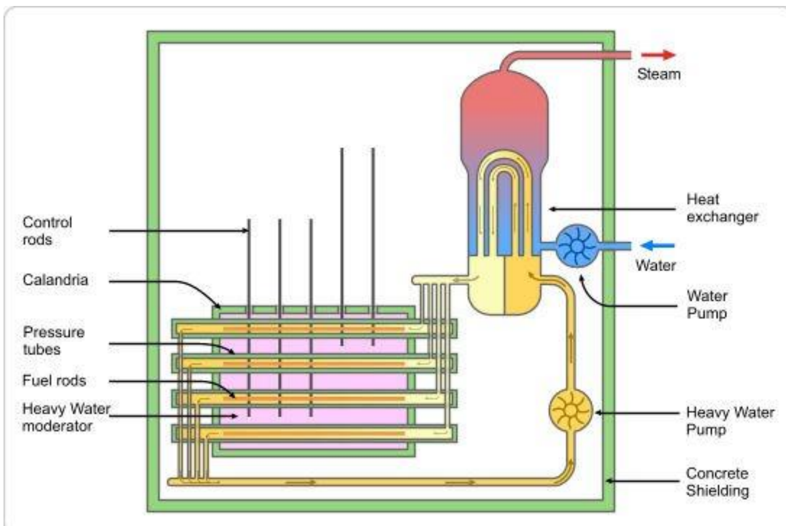


Control System: (two methods)

***1. By inserting or withdrawing control rods*:** With the withdrawing of control rods, neutron absorption decreases in control rods but increases in the fuel and thus the reactor power increases. In case of inserting the situation is just opposite

2. By changing the flow of water through reactor core: When the water flow increases steam bubbles are more quickly removed, so amount of liquid water in the core increases, so neutron moderation increases , more neutrons are absorbed by fuel and so reactor power increases.

2.2.3 PRESSURIZED HEAVY WATER REACTOR



First introduced in 1950 in CANADA & more recently also used in INDIA

Basic structure:

- ✓ same as Pressurized water reactor(PWR)

Coolant and moderator:

- ✓ heavy water D_2O which is expensive

Fuel:

- ✓ Unenriched natural Uranium(U-238 & 0.72% U-2)

Working principle:

- ✓ U-238 can only be fissioned by neutron which requires 1Mev or above.

- ✓ No of amount of U-238 can be made critical but it will absorb more neutrons than it releases
- ✓ U-235 can not be self sustained due to low natural abundance
- ✓ D_2o slows down some neutrons to the point where U-235 can sustain self sustained fission reaction
- ✓ During slowing down process it is effective to separate neutrons

  Dlhldh

3. Analysis of PWR Power Plant Systems

In a PWR's primary coolant system, boiling is suppressed and steam is generated via steam generators in the secondary coolant loops. A pressurizer is used to maintain the primary coolant in sub-cooled condition and the pressure close to a constant. Reactor coolant pumps are used to circulate the primary coolant through steam generators; at which steam is generated at the secondary side to drive the turbine. The major plant systems are described in this section.

3.1 Reactor Power Control

PWR has sophisticated automatic control systems. The control rod system and soluble boron control the core neutron flux. The Chemical and Volume Control System (CVCS) control the primary coolant inventory and water chemistry. On the secondary side, steam output is controlled by the turbine control valve and steam dump system. The steam generator water level is controlled by the feed water system. During the automatic control mode, they work in a synchronized way so that transition to stabilized conditions will be achieved smoothly.

3.2 Pressurizer Pressure Control

All PWRs are designed to operate close to a constant pressure in the neighborhood of 15 MPa during power operation. The error between the system pressure and set point goes through a controller circuit. When the error is too high, the spray is turned on. If the pressure increases further during a transient, there are relief valves and safety valves set to open to relieve the pressure. If the pressure decreases and a negative pressure error exists, the proportional heater turns on and increases linearly to its maximum power. If the discrepancy develops further, the backup heater turns on. Detail of the heater functions is design specific. The PCTRAN/U model is generic and thus it is intended for basic principle instruction only.

3.3 Pressurizer Water Level Control

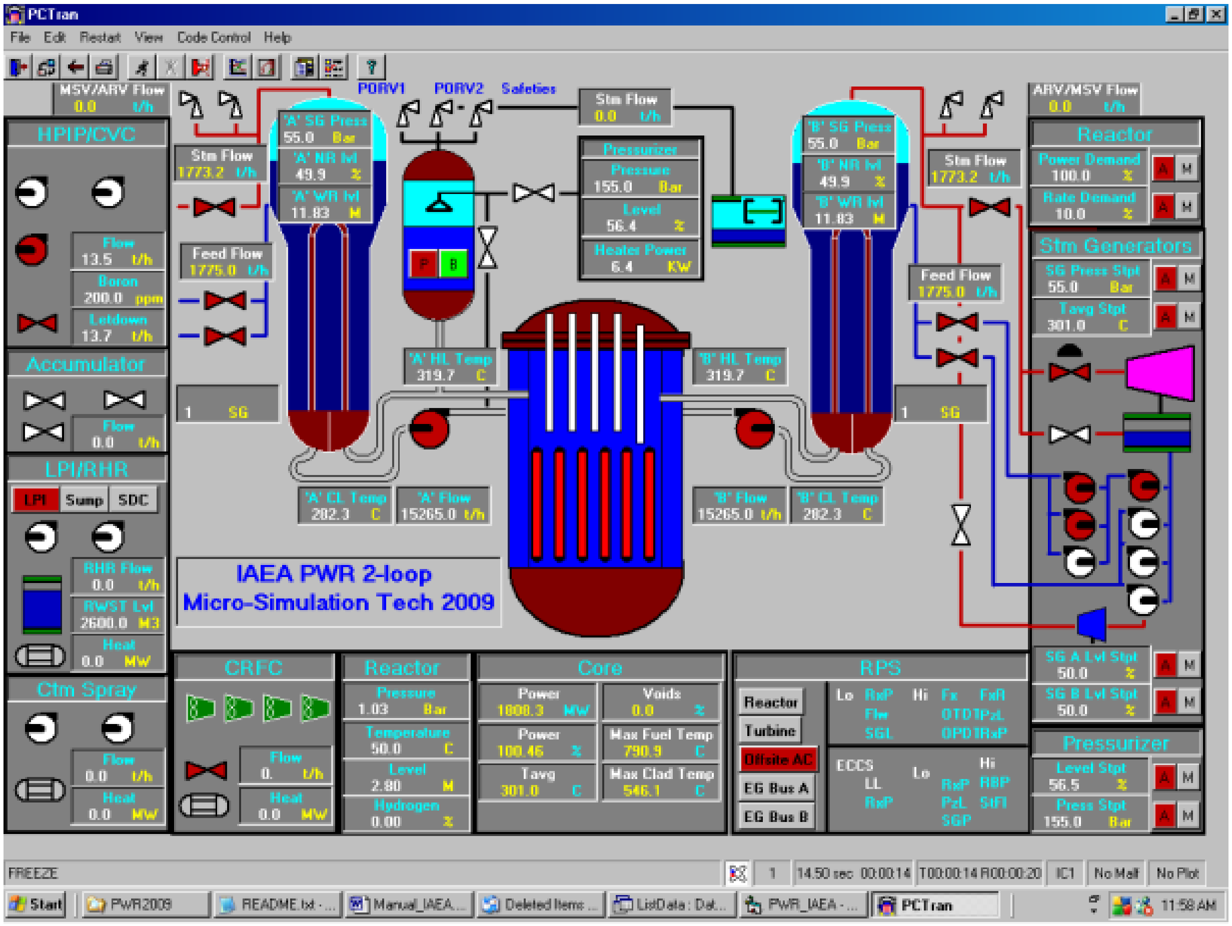
The charging (also called makeup) pump using an error of pressurizer level to the level set point controls pressurizer water level. Depending upon a reactor's design, the level set point may be a constant or programmed as a function of the unit power. Letdown is turned on when the pressurizer level exceeds the set point. The charging and letdown system also controls the reactor coolant's chemical composition. Therefore, it is also called the Chemical and Volume Control System (CVCS). When the pressurizer level is too low, the letdown is isolated and the heaters are turned off.

3.4 Steam Generator Control

3.4.1 Steam Header Pressure Control

The steam header pressure is controlled at a set pressure by the turbine control (throttle) valve. It may either be a constant or programmed as a function of the unit power depending upon the reactor's design. The Steam Dump System controls the turbine bypass valves' opening. At a higher pressure, there are atmospheric dumps and safety valves set to relieve over-pressure in the steam lines.

Figure of PCTRAN/U 6.0.1 Windows Mimic



3.4.2 Steam Generator Water Level and Feed water Control

During normal operation, feedwater pumps provide water to the steam generators. The feedwater control valve is regulated by the sum of two errors: steam generator water level relative to the level set point, and feedwater to steam flow mismatch. Through a proportional-plus-integral controller, the valve regulates the feedwater flow until any transition is stabilized and the errors diminish.

When the main feedwater pumps are not in service, there are typically turbine and/or motor-driven auxiliary feedwater pumps. The operators will start them on a low water-level signal or manually.

3.5 Reactor Protection System

Whenever the reactor's operating parameters exceed certain defined safety limits; all control rod are dropped by gravity into the core to suppress the chain reactor. The following trip functions are typical for a PWR:

- High reactor pressure and/or pressurizer water level
- High neutron flux
- Over-temperature delta-T
- Over-power delta-T
- High RC outlet temperature
- Low reactor pressure and/or pressurizer water level
- Low SG water level
- Low loop or core flow
- Containment pressure

The over-temperature and over-power delta-T trips are temperature differences between the reactor coolant inlet and outlet for core DNBR protection.

Liquid boron injection is used to provide negative reactivity if all rod insertion functions fail.

3.6 Emergency Core Cooling Systems

PWR is equipped with redundant trains of ECCS for core heat removal during emergency. They are generally composed of:

3.6.1 High Pressure Safety Injection (HPSI) System

Consisting of redundant trains of centrifugal pumps that run on emergency diesel power and operable on high (reactor operating) pressure. It is started on a low reactor pressure and/or low pressurizer level signal, or high containment pressure signal. The objective is to make up coolant loss on a small break LOCA beyond the regular makeup (charging) system's capability.

3.6.2 Accumulators (ACC)

Tanks are filled with borate water and pressurized nitrogen. For a LOCA not recoverable by the HPSI, valves connecting the ACC and the reactor coolant system are opened at about 40 bar (4

MPa). They will be closed when the two side's pressures are equalized so that nitrogen is prevented from entering the RCS.

3.6.3 Low Pressure Safety Injection (LPSI) System

It consists of redundant trains of centrifugal pumps to be started on Safety Feature Actuation System (SFAS) signals. Their shutoff head (around 10 - 15 bar) is considerably lower than the HPSI's. But its flow rate is much greater. It has the capacity to completely refill the reactor vessel following a major LOCA to the point of break. LPSI normally takes its suction from the Borate Water Storage Tank (BWST). When the water is about exhausted, the operator will switch the suction from the building sump and run through heat exchangers before injecting back to the reactor. Note that for some plants the same pumps used for LPSI are used for decay heat removal during the cooldown period after a normal shutdown. The piping lineup and heat exchangers belong to the Decay Heat or Residual Heat Removal (RHR) system and thus not part of the ECCS.

3.7 Containment System

To prevent over-pressure in the containment following a LOCA, PWR is equipped with a containment spray system and emergency fan coolers. Suction of the spray pumps is from the Borate Water Storage Tank (BWST). It can also be switched to recirculation mode when water supply is exhausted. Heat exchangers are then used to remove the heat content inside the containment to outside ambiance.

Containment is designed to about 4 bar above the atmospheric pressure with a leakage rate in the order of 1% per day at the design pressure.

4.0 PWR Benchmark Analysis

In order to demonstrate that the PCTRAN simulation software is capable of simulating the PWR plant operation, two types of runs were conducted. First is to perform normal operation with load change etc. Second is a set of transient and accident analyses as in the Westinghouse 2-loop Point Beach FSAR. In this chapter they are described in detail.

4.1 Normal Operation

4.1.1 Load Reduction to 40%

This is a test of the reactor control system for load control. We can enter a load demand different from the panel indicated and the reactor will respond to reach the desired load with a ramp rate RAMP in percent per minute. For example, by clicking at "M" for manual control for Pwr Dmd in the upper right reactor control panel and entering 40%, the reactor will drop it power output to 40% at a rate of 10%/min. This will be achieved by precise control of the turbine control valve. The neutron flux and thermal power follow the turbine load with a noticeable lag.

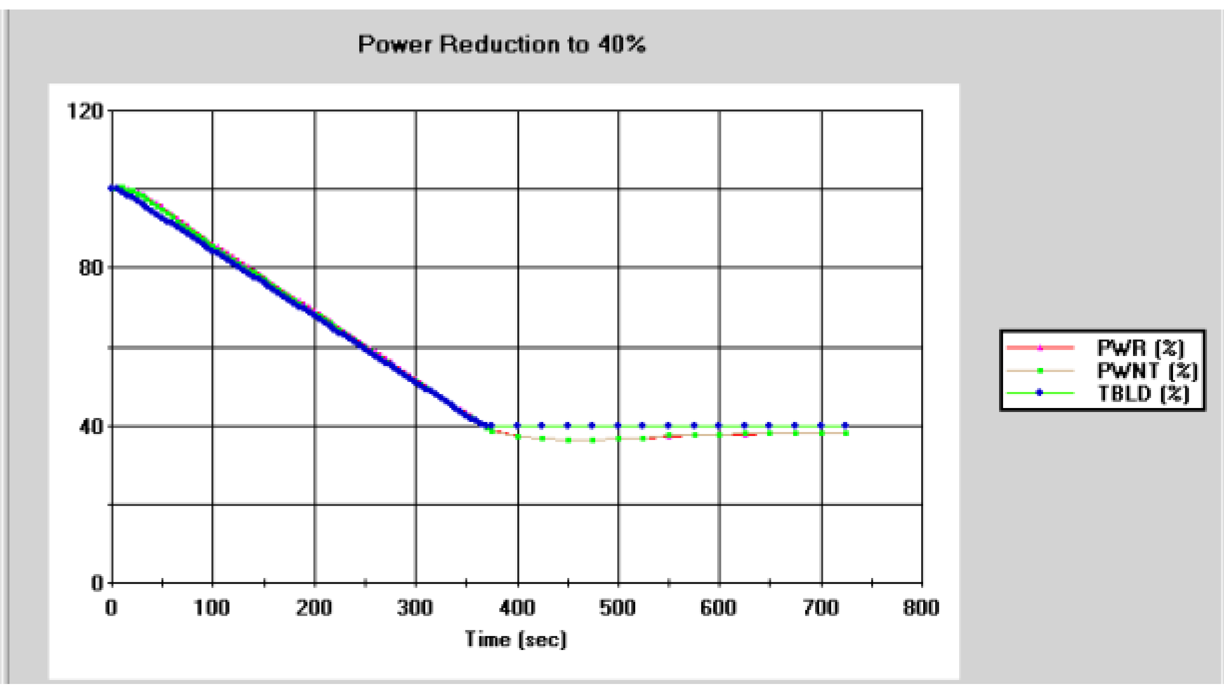
The reactor primary pressure after some perturbation returns to the original pressure (about 155 bar) while the secondary pressure rises to a higher value corresponding to the lower power level. The pressurizer level and reactor coolant Tavg will decrease according to the load program. The feedwater flow will be run-back to balance the steam flow. The steam generator narrow-range level returns to the set point of 50% after its initial rise by overfeeding. The rod reactivity is a result of the rod control system that inserts the assemblies into the core. Feedback from Doppler and moderator temperature are also presented, they're combined total reactivity controls the nuclear power in this load reduction process.

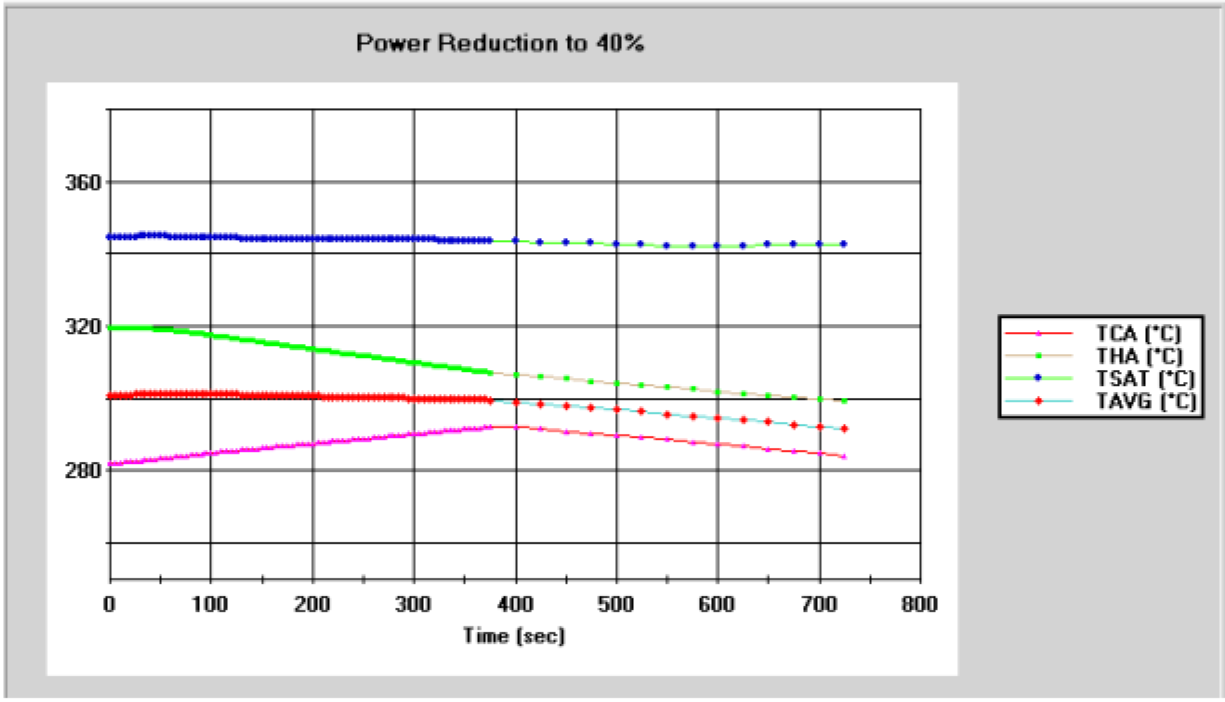
Individual plant control systems can be taken into manual by clicking at the "M" button in the PCTRAN/U's mimic. By entering a set point other than the original value, click at "Inactive" to change it to "active" and close the window, the system will evolve into a new stabilized status corresponding to that condition.

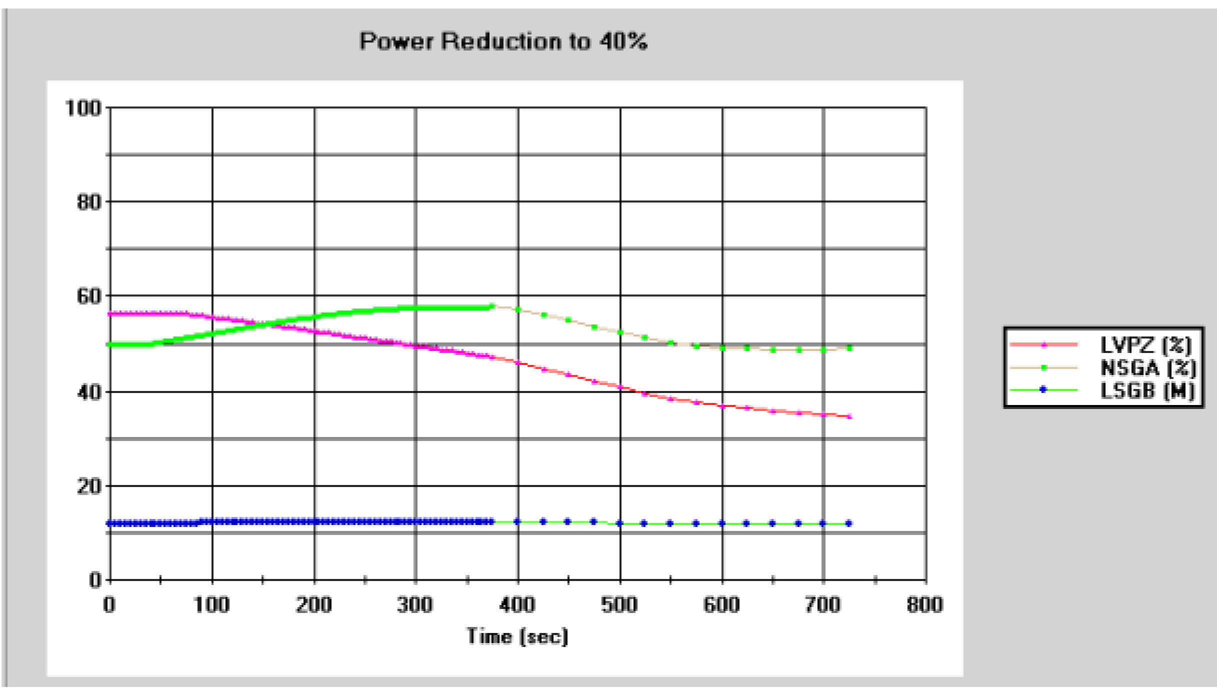
For exercises we should try to change every manual control function and observe the simulator response. For example, in addition to the power demand setpoint change, the ramp rate, RAMP, can be altered to 20% per minute, or the pressurizer level to 50%, the SG level to 45%, etc.. The pressurizer heaters can also be set to turn on or off using the equipment malfunction (right mouse). This is instructive for comprehension of each component's effect to the whole reactor system.

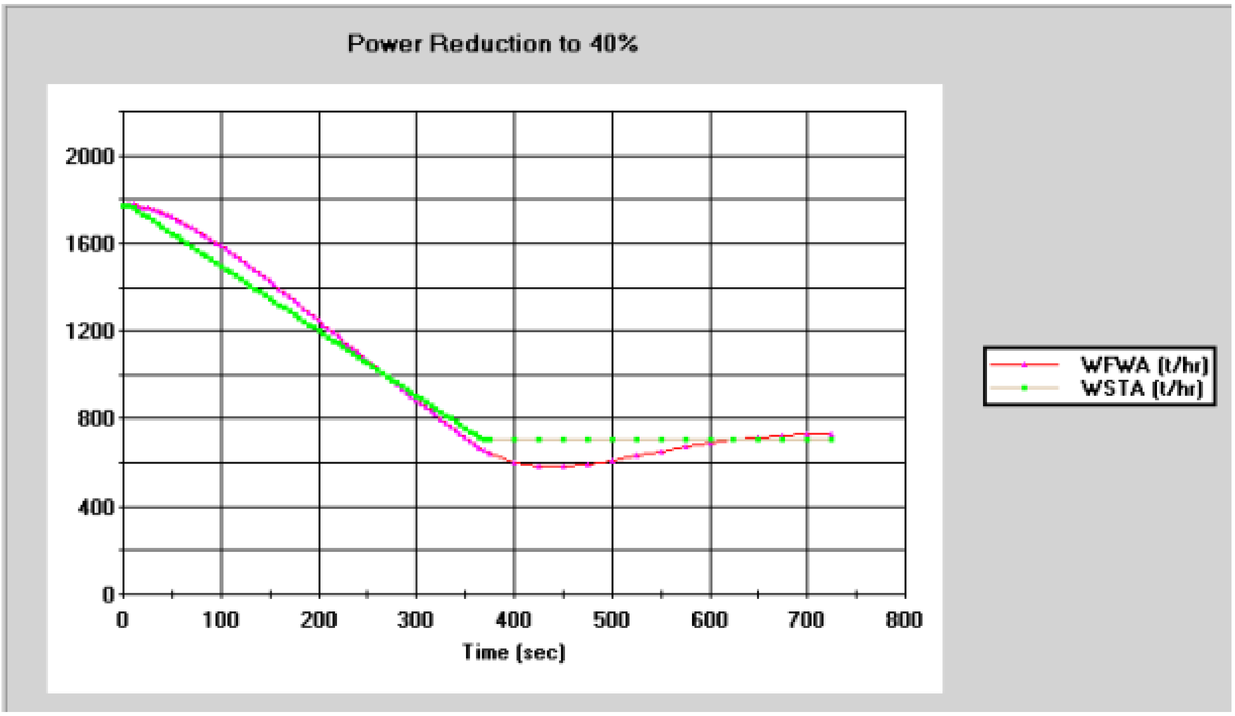
Run Time = 800 seconds

Initial Condition (IC #)	Malfunction (#/%)	Interactive Control (panel/%)	Output Variable (Name)	Range (min/max/ unit)
1	None	Pwr Dmd/40	TBLD PWTH PWNT THA/THB TCA/TCB TFPK TFSB TPCT LVPZ P PSGA NSGA/B LSGA/B WSTA/B WFWA/B RHDP RHRD RHMT RH	0/120(%) 260/350(°C) 0/900 (°C) 0/100 (%) 0/200 (bar) 0/100 (%) 0/3000(t/hr) -100/100 pcm(E-5dk/k)

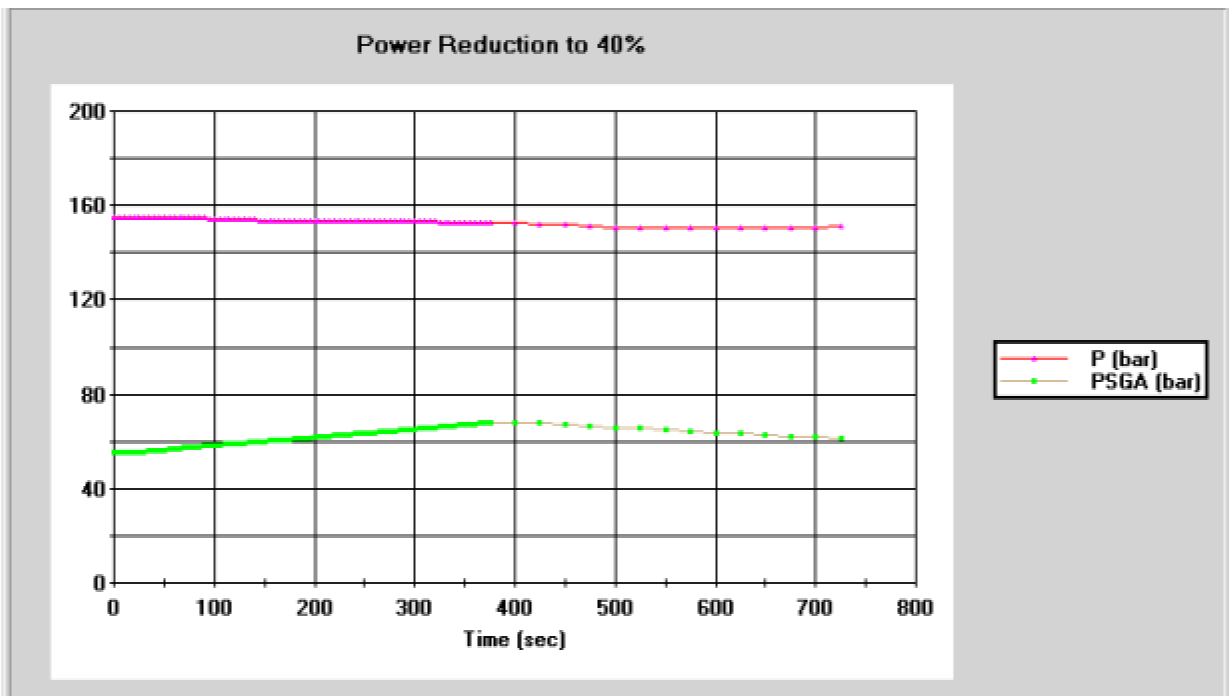



Power Reduction to 40%
360
320
280
0
100
200
300
400
500
600
700
800
Time (sec)
TCA (°C)
THA (°C)
TSAT (°C)
TAVG (°C)

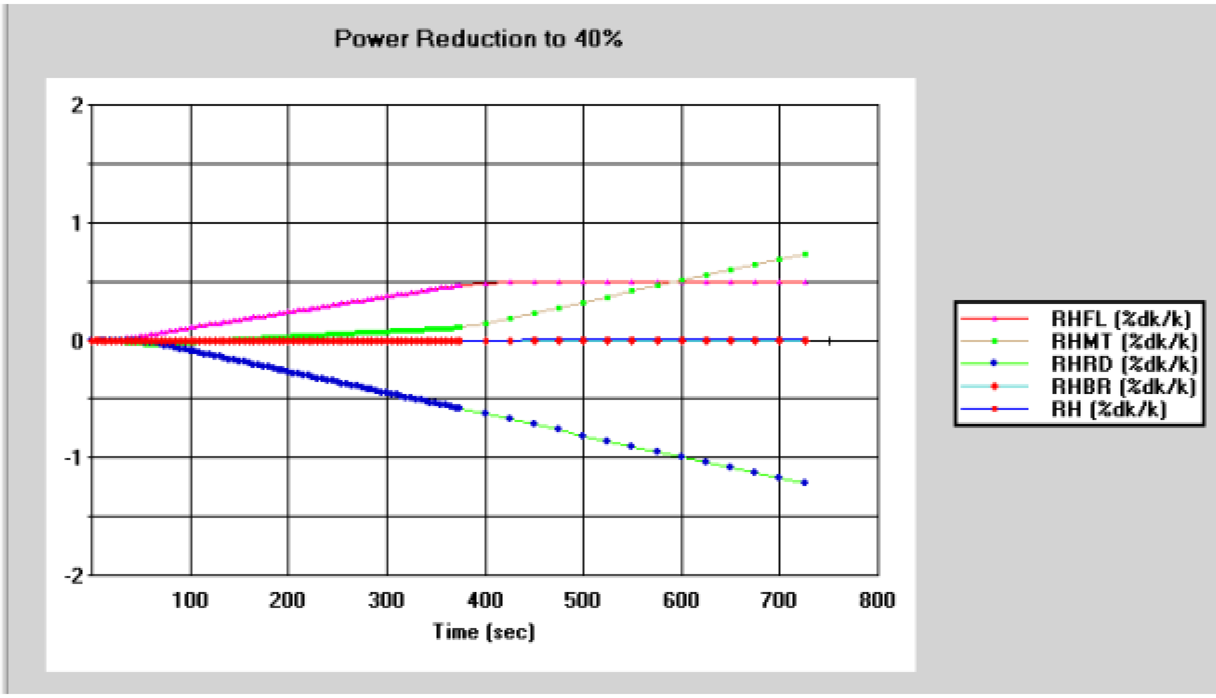

Power Reduction to 40%
100
80
60
40
20
0
0
100
200
300
400
500
600
700
800
Time (sec)
LVPZ (%)
NSGA (%)
LSGB (M)



Power Reduction to 40%
2000
1600
1200
800
400
0
0
100
200
300
400
500
600
700
800
Time (sec)
WFWA (t/hr)
WSTA (t/hr)



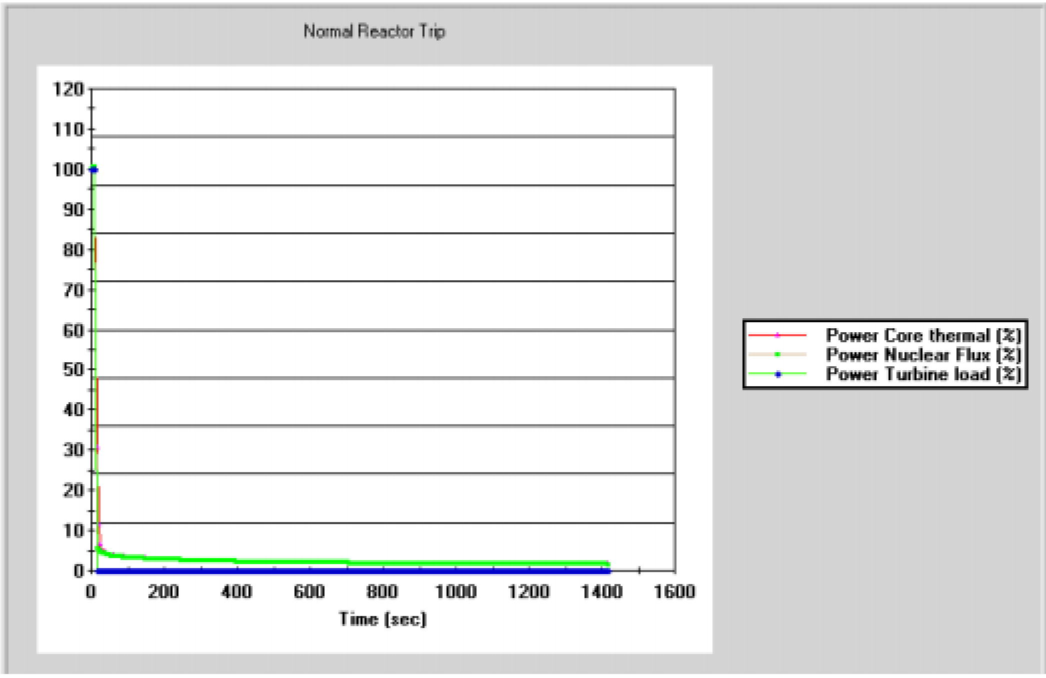
Power Reduction to 40%
200
160
120
80
40
0
0
100
200
300
400
500
600
700
800
Time (sec)
P (bar)
PSGA (bar)

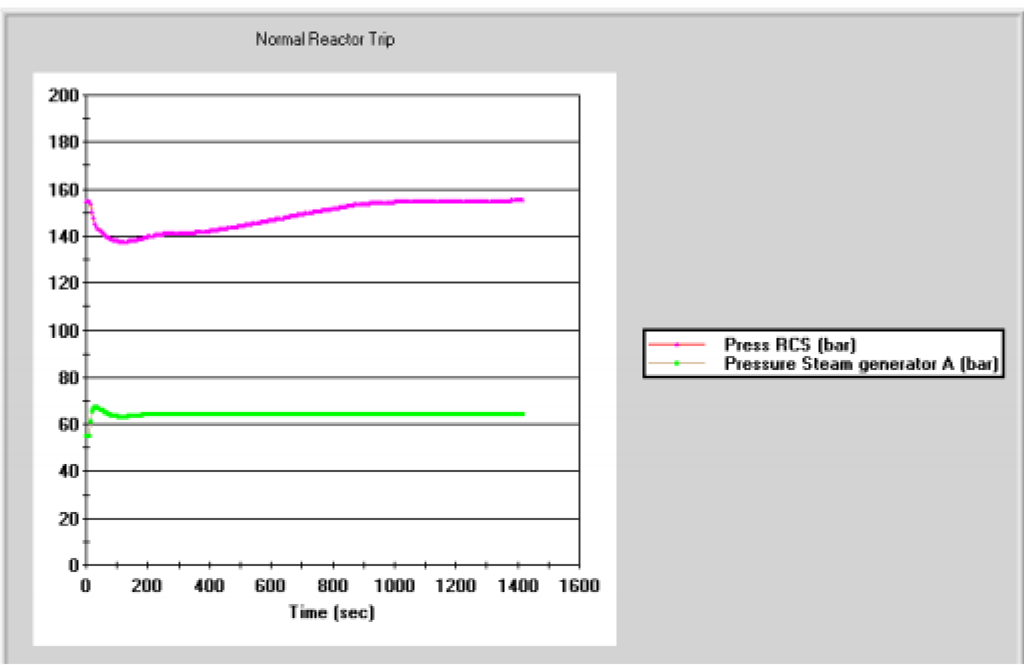


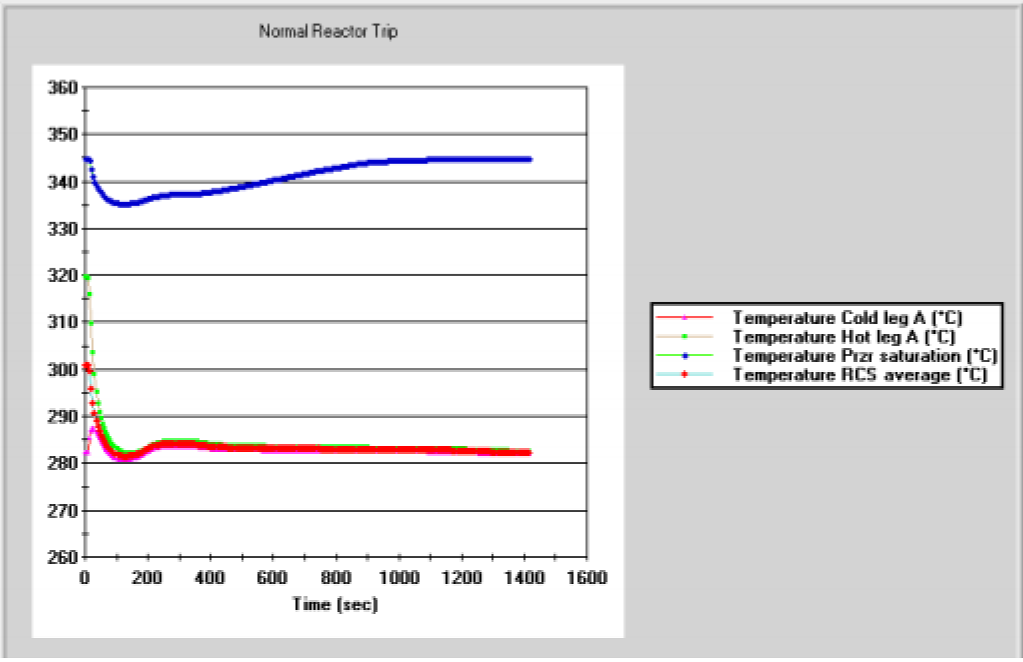
4.1.2 Normal Reactor Trip

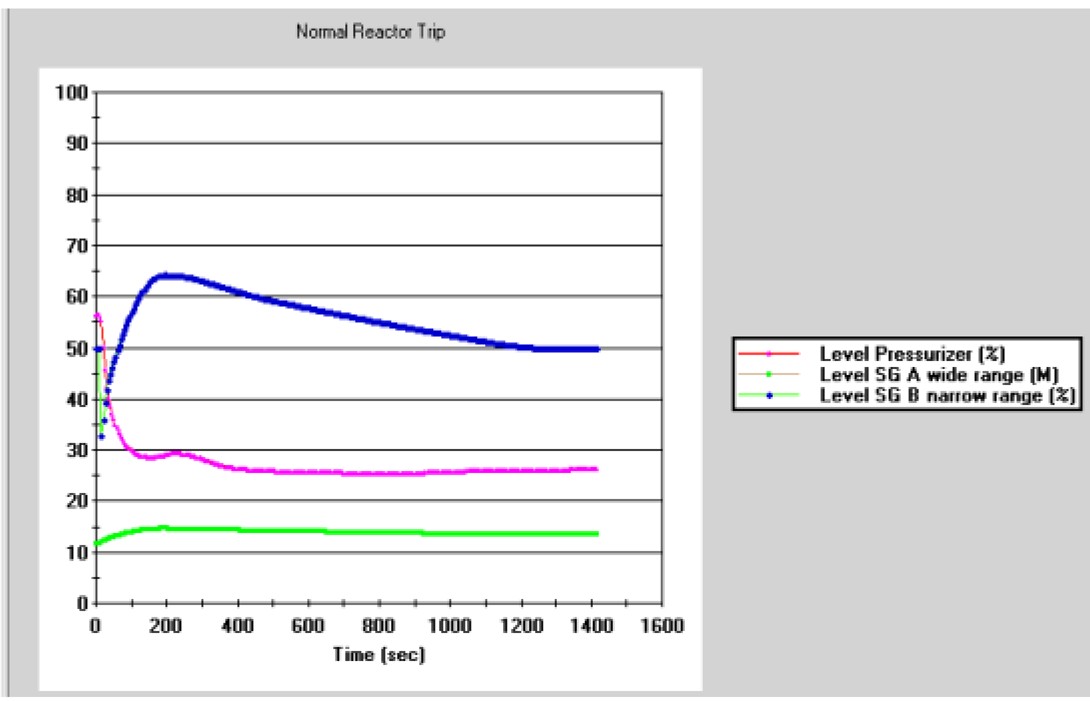
The reactor is manually scrammed after full power operation. This transient is to verify that all control systems work as designed to stabilize at the post-trip hot zero power condition.

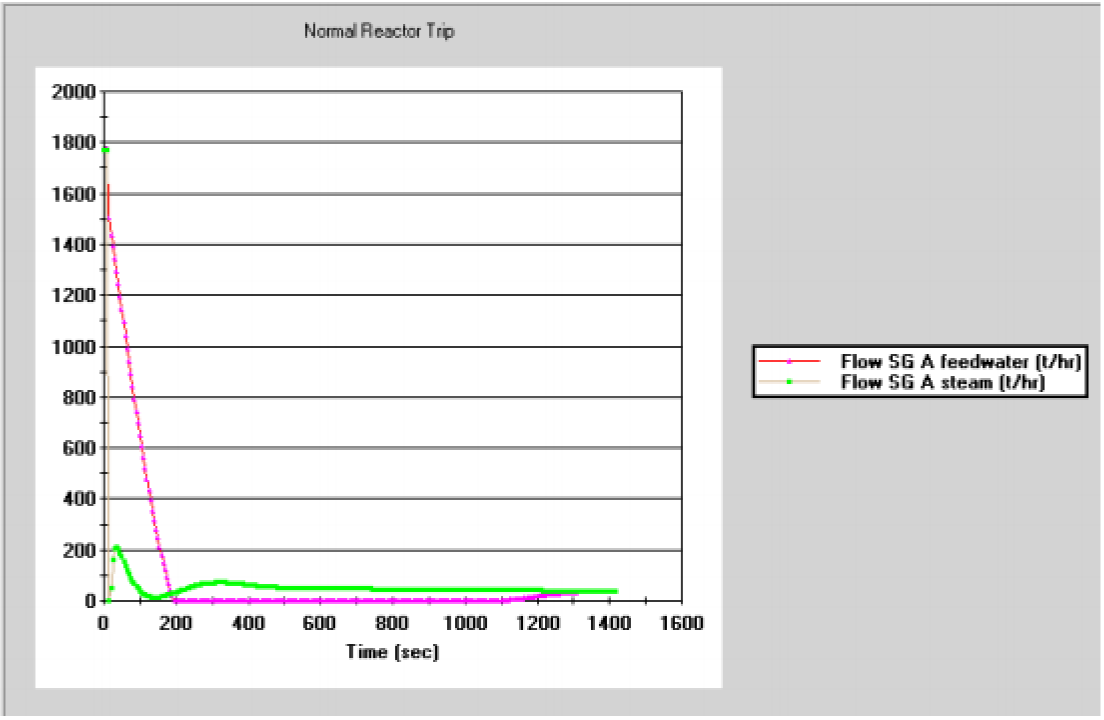
In the following plots it is noted the reactor primary pressure drops after the reactor scram. It recovers to the set point of 155 bar. The loop temperatures and the pressurizer and steam generator pressures and levels are stabilized at their corresponding post-trip set points in the control diagrams. The feedwater and steam flow rates are reduced to balance the core decay heat. Charging and letdown flows are controlled properly to maintain the pressurizer level. The reactivity feedback and scram (rod) reactivity keeps the core sub-critical with a significantly margin (about 4% dk/k).

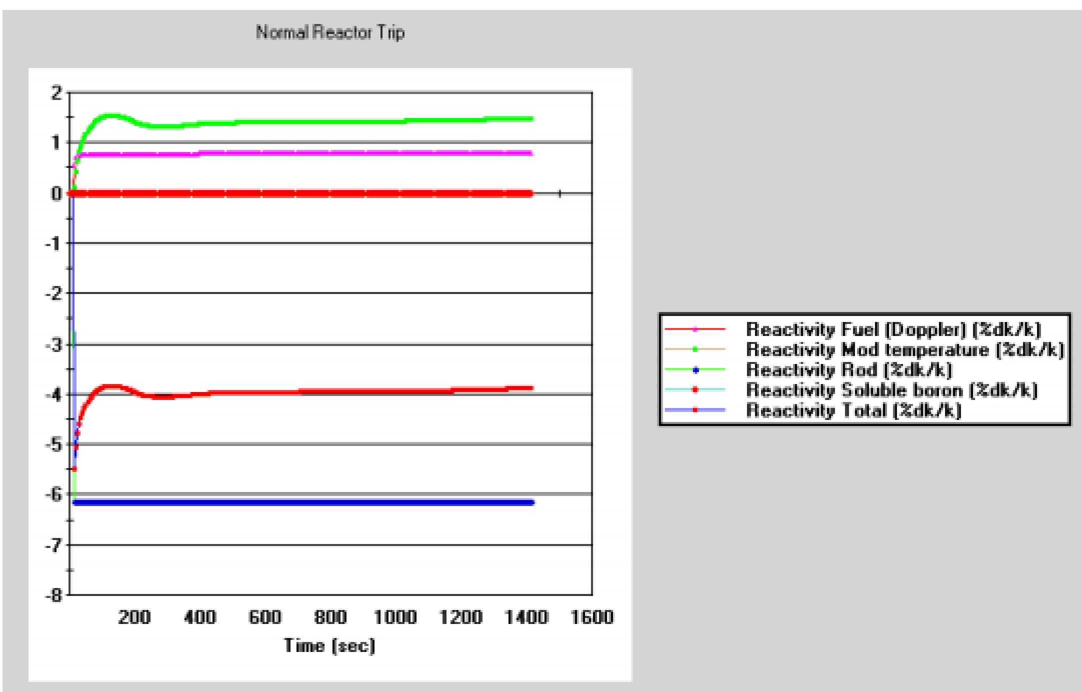

Normal Reactor Trip
120
110
100
90
80
70
60
50
40
30
20
10
0
0
200
400
600
800
1000
1200
1400
1600
Time (sec)
Power Core thermal (%)
Power Nuclear Flux (%)
Power Turbine load (%)

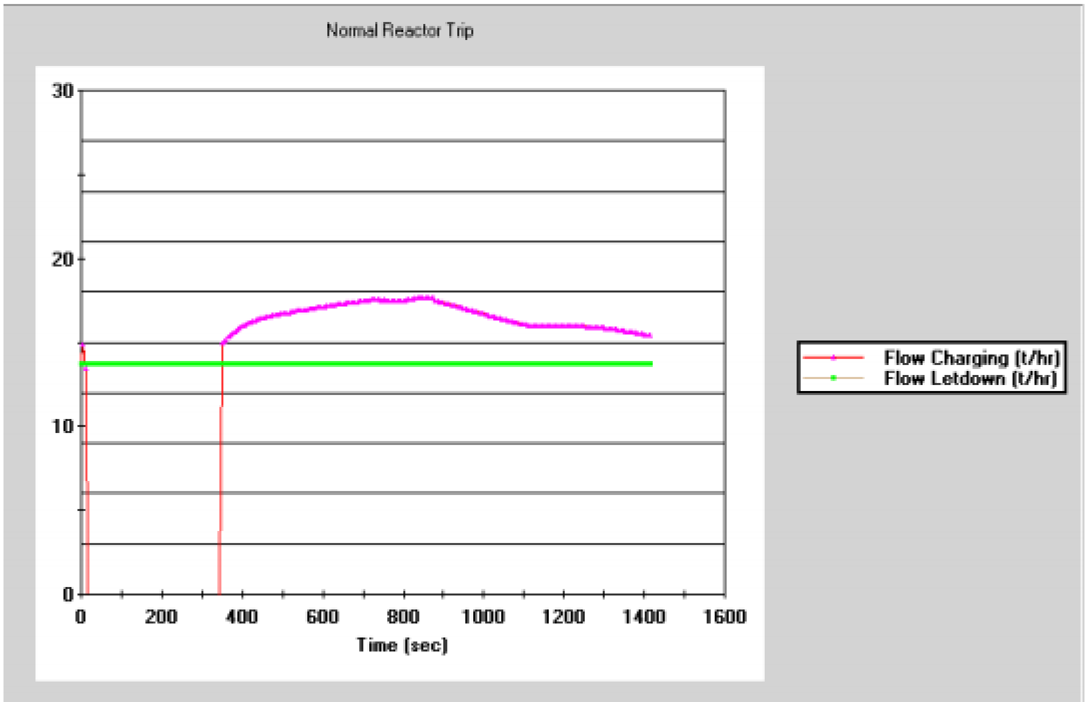

Normal Reactor Trip
200
180
160
140
120
100
80
60
40
20
0
0
200
400
600
800
1000
1200
1400
1600
Time (sec)
Press RCS (bar)
Pressure Steam generator A (bar)


Normal Reactor Trip
360
350
340
330
320
310
300
290
280
270
260
0
200
400
600
800
1000
1200
1400
1600
Time (sec)
Temperature Cold leg A (°C)
Temperature Hot leg A (°C)
Temperature Przr saturation (°C)
Temperature RCS average (°C)


Normal Reactor Trip
100
90
80
70
60
50
40
30
20
10
0
0
200
400
600
800
1000
1200
1400
1600
Time (sec)
Level Pressurizer (%)
Level SG A wide range (M)
Level SG B narrow range (%)


Normal Reactor Trip
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
200
400
600
800
1000
1200
1400
1600
Time (sec)
Flow SG A feedwater (t/hr)
Flow SG A steam (t/hr)


Normal Reactor Trip
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
200
400
600
800
1000
1200
1400
1600
Time (sec)
Reactivity Fuel (Doppler) (%dk/k)
Reactivity Mod temperature (%dk/k)
Reactivity Rod (%dk/k)
Reactivity Soluble boron (%dk/k)
Reactivity Total (%dk/k)

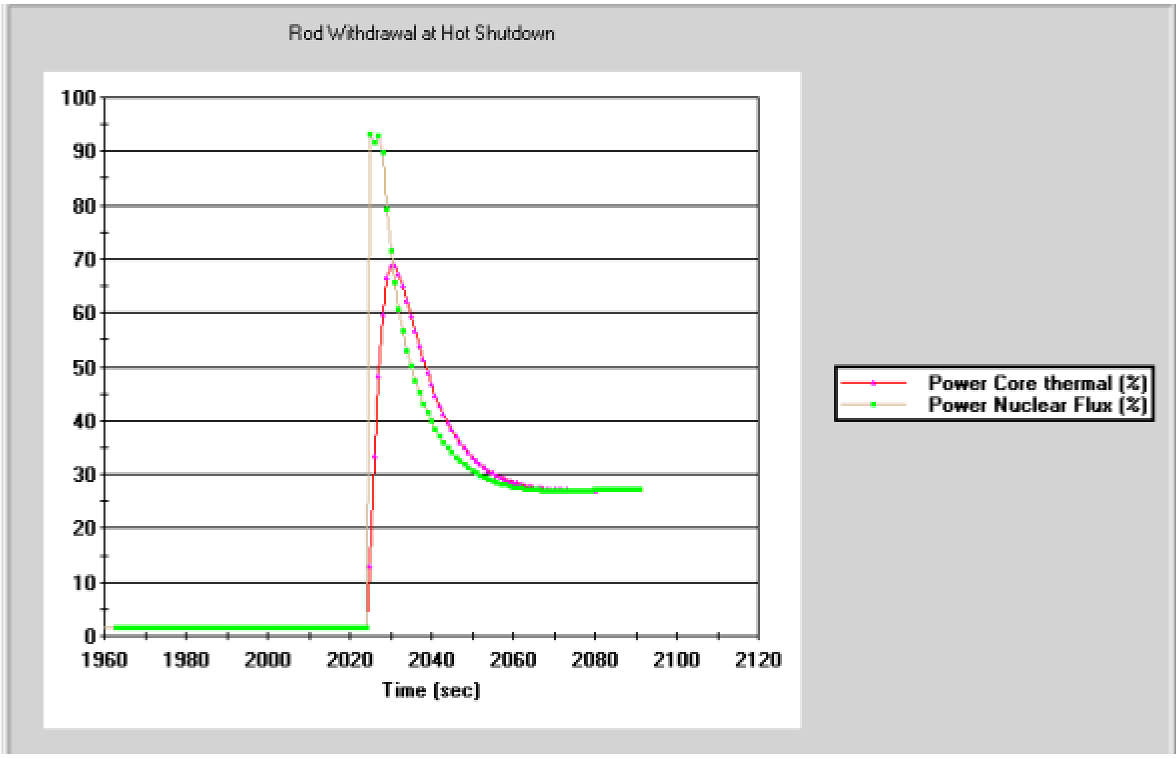


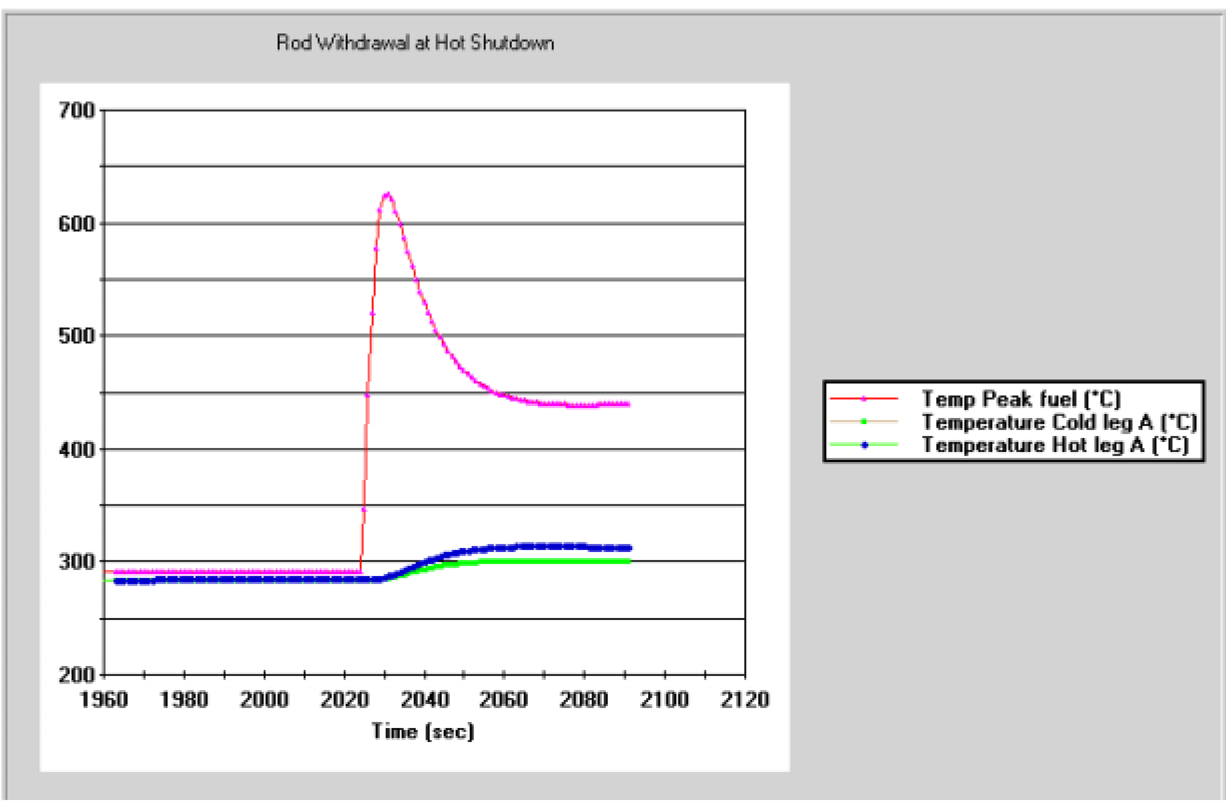
4.2 Transient and Accident Analyses

Transient benchmark analysis

Event	Initial Condition	Malfunction	Interactive Control	Run Time (Seconds)	Output
Uncontrolled Rod Withdrawal (Subcritical)	7	12 (40 sec ramp, 600% failure)	None	60	Neutron Flux, % power, fuel temp, peak clad temp, average coolant temp.
Uncontrolled Rod Withdrawal (Fast)	3	12 (100 sec ramp, 600% failure)	None	20	Neutron Flux, pressure, DNBR, average coolant temp.
Uncontrolled Rod Withdrawal (Slow)	3	12 (100 sec ramp, 25% failure	None	120	Neutron Flux, pressure, DNBR, average coolant temp.
Hot Full Power Rod Drop	1	13 (3 sec ramp, 63% failure)	None	120	Neutron Flux, % power, pressure, average coolant temp, steam flow
Moderator Dilution	1	14 (500 sec ramp, 50% failure)	None	480	Neutron flux, pressure, DNBR
Loss of Flow – 1 RCP Trip	3	None	Trip 1 pump	30	Loop flow, neutron flux, % power, DNBR
Loss of Flow – 4 RCP Trip	3	None	Trip 2 pumps	100	Loop flow, neutron flux, % power, DNBR
Locked Rotor	3	7	None	20	Loop flow, pressure, DNBR
Startup of Inactive Loop	11	None	Start idle RCP	60	Neutron Flux, pressure, average coolant temp
Turbine Trip	1 and 3	None	Disable TBV, trip the turbine	25	Neutron Flux, pressure, average coolant temp, DNBR, power, pressurizer level
Loss of Feedwater	1	5	Disable TBV, 1 aux feed pump	400	Pressurizer level, average coolant temp, SG level
Reduction in Feedwater Enthalpy	1	None	Change HMFW to 900 kJ/kg	100	Power, average coolant temperature, pressure, DNBR

4.2.1 Uncontrolled Rod Bank Withdrawal





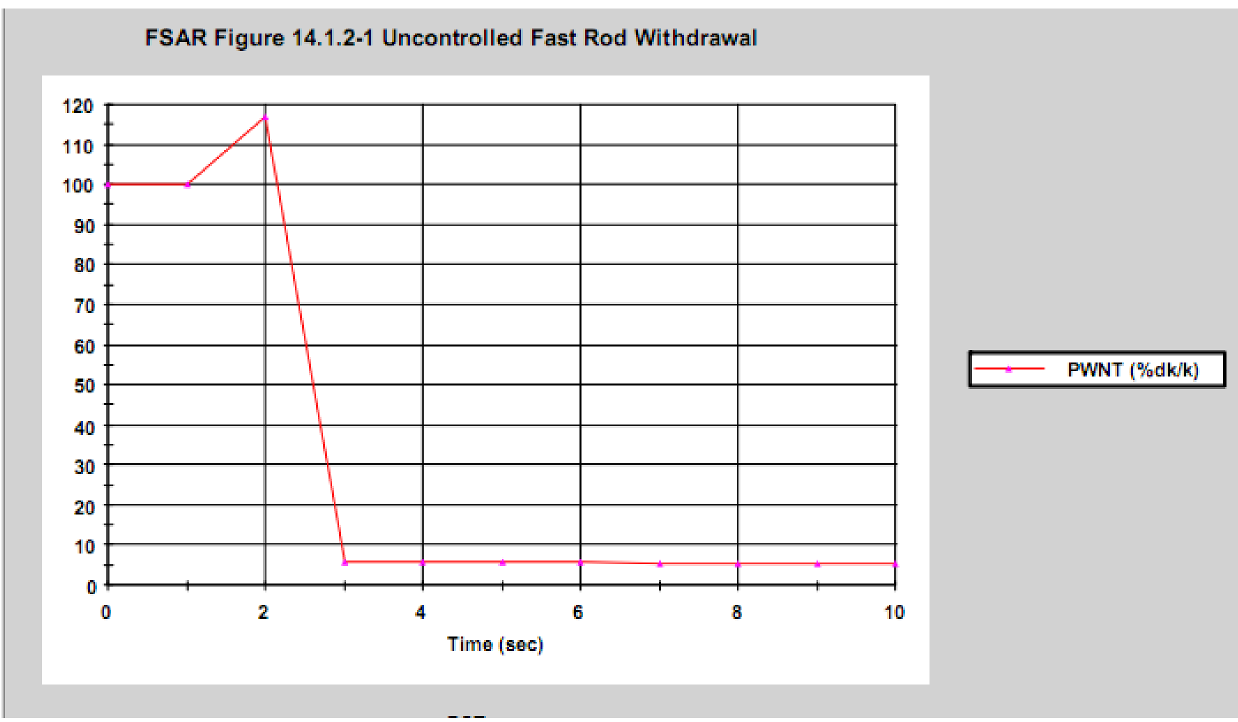
4.2.1.1 Hot Full Power Fast Rod Withdrawal :

In the FSAR, the fast withdrawal of a rod at power results in the reactivity insertion of $6 \times 10^{-4}\Delta k$/sec. This uncontrolled withdrawal results in an increase in core heat flux, which causes average RCS temperature to increase. The transient is terminated by a reactor trip at 118% neutron flux.

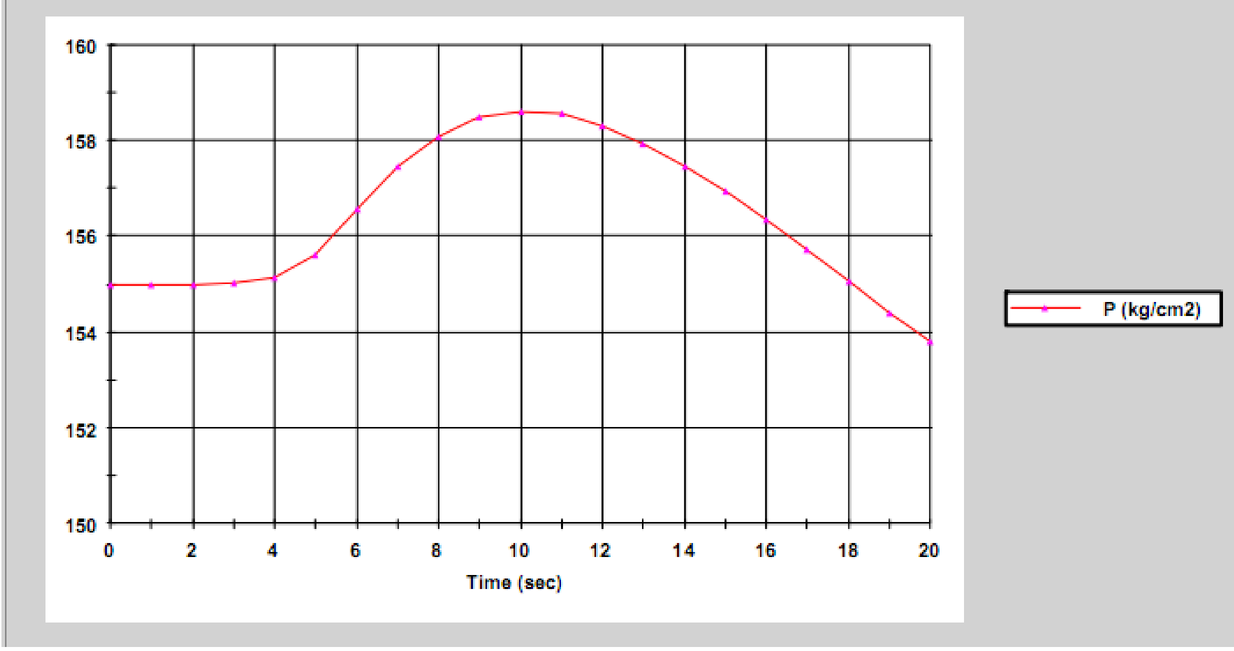
The case is benchmarked in PCTRAN by selecting a beginning of life full power initial condition (IC #3). This IC uses a zero moderator coefficient, which was specified in the FSAR. Malfunction 12 was selected with a ramp time of 100 seconds and a reactivity insertion of 6% to produce the desired reactivity insertion rate. Neutron flux, RCS pressure, RCS average temperature, and DNB ratio are plotted for comparison to the FSAR.

4.2.1.2 Hot Full Power Slow Rod Withdrawal :

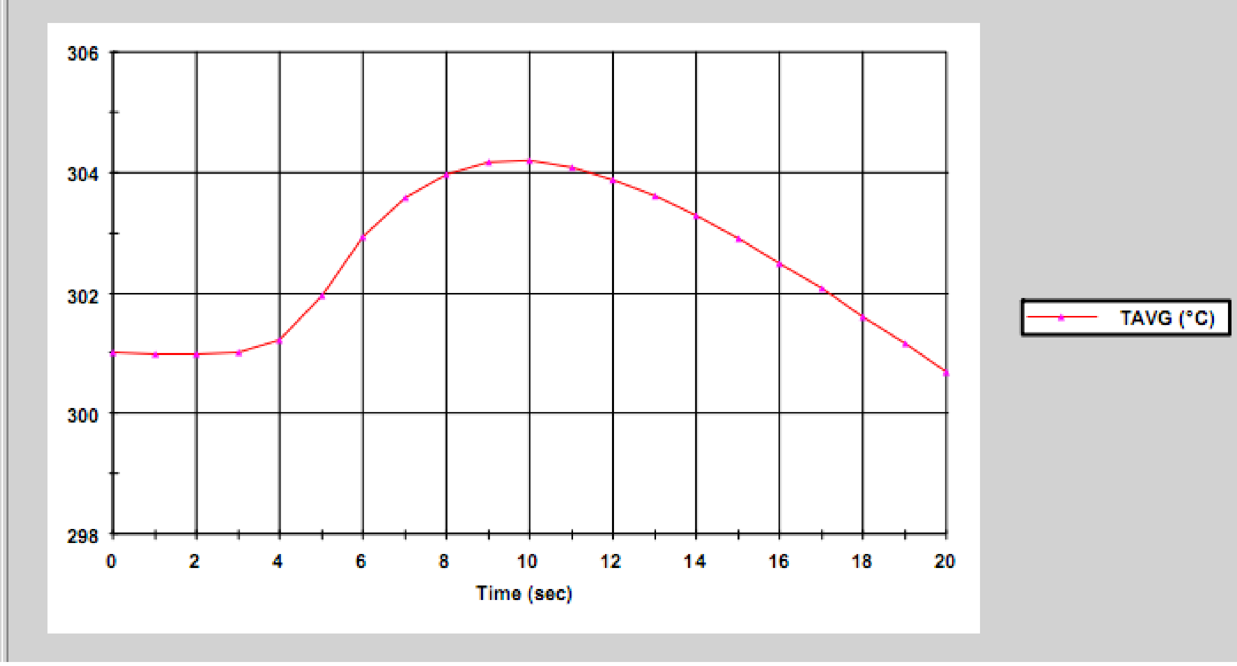
For this case, a reactivity insertion rate of 2.5×10^{-5} Δk/sec was specified. In PCTRAN, this is simulated by selecting Malfunction 12 with a reactivity insertion of .25% over 100 seconds. Neutron flux, RCS pressure, RCS average temperature, and DNB ratio are plotted for comparison to the FSAR.

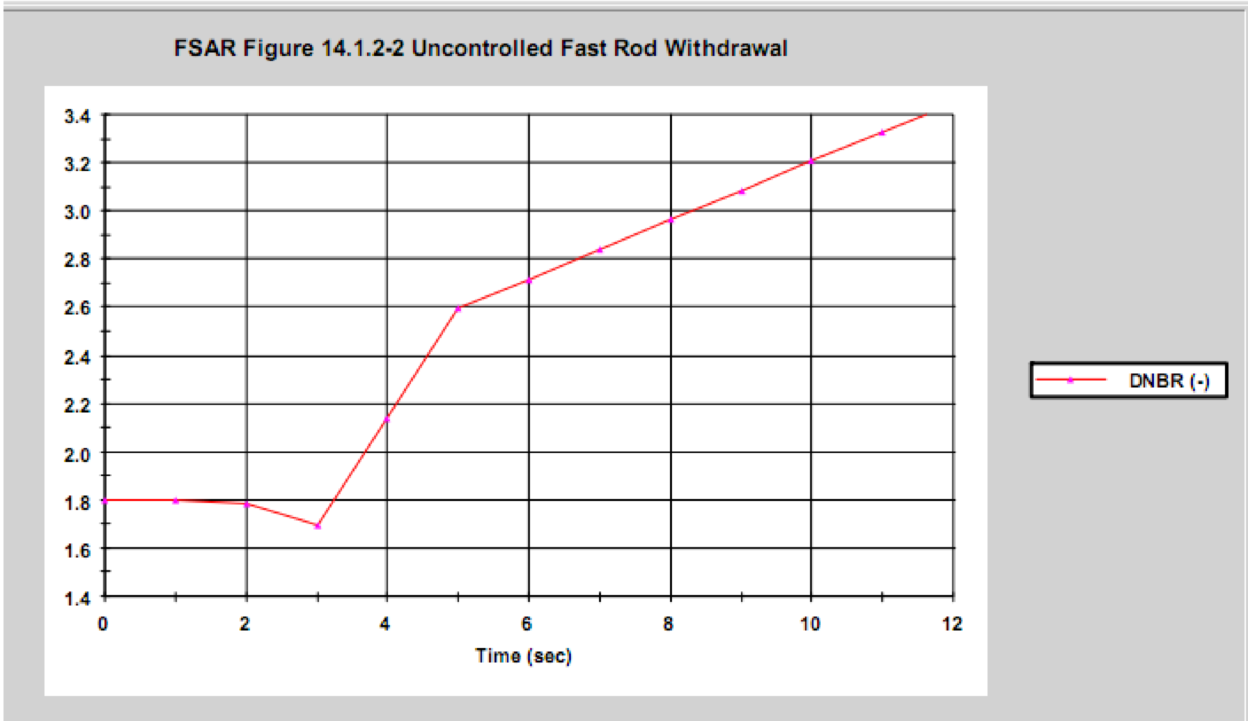


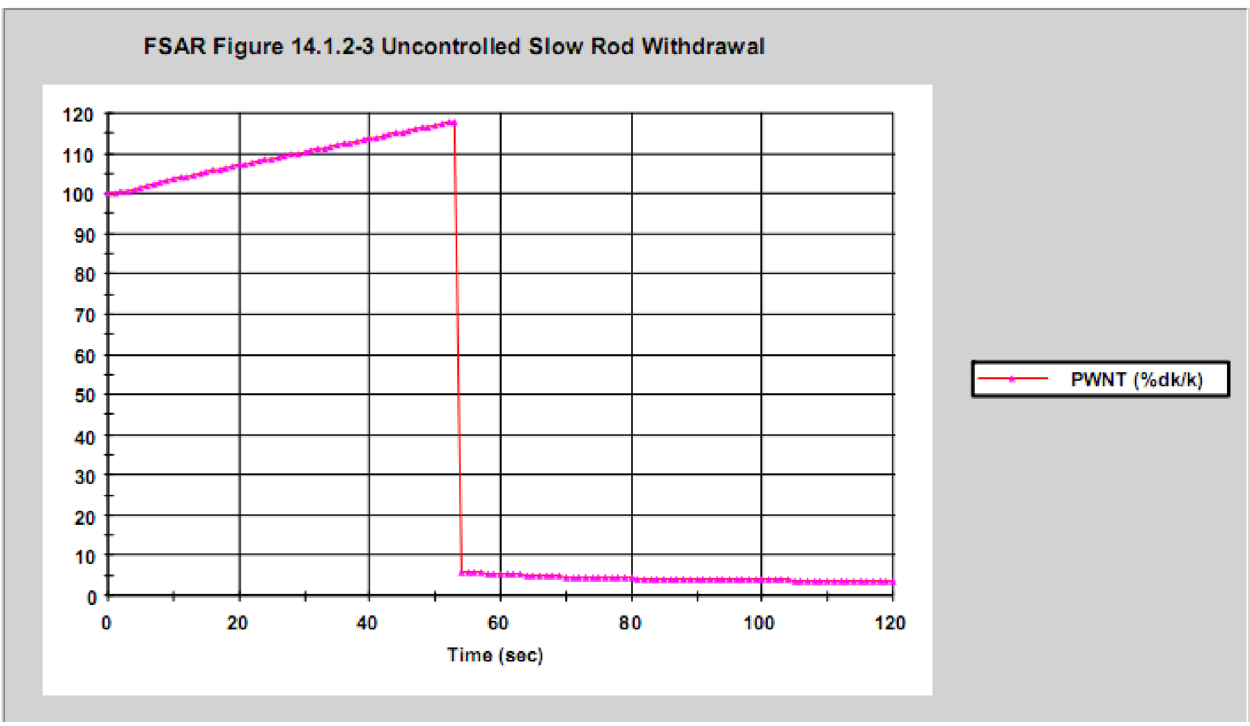
FSAR Figure 14.1.2-1 Uncontrolled Fast Rod Withdrawal

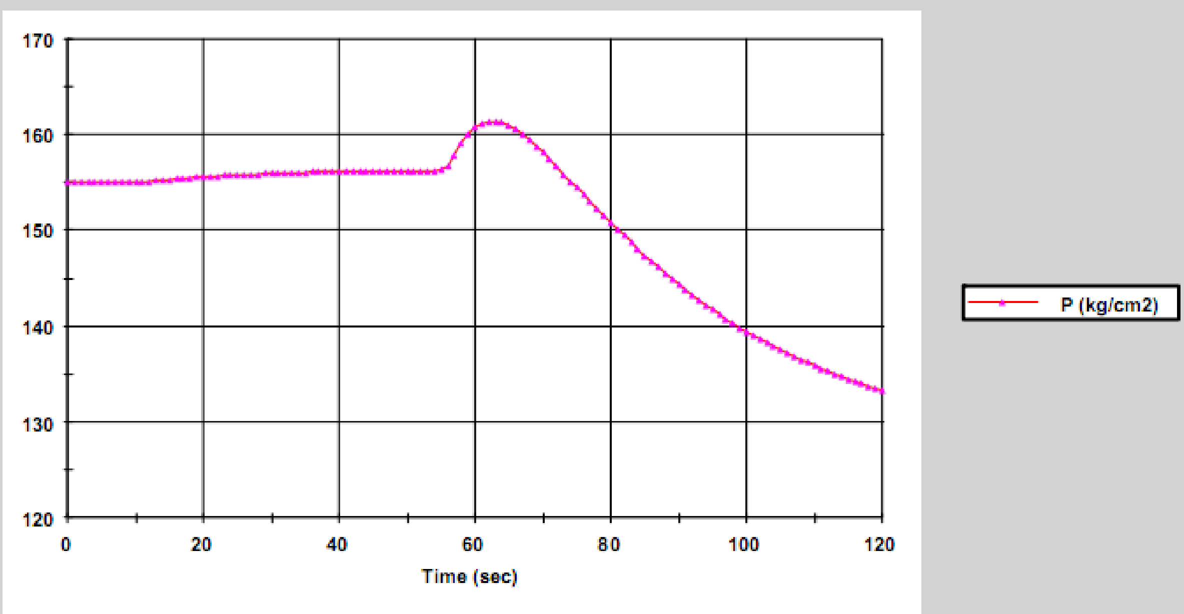


FSAR Figure 14.1.2-2 Uncontrolled Fast Rod Withdrawal

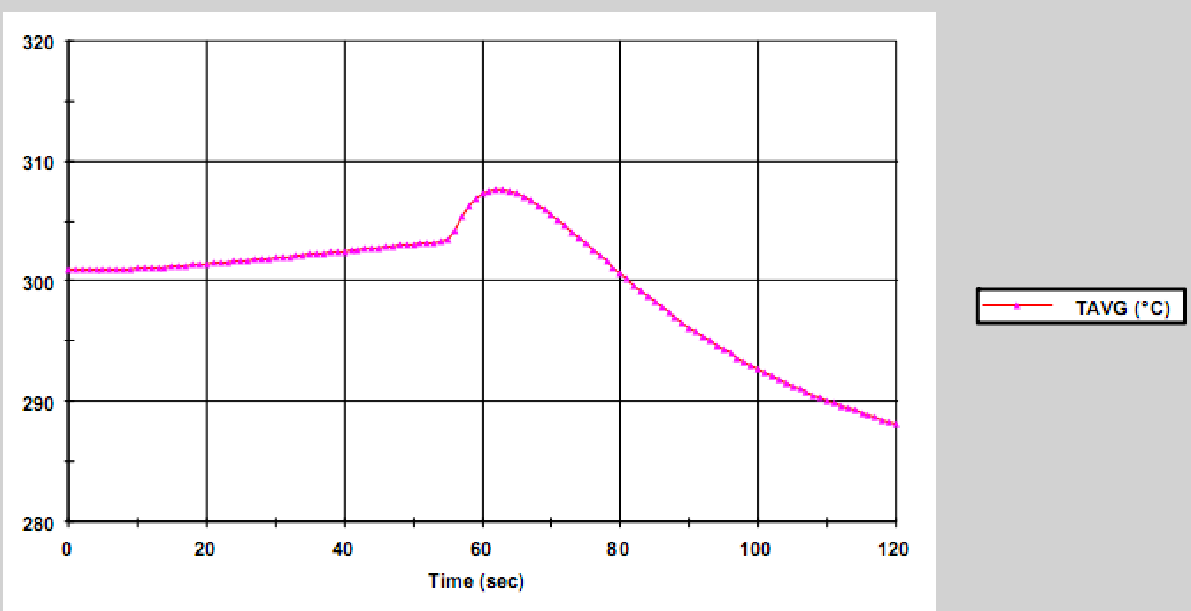



FSAR Figure 14.1.2-2 Uncontrolled Fast Rod Withdrawal
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
0
2
4
6
8
10
12
Time (sec)
DNBR (-)

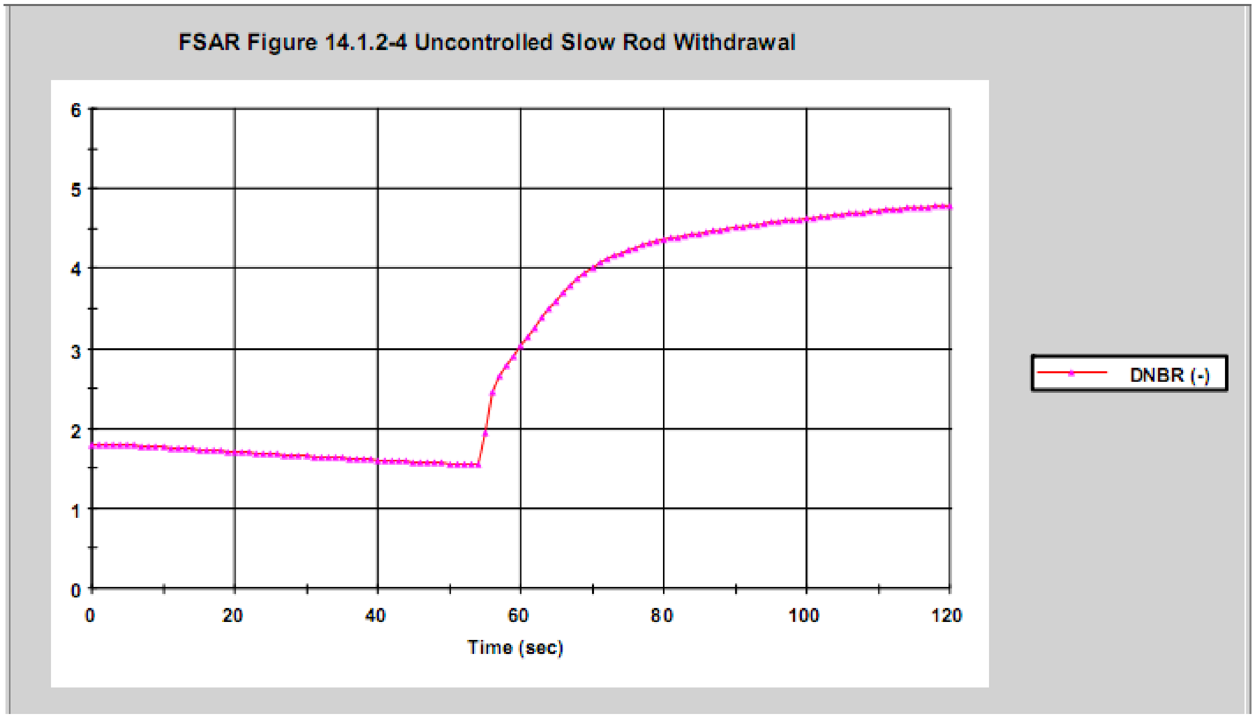

FSAR Figure 14.1.2-3 Uncontrolled Slow Rod Withdrawal
120
110
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
Time (sec)
PWNT (%dk/k)



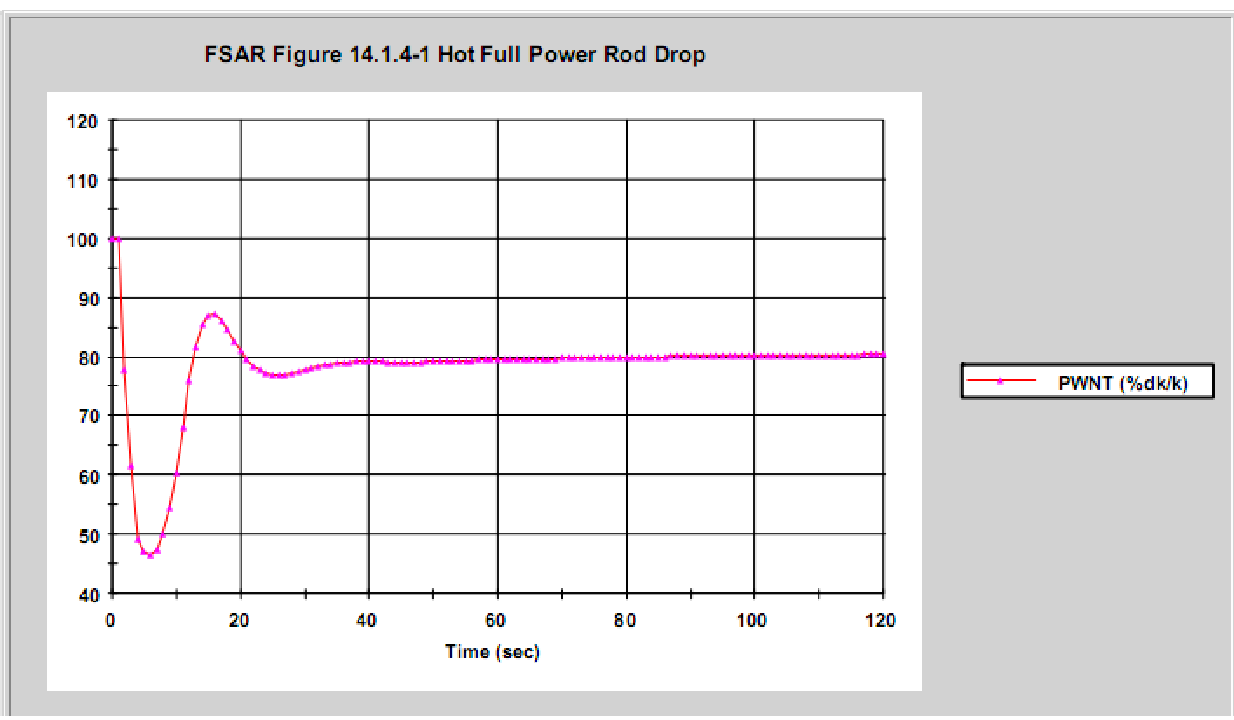
FSAR Figure 14.1.2-3 Uncontrolled Slow Rod Withdrawal

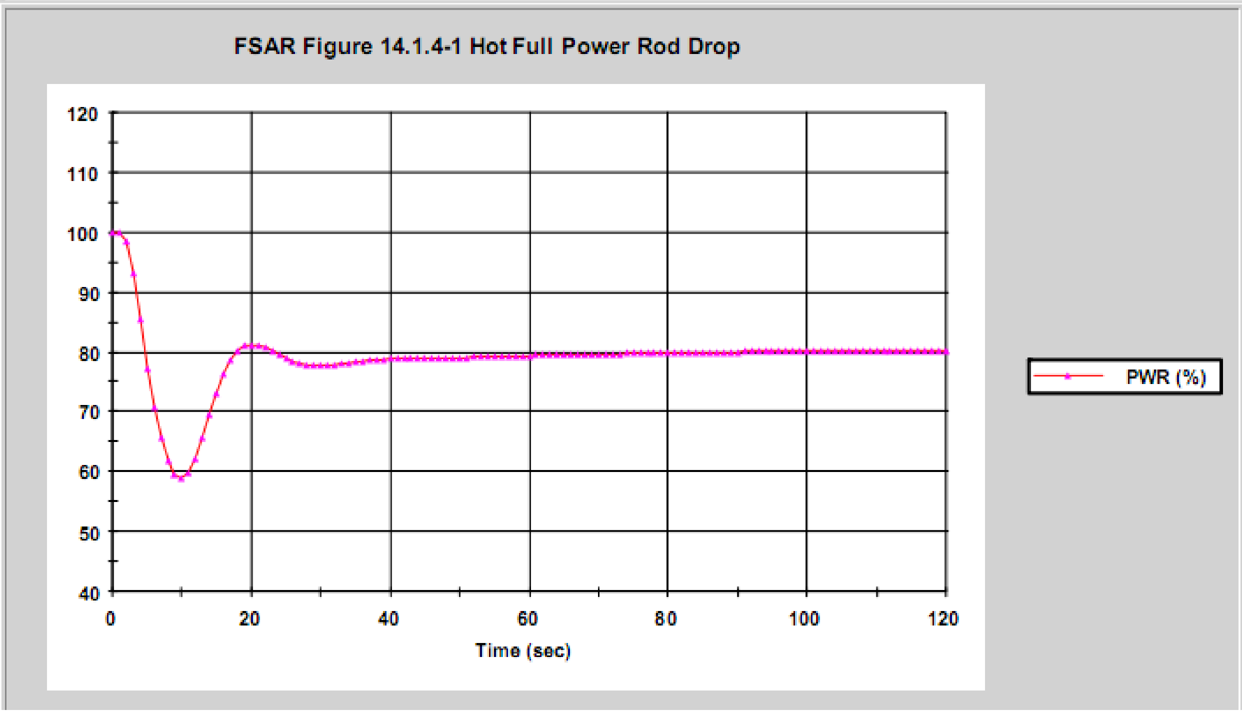


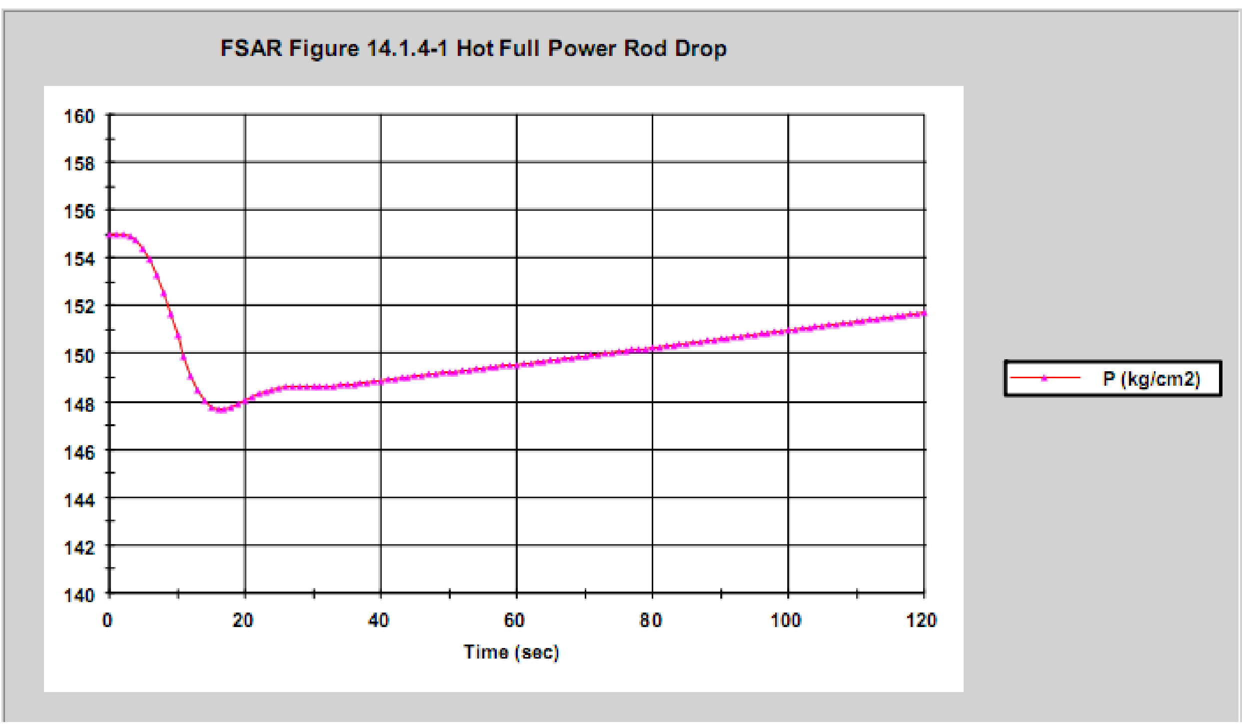
FSAR Figure 14.1.2-4 Uncontrolled Slow Rod Withdrawal

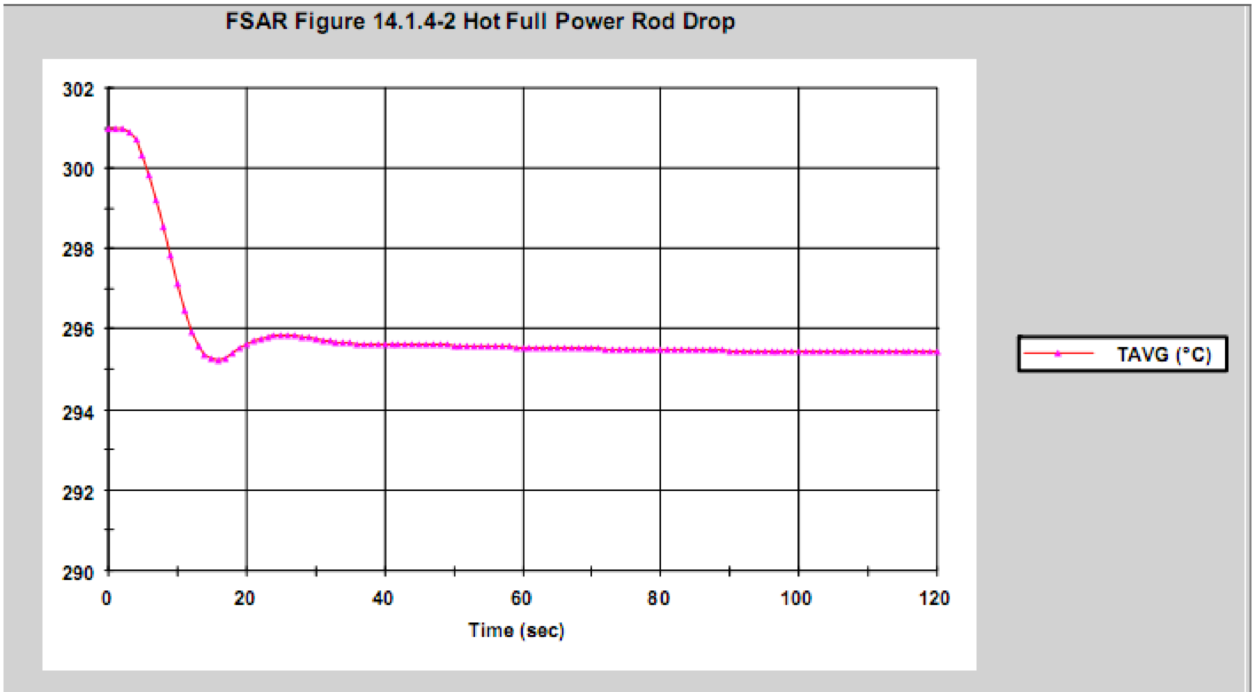


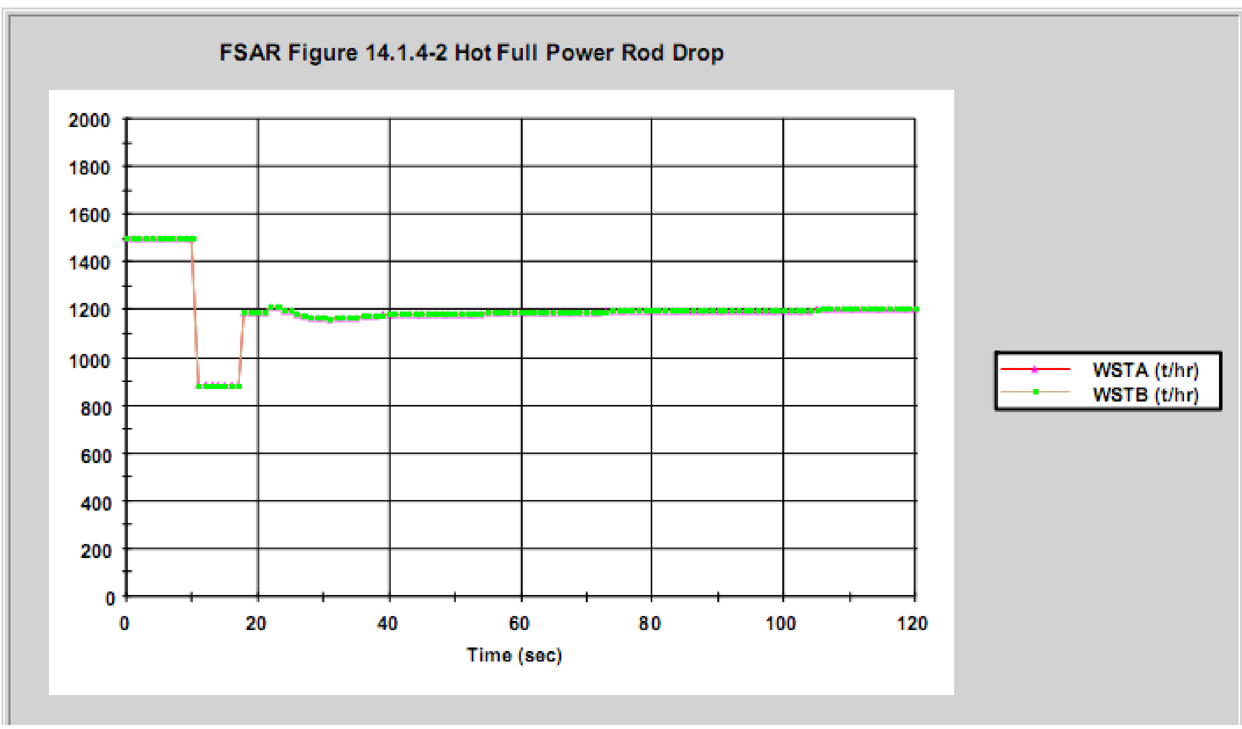
4.2.2 Hot Full Power Rod Drop :



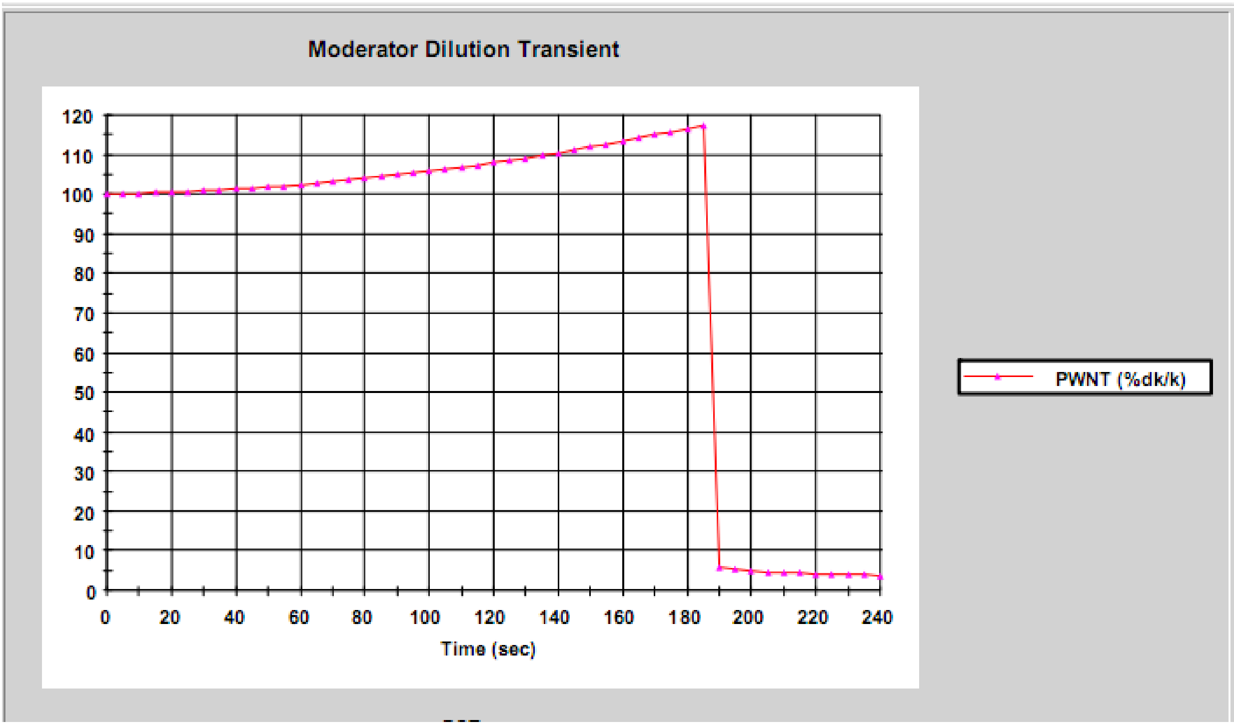

FSAR Figure 14.1.4-1 Hot Full Power Rod Drop
120
110
100
90
80
70
60
50
40
0
20
40
60
80
100
120
Time (sec)
PWR (%)

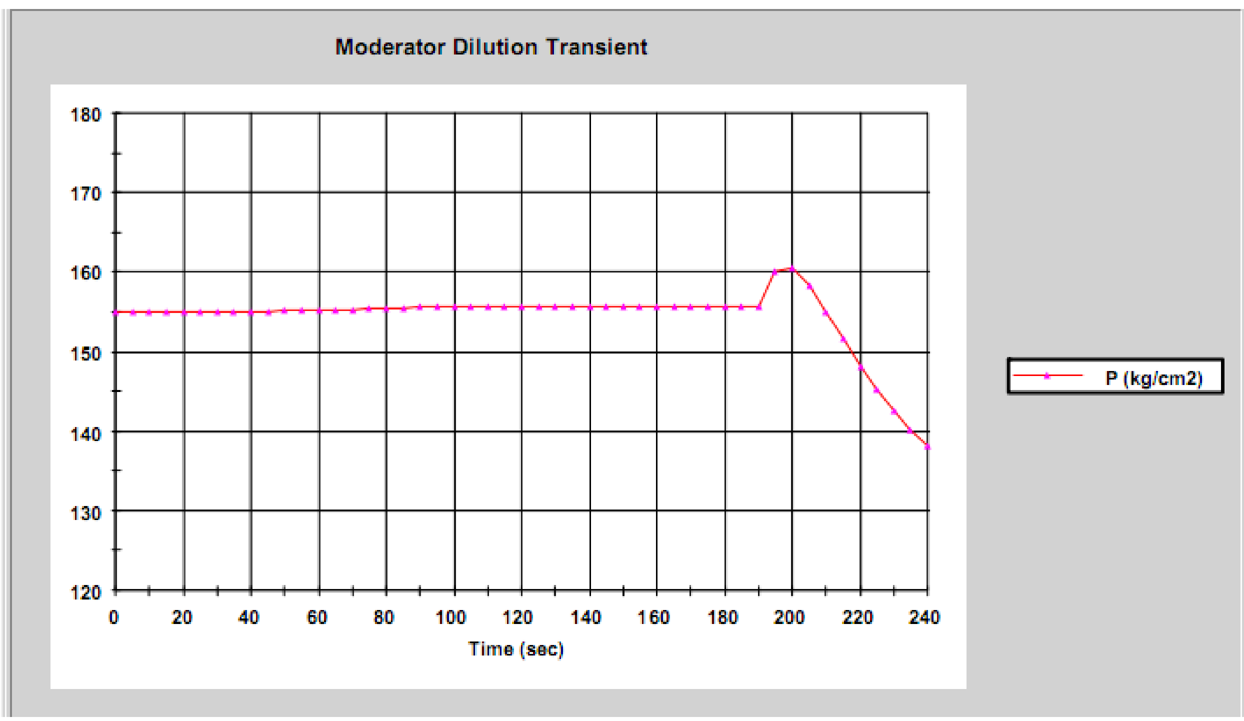

FSAR Figure 14.1.4-1 Hot Full Power Rod Drop
160
158
156
154
152
150
148
146
144
142
140
0
20
40
60
80
100
120
Time (sec)
P (kg/cm2)

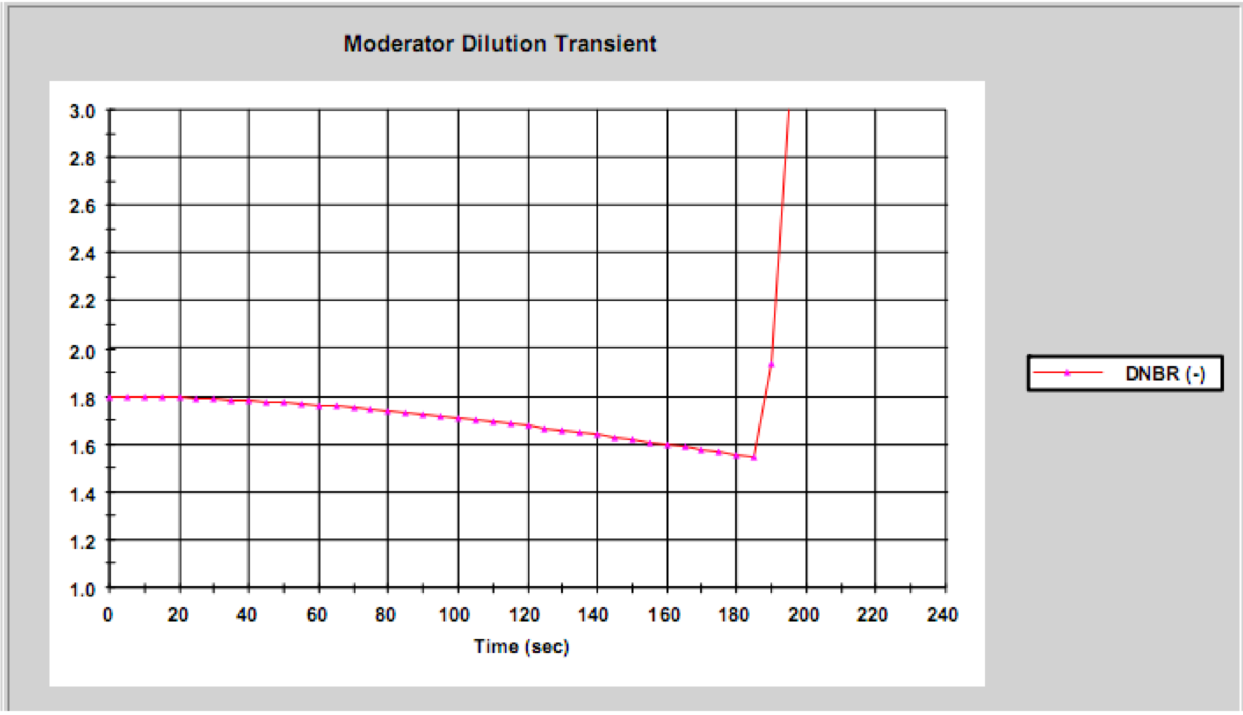




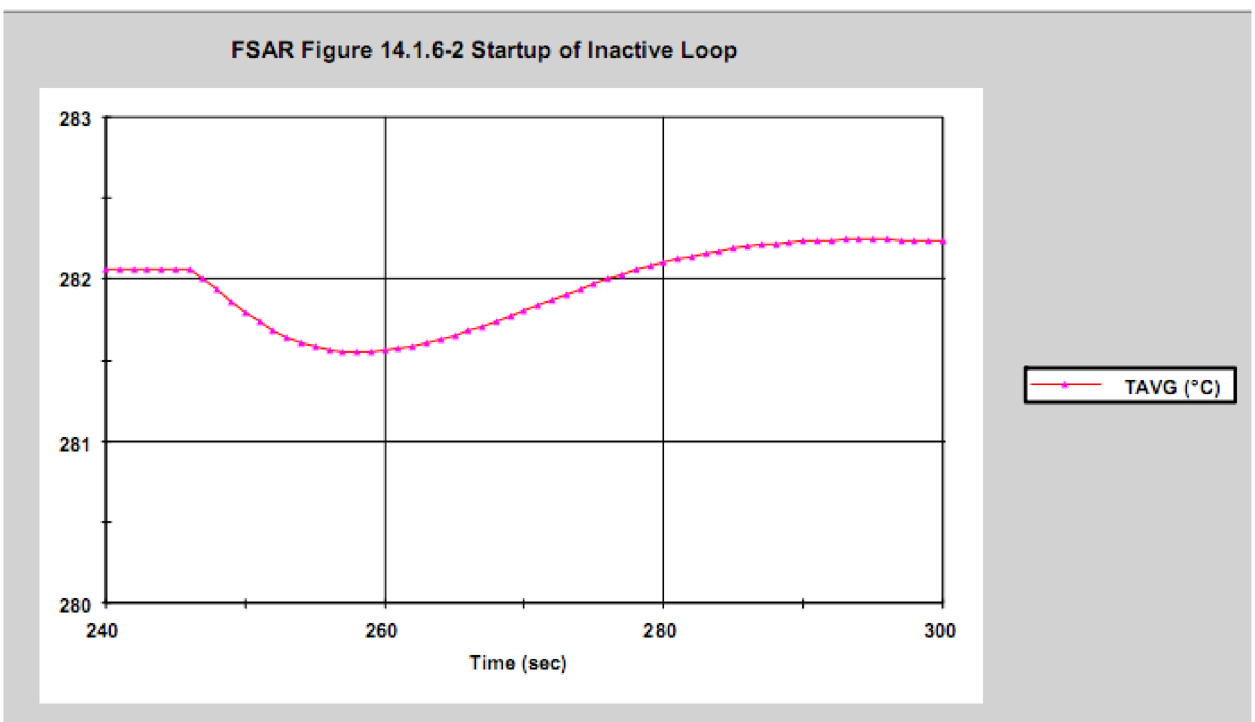
4.2.3 Moderator Dilution :


Moderator Dilution Transient
120
110
100
90
80
70
60
50
40
30
20
10
0
0 20 40 60 80 100 120 140 160 180 200 220 240
Time (sec)
PWNT (%dk/k)

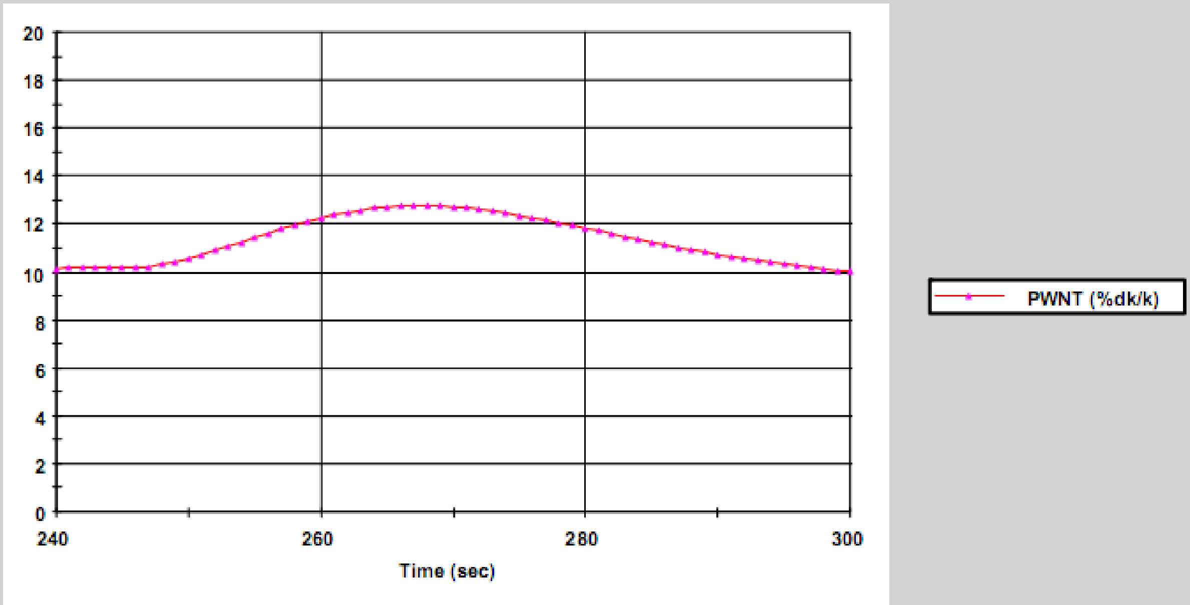

Moderator Dilution Transient
180
170
160
150
140
130
120
0 20 40 60 80 100 120 140 160 180 200 220 240
Time (sec)
P (kg/cm2)



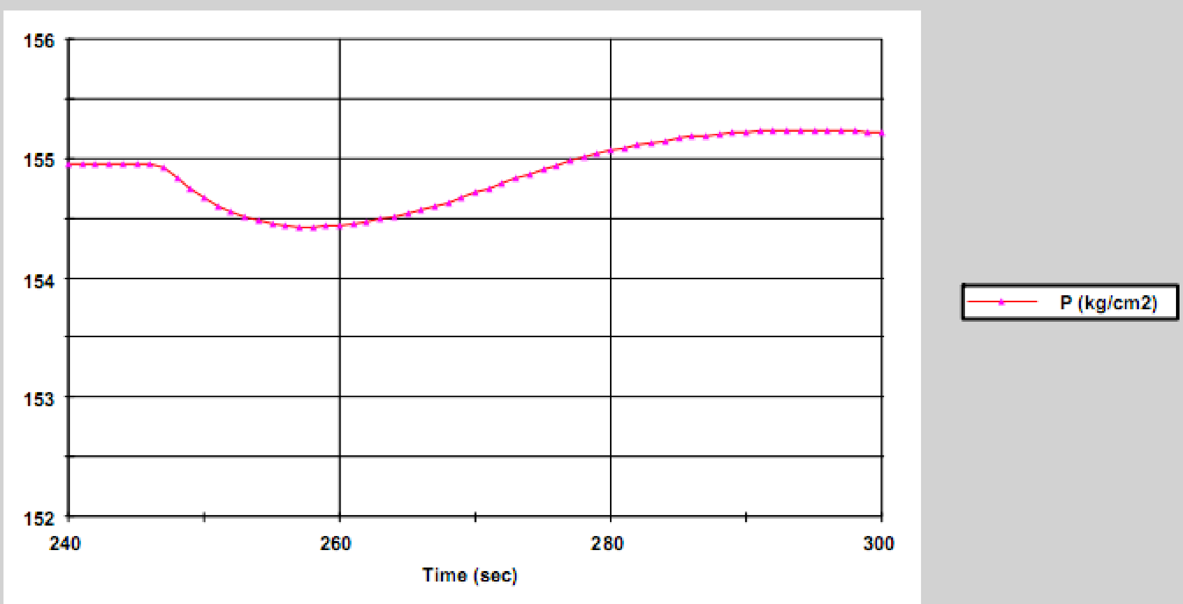
4.2.4 Startup of Inactive Loop :



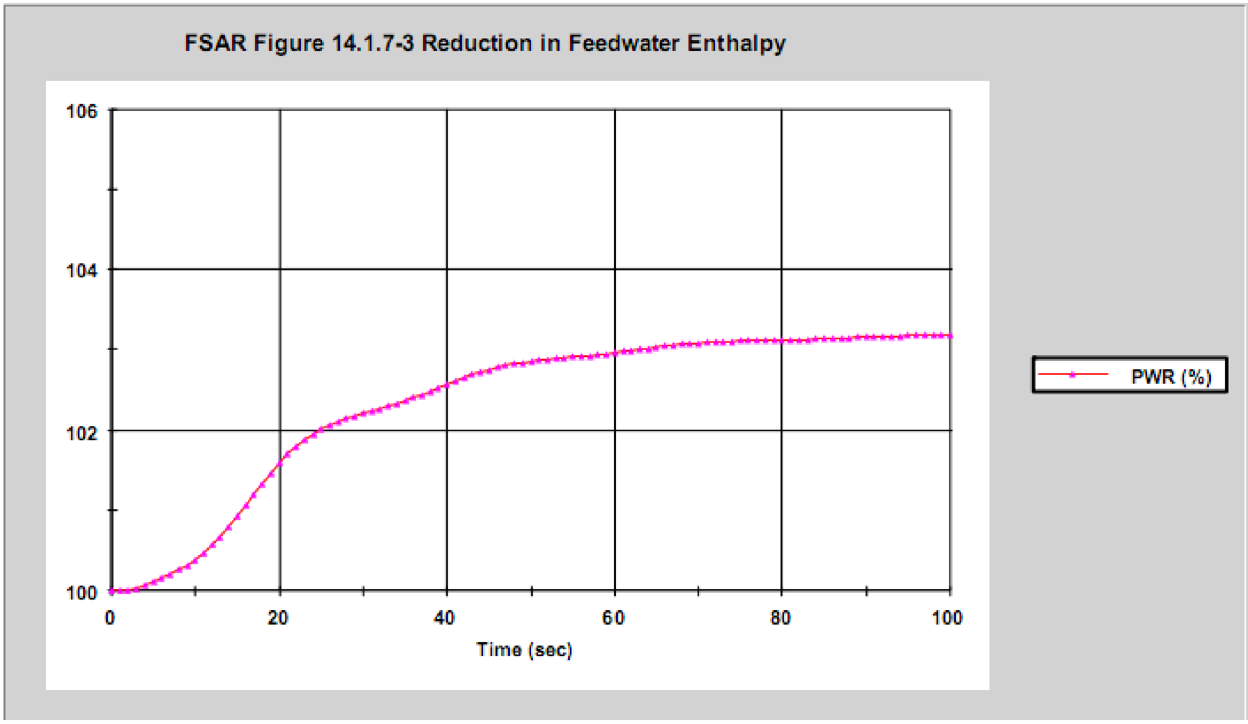
FSAR Figure 14.1.6-3 Startup of Inactive Loop

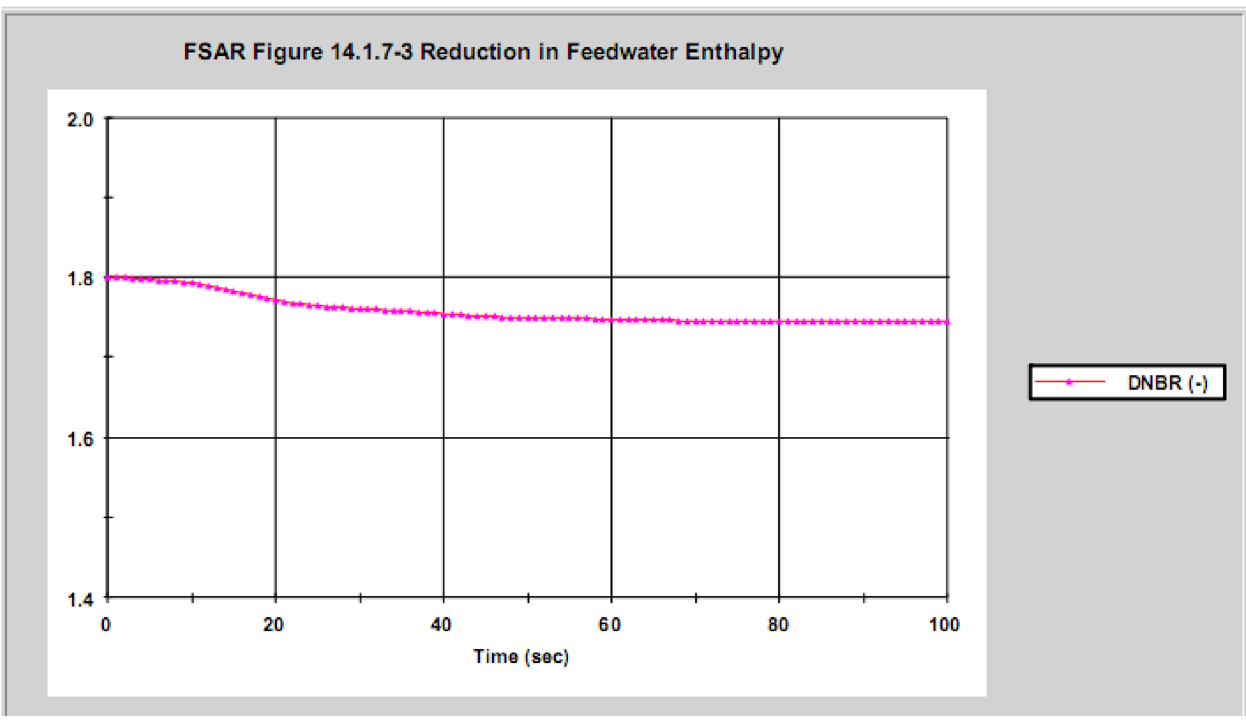


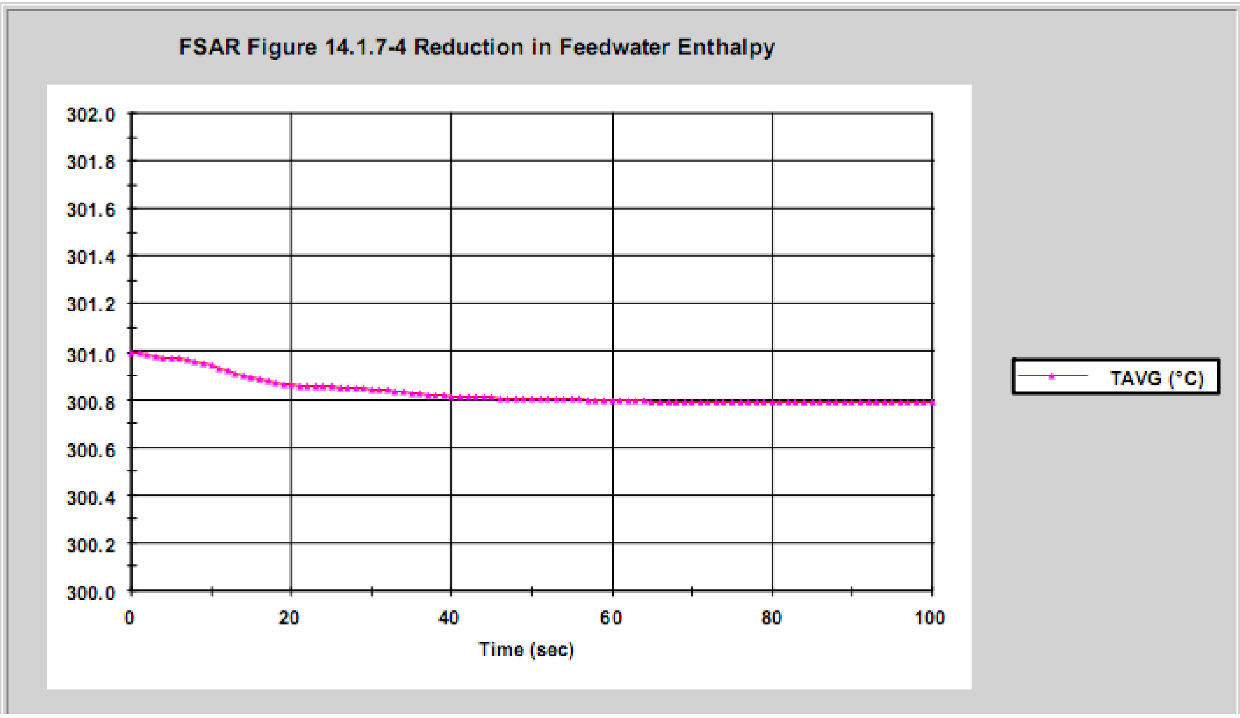
FSAR Figure 14.1.6-4 Startup of Inactive Loop

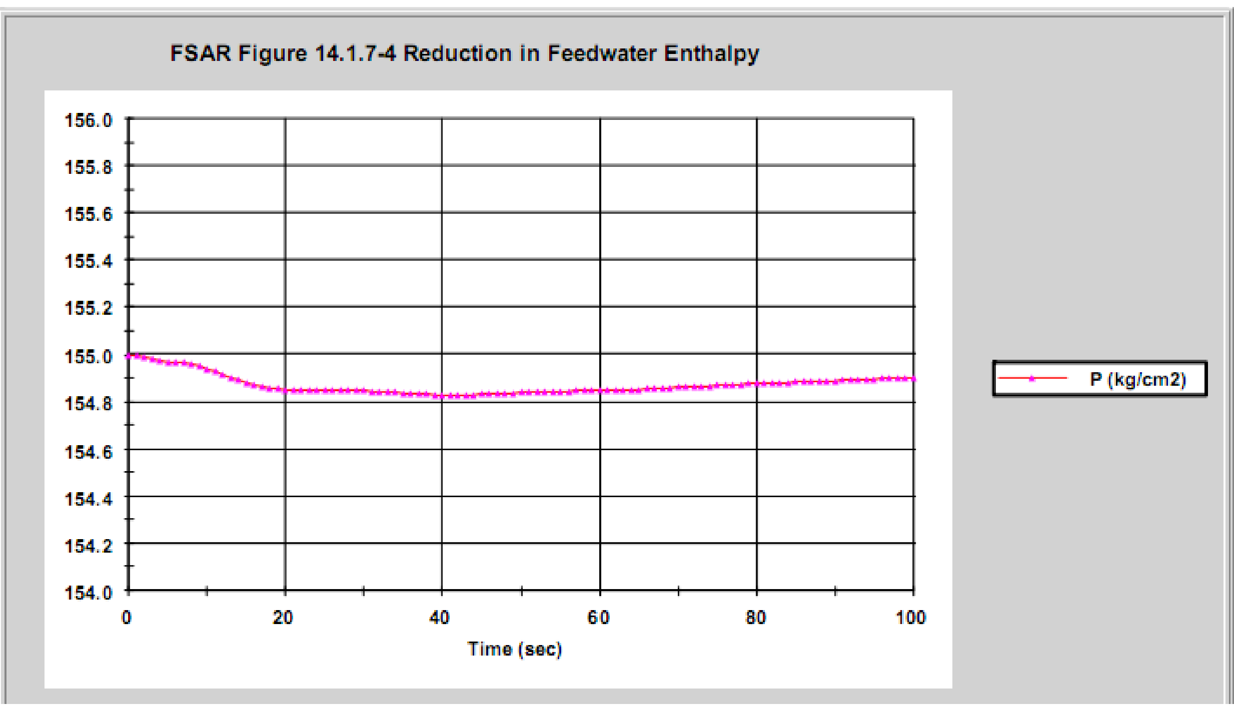


4.2.5 Reduction in Feedwater Enthalpy





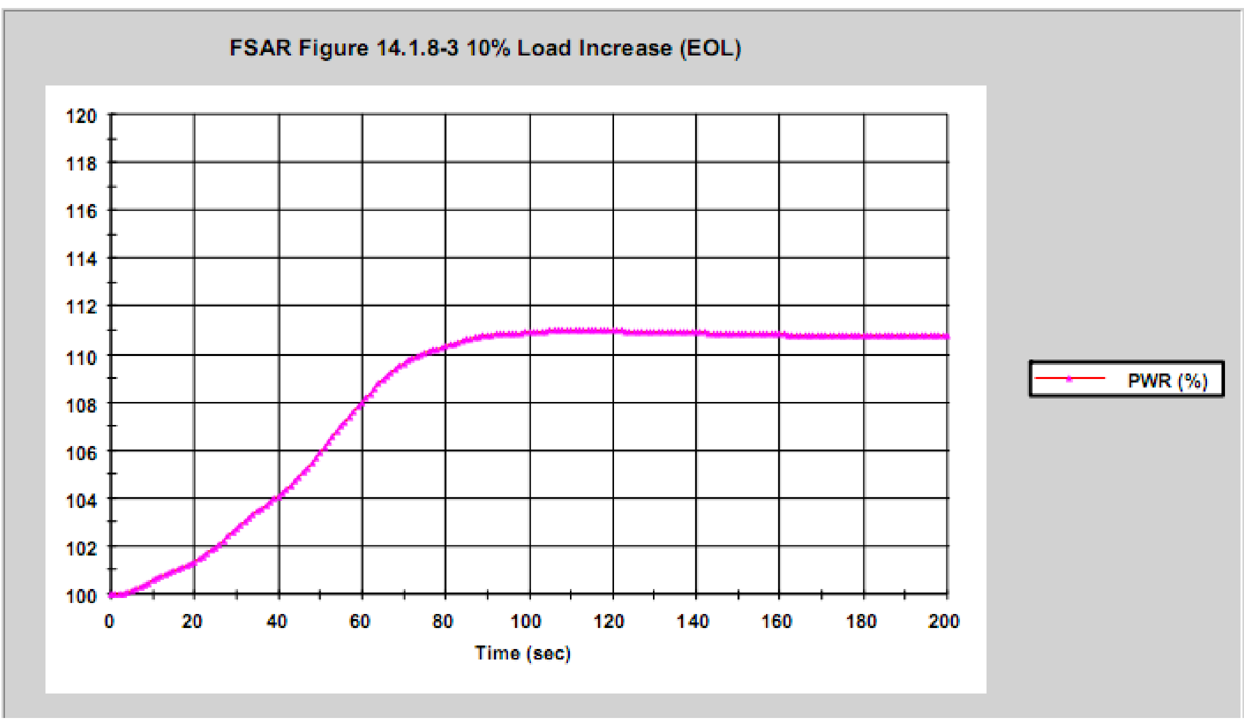

FSAR Figure 14.1.7-4 Reduction in Feedwater Enthalpy
302.0
301.8
301.6
301.4
301.2
301.0
300.8
300.6
300.4
300.2
300.0
0
20
40
60
80
100
Time (sec)
TAVG (°C)

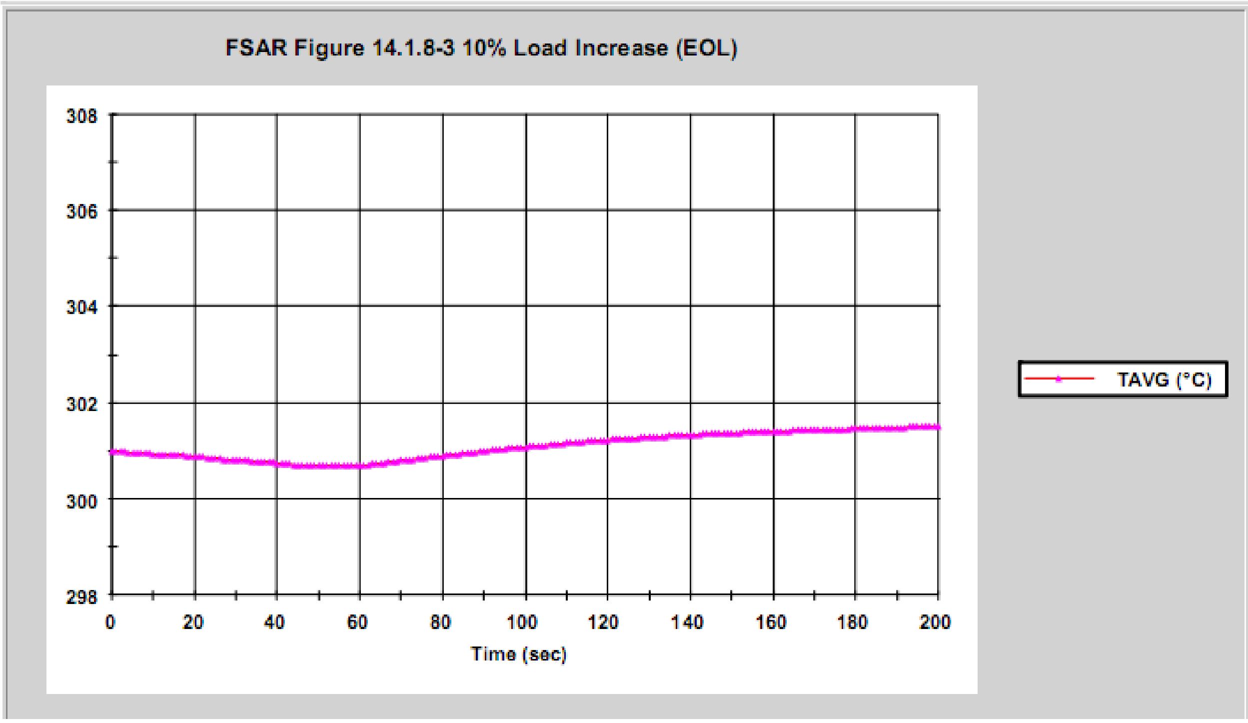

FSAR Figure 14.1.7-4 Reduction in Feedwater Enthalpy
156.0
155.8
155.6
155.4
155.2
155.0
154.8
154.6
154.4
154.2
154.0
0
20
40
60
80
100
Time (sec)
P (kg/cm2)

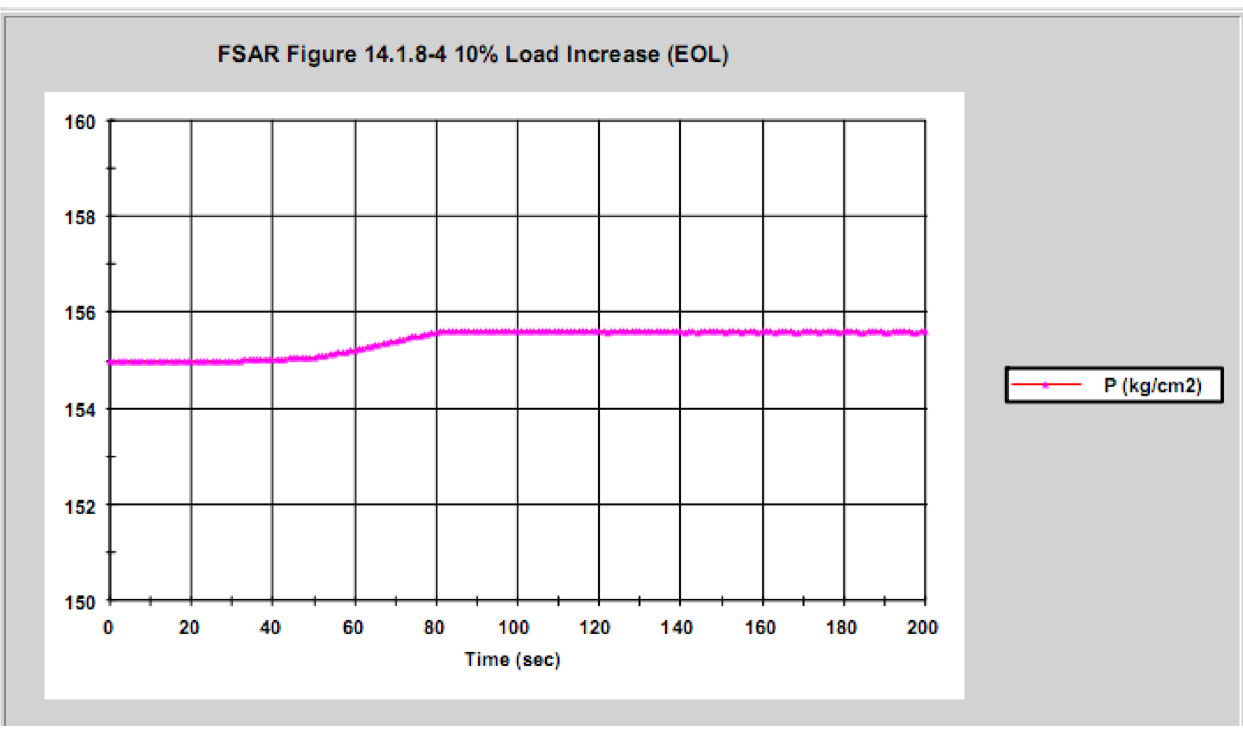
4.2.6 Excessive Load Increase

An excessive load increase incident could result from either an administrative violation such as excessive loading by the operator or an equipment malfunction in the steam dump control or turbine speed control. The reactor control system is designed to accommodate a 10 percent step load increase or a 5 percent per minute ramp load increase (without reactor trip) in the range of 15 to 100 percent of full power. Four cases are discussed in section 14.1.8 of the FSAR, but only two analyzed here. They are the ones that occur with the reactor in automatic control. The End of Life (EOL) condition involves running the transient with a large negative moderator coefficient (maximum feedback). The Beginning of Life (BOL) case uses a zero moderator coefficient (minimum feedback). Because of the feedback, the reactor responds more quickly to the increase in demand due to the reduction in core inlet temperature.

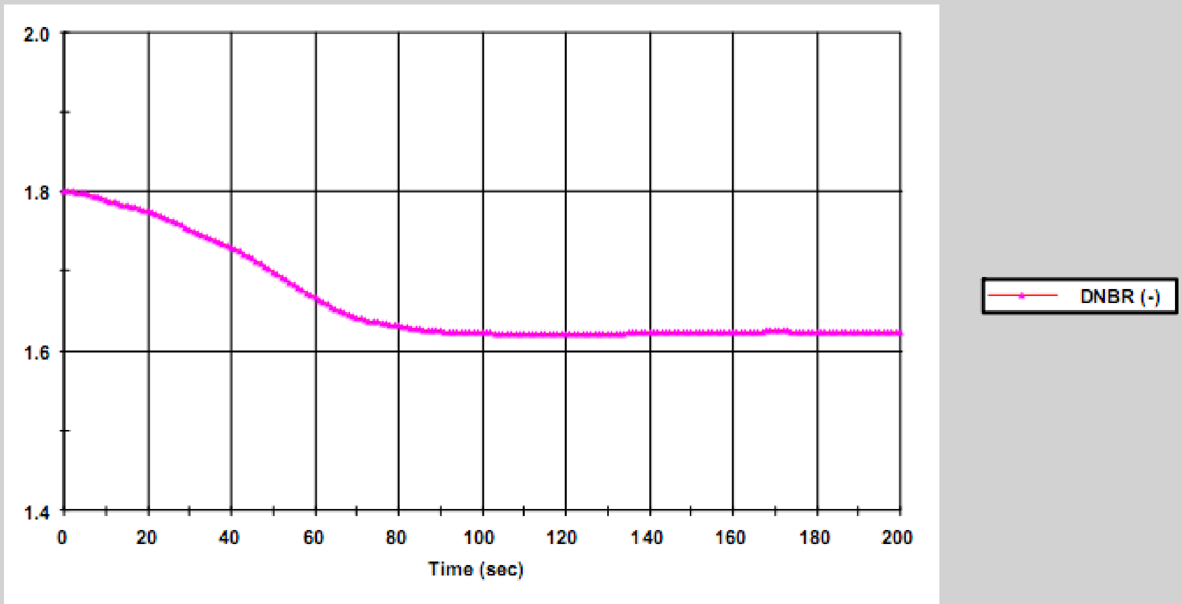
The transient is run in PCTRAN by setting the reactor power demand to 110%, with all other controls in auto. Initial condition #1 is selected for the EOL case and #3 is selected for the BOL case. No malfunctions are needed for this transient. The responses of power, average temperature, reactor pressure, and DNBR are consistent with the FSAR.



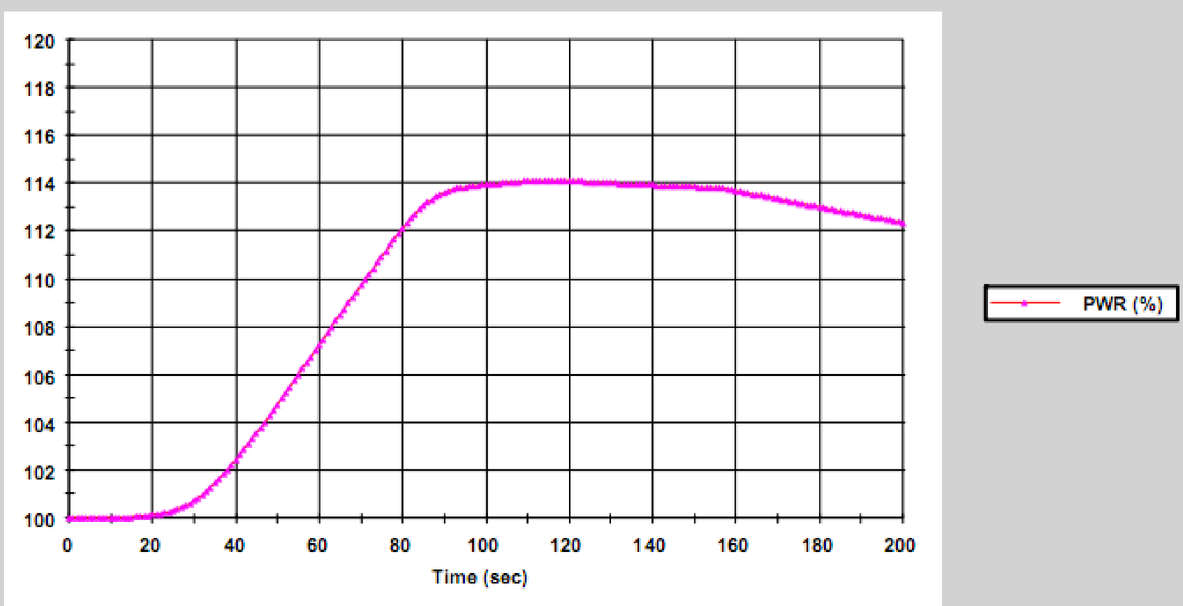

FSAR Figure 14.1.8-3 10% Load Increase (EOL)
308
306
304
302
300
298
0
20
40
60
80
100
120
140
160
180
200
Time (sec)
TAVG (°C)


FSAR Figure 14.1.8-4 10% Load Increase (EOL)
160
158
156
154
152
150
0
20
40
60
80
100
120
140
160
180
200
Time (sec)
P (kg/cm2)

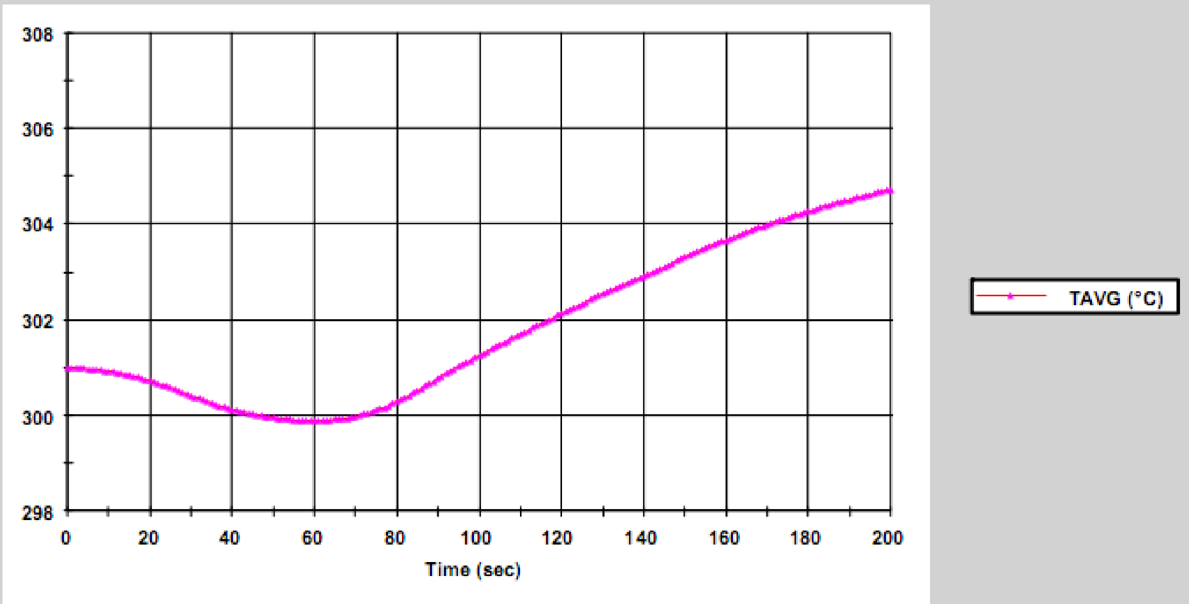
FSAR Figure 14.1.8-4 10% Load Increase (EOL)



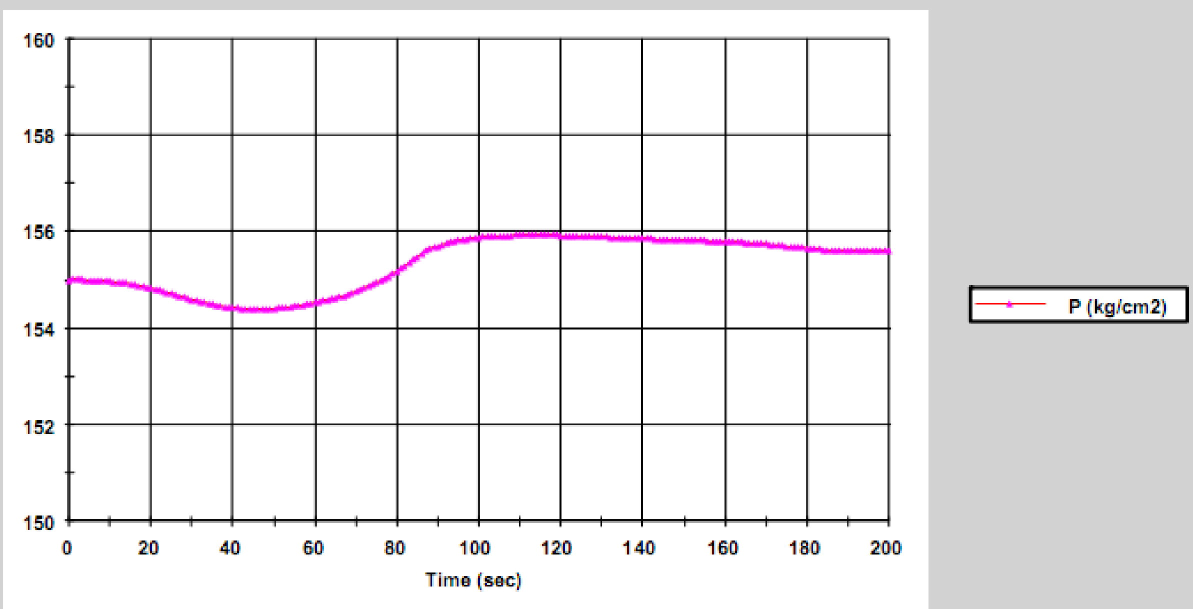
FSAR Figure 14.1.8-3 10% Load Increase (BOL)

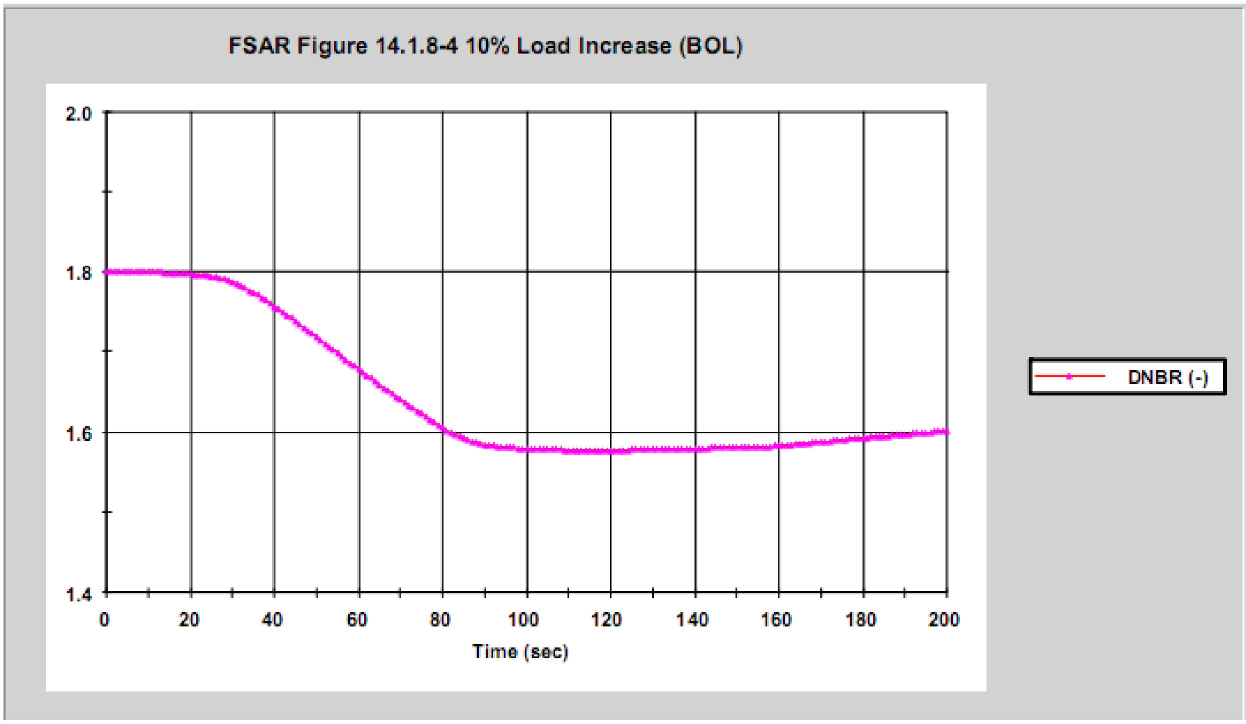


FSAR Figure 14.1.8-3 10% Load Increase (BOL)



FSAR Figure 14.1.8-4 10% Load Increase (BOL)





5. Nuclear Fuel

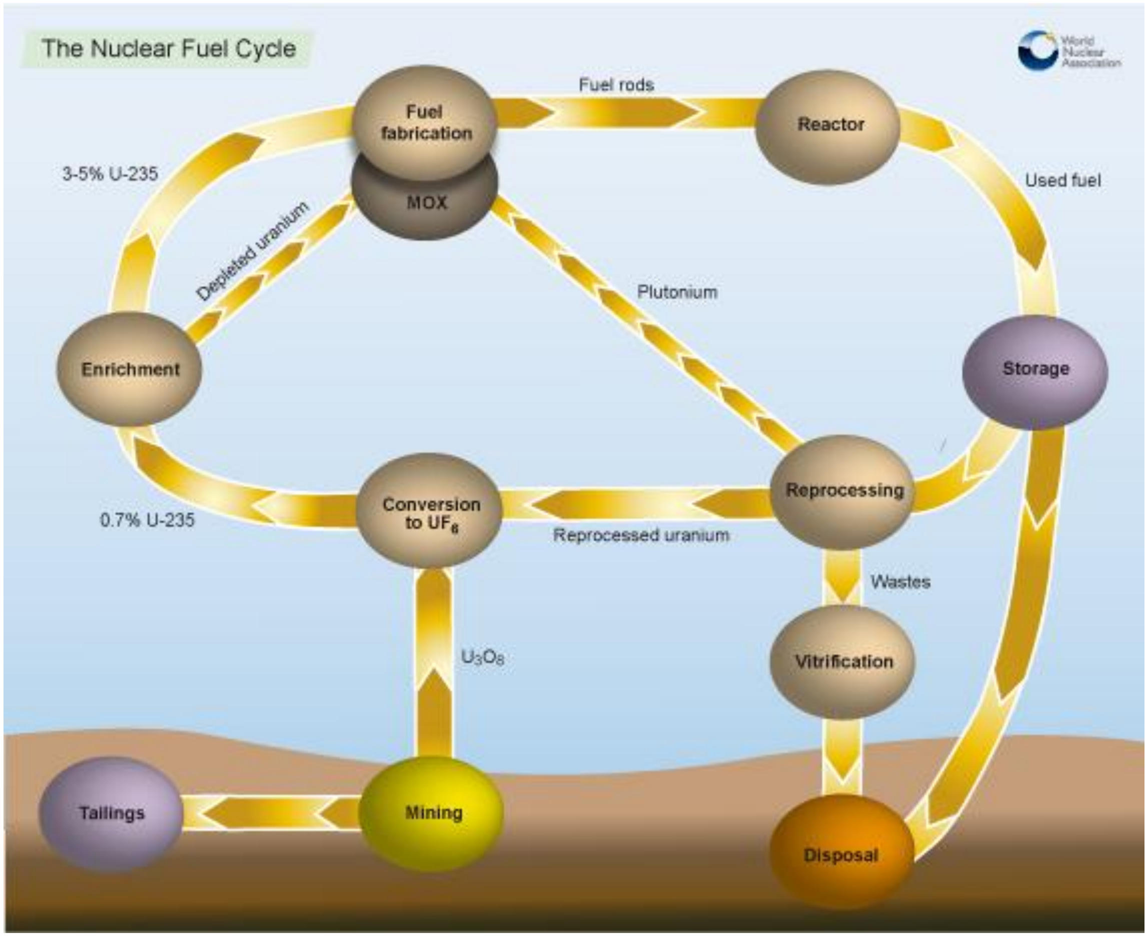
5.1 Nuclear Fuel Cycle

- The nuclear fuel cycle is the series of industrial processes which involve the production of electricity from uranium in nuclear power reactors.
- Uranium is a relatively common element that is found throughout the world. It is mined in a number of countries and must be processed before it can be used as fuel for a nuclear reactor.
- Fuel removed from a reactor, after it has reached the end of its useful life, can be reprocessed to produce new fuel.

The various activities associated with the production of electricity from nuclear reactions are referred to collectively as the nuclear fuel cycle. The nuclear fuel cycle starts with the mining of uranium and ends with the disposal of nuclear waste. With the reprocessing of used fuel as an option for nuclear energy, the stages form a true cycle.

To prepare uranium for use in a nuclear reactor, it undergoes the steps of mining and milling, conversion, enrichment and fuel fabrication. These steps make up the 'front end' of the nuclear fuel cycle.

After uranium has spent about three years in a reactor to produce electricity, the used fuel may undergo a further series of steps including temporary storage, reprocessing, and recycling before wastes are disposed. Collectively these steps are known as the 'back end' of the fuel cycle.



Uranium is one of the heaviest of all the naturally-occurring elements and has a specific gravity of 18.7. Its melting point is 1132ºC.

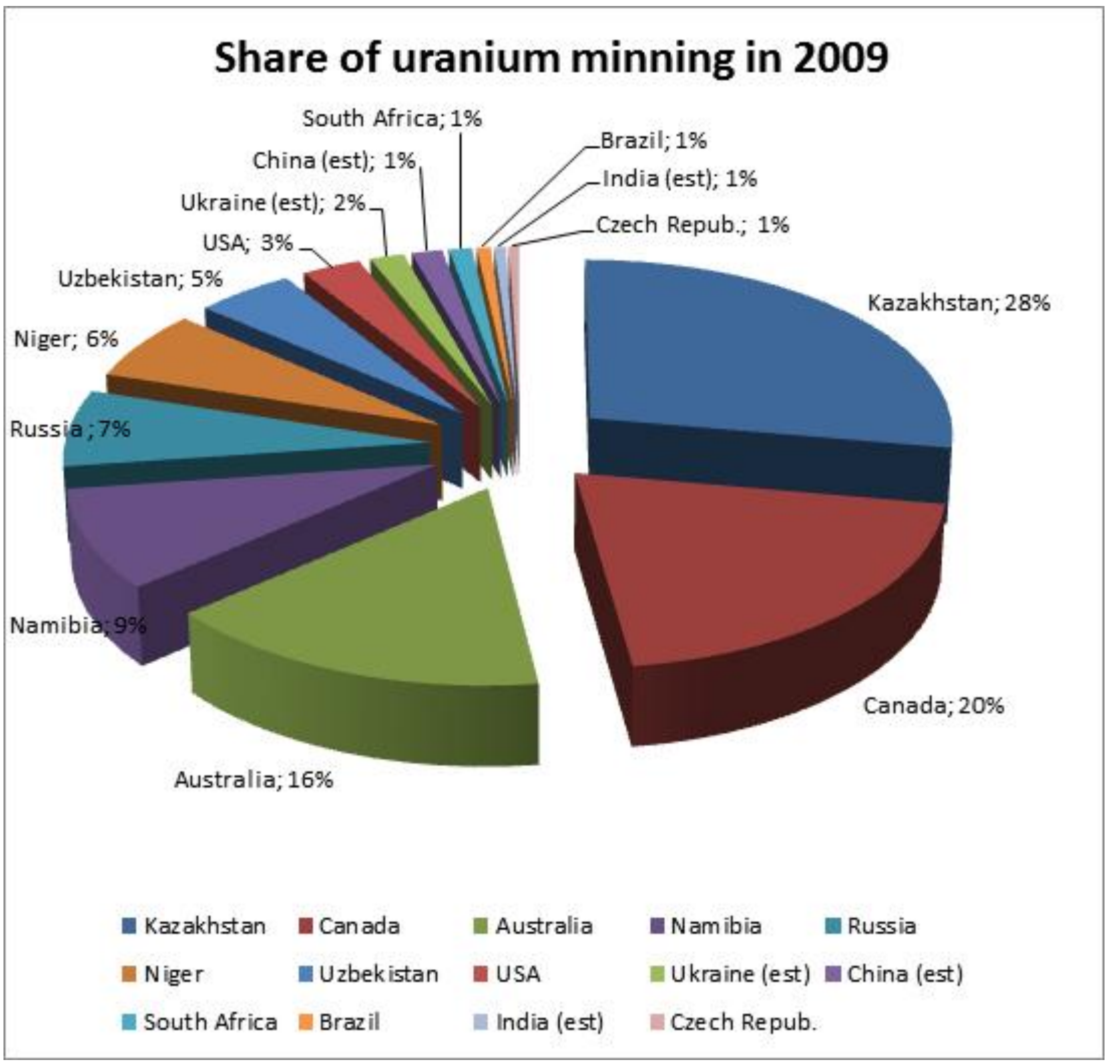
Like other elements, uranium occurs in slightly differing forms known as isotopes. These isotopes differ from each other in the number of neutron particles in the nucleus. Natural uranium as found in the Earth's crust is a mixture of three isotopes: uranium-238 (U-238), accounting for 99.275%; U-235 – 0.720%; and traces of U-234 – 0.005%.

The isotope U-235 is important because under certain conditions it can readily be split, yielding a lot of energy. It is therefore said to be 'fissile'. Meanwhile, like all radioactive isotopes, it decays. U-238 decays very slowly, its half-life being the same as the age of the Earth. This means that it is barely radioactive, less so than many other isotopes in rocks and sand. Uranium-238 has a specific radioactivity of 12.4 kBq/g, and U-235 80 kBq/g, but the smaller amount of U-234 is very active (231 MBq/g) so the specific radioactivity of natural uranium (25 kBq/g) is about double that of U-238 despite it consisting of over 99% U-238.[c] In decay it generates 0.1 watts/tonne and this is enough to warm the Earth's mantle.

5.2 Sources of uranium

Uranium is widespread in many rocks, and even in seawater. However, like other metals, it is seldom sufficiently concentrated to be economically recoverable. Where it is, we speak of an ore body. In defining what is one, assumptions are made about the cost of mining and the market price of the metal. Uranium resources are therefore calculated as tonnes recoverable up to a certain cost.

Three, the most important uranium producers are Kazakhstan, Canada and Australia. Location of mines is very neutral. Those country are politically balanced and predictable. Therefore uranium prices do not depend on geopolitical conditions.

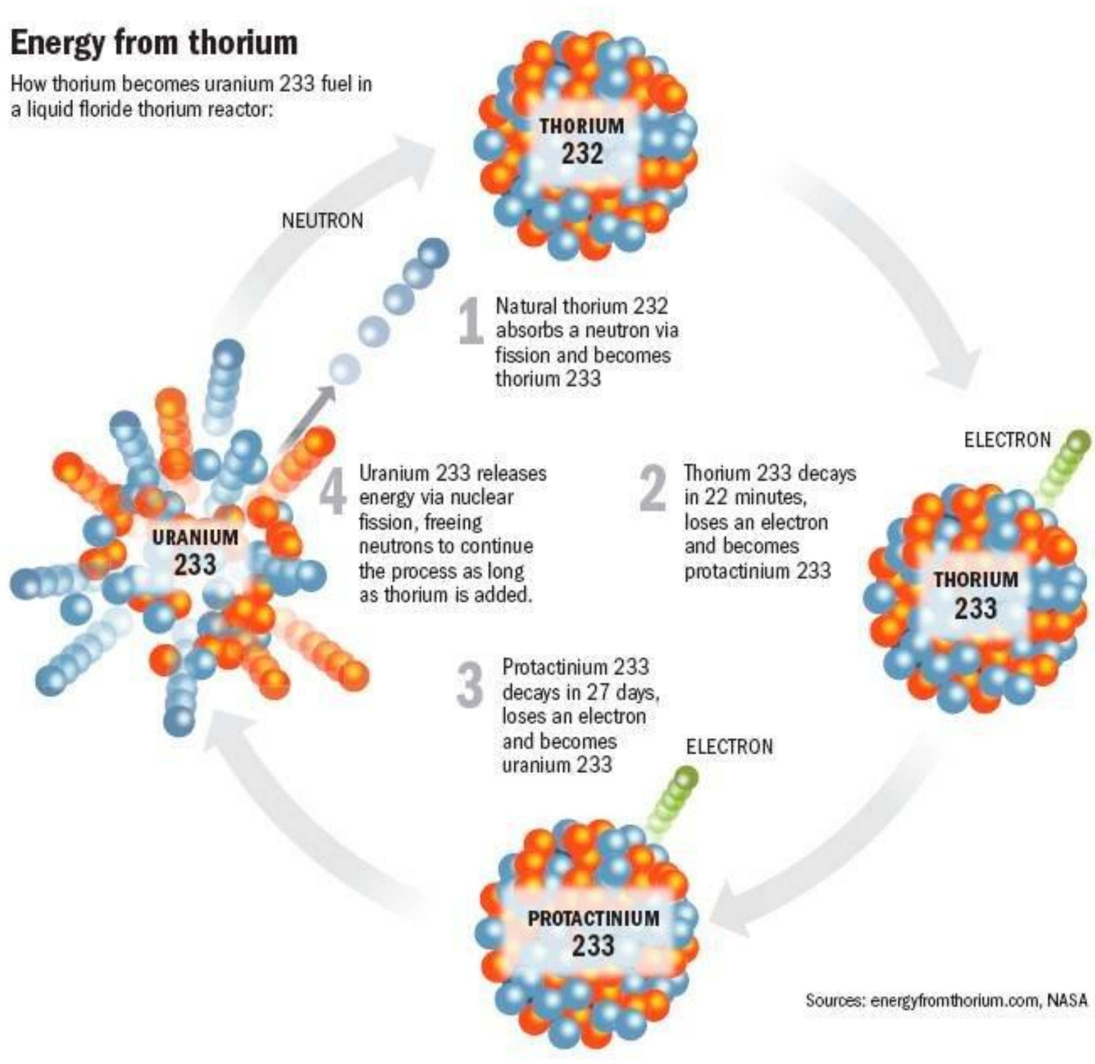


5.3 Thorium as a secure fuel alternative:

America and the world face enormous challenges relating to the procurement of energy, and to the corresponding security ramifications this represents. There exists today a virtuallyunknown alternative to the standard uranium fuel cycle for nuclear power reactors, which offers a variety of significant strategic and economic advantages. This alternative is thorium.

Thorium is not new technology, but rather, it is as old as the nuclear age itself, with research ongoing since its inception. The first nuclear reactors in America and Russia were fuelled by thorium. It was then dismissed by policy-makers – the key reason being that the thorium fuel cycle provides no opportunity for obtaining bomb materials. The 21st Century is a different era than the Cold War era. The Obama Administration has recently announced its goal to rid the entire world of nuclear weapons while it must confront both energy and environmental crises. Fossil fuels are expensive and experience wildly volatile price fluctuations. Uranium is in dangerously short supply. The world was not ready for thorium in the 1950s. Thorium could not be more appropriate now.

Thorium is a naturally-occurring fertile material – the only other one on earth besides natural uranium. Like uranium, 232-thorium can accept a slow neutron and transmute into a nuclear fuel, which then undergoes nuclear reactions, releasing enormous amounts of energy.



The fissile material created is 233-uranium isotope. This thorium fuel cycle carries with it a number of important natural properties some of which contrast sharply with the uranium fuel cycle:

-At no point in the thorium cycle – from mining to waste – can fuel or waste products be used as bomb material in any way;
-The thorium fuel cycle is inherently incapable of causing a meltdown according to the laws of physics; in nuclear reactor parlance, the fuel is said to contain passive safety features;
-Thorium-based fuels do not require conversion or enrichment – two essential phases of the uranium fuel cycle that are exceedingly expensive, and create proliferation risk;
-Thorium fuel cycle waste material consists mostly of 233-uranium, which can be recycled as fuel (with minor actinide content decreased 90-100%, and with plutonium content eliminated entirely);
-Thorium-based fuels are significantly energy efficient;
-Thorium fuel cycle waste material is radiotoxic for tens of years, as opposed to the thousands of years with today's standard radioactive waste;
-Thorium fuel designs exist today that can be used in all existing nuclear reactors;
-Thorium exists in greater abundance and higher concentrations than uranium making it much less expensive and environmentally-unobtrusive to mine;

These facts have many serious implications for the efficiency and security of energy delivery in the United States, and the world.

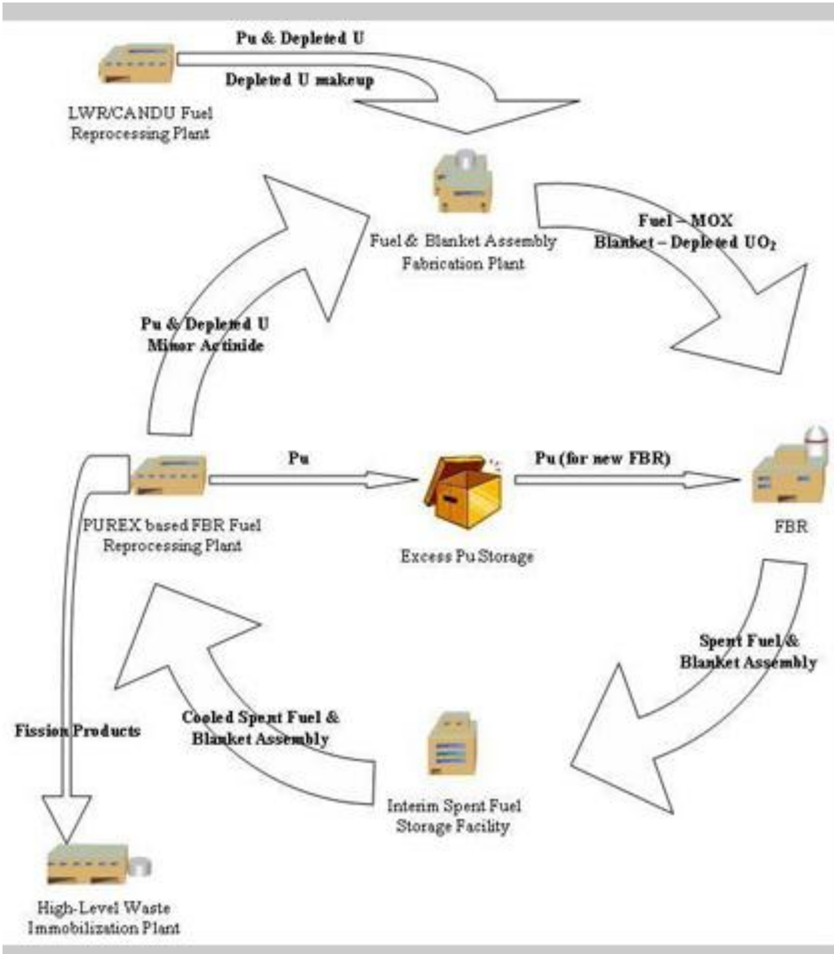


Figure: The (simplified) Thorium Fuel Cycle

5.4 Proliferation resistance

Proliferation resistance is important in a nuclear fuel solution for many reasons. Thorium delivers added security to every nuclear installation using thorium fuels, as well as to every other phase of the fuel cycle, including mining, processing, fuel fabrication, waste, and all the transport in between each phase. Each of these phases and the corresponding transport require heavy security in order to protect against theft or sabotage of radioactive materials. By using thorium, processing is not even required and all security can be dramatically reduced because the threat simply does not exist.

Abroad, the benefit to having proliferation-resistant nuclear energy in foreign locales is obvious. Never again will the world worry that a foreign state developing its own nuclear program is not genuine about its motives. With a thorium fuel cycle in place, the foreign state in question reduces their costs significantly, increases their energy efficiency, increases their access to fuel, and eliminates any international doubt of their probity.

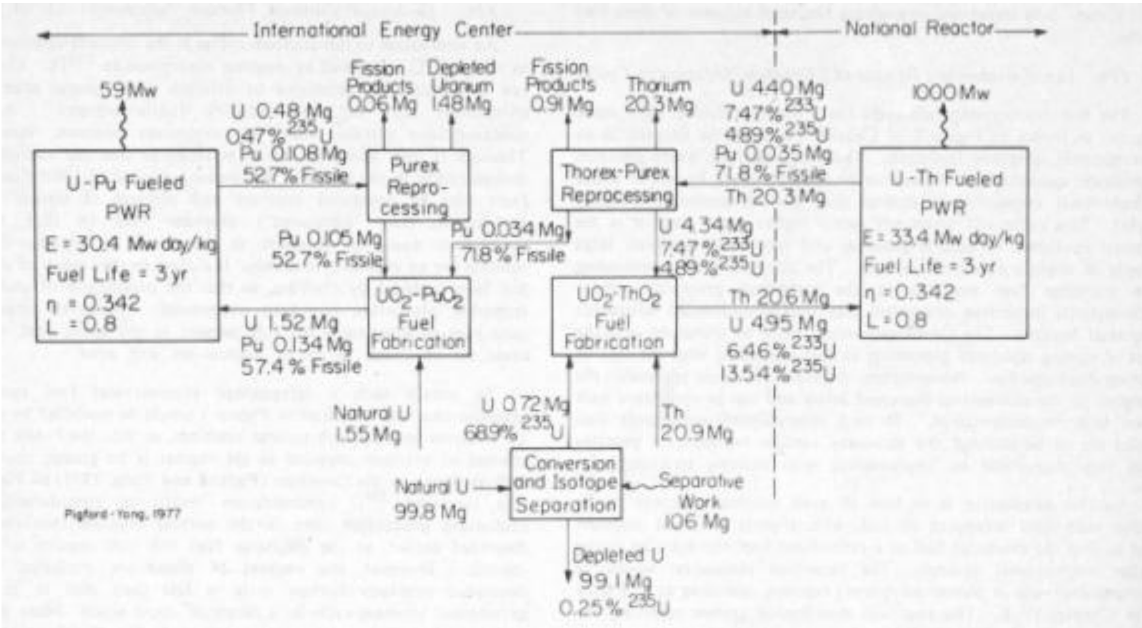


Fig: Proliferation resistance

5.5 Increased energy efficiency

Due to the chemical properties of thorium, when it is used as fuel in a nuclear reactor, it has the ability to give off more neutrons than it absorbs. This means that the neutron economy of any contemplated thorium fuel cycle is superior to the uranium fuel cycle. The fuel burns longer and uses all of the fissile material required to ignite a reaction.

As explained above in today's standard fuel natural uranium is enriched to increase its concentration of 235U fissile content. Approximately two-thirds of this fissile material is burned, with the remainder in the waste product. Natural uranium in the fuel absorbs a neutron to eventually become 239-plutonium. Approximately 0.9% of the final waste consists of this 239-plutonium isotopic material. When concentrated, this is the best material for bomb production. It is due to an inherently inefficient fuel cycle that there is so much residual material.

In the thorium fuel cycle, 232-thorium absorbs a neutron to breed 233-thorium, which decays naturally in 22 minutes into 233-protracinium, which decays naturally after 27 days to become 233-uranium. One hundred per cent of this 233-uranium burns in the reaction (as opposed to only two-thirds of the 238U-bred fuel.) However, approximately one out of every ten 233-Pa molecules are lost in the decay process and become a 234-uranium isotope. In sum, thorium-bred fuel burns with 90% efficiency, whereas uranium-bred fuel burns with only 66% efficiency. The waste products are, respectively, 233U, which cannot be used for bomb production, and 239Pu, which is the best possible bomb material.

The energy differential from this efficiency has been demonstrated to be anywhere from 60% to 200% greater. It should also be noted that because thorium fuel does not require enrichment, whereas uranium fuel does, much less raw material is required. In order to produce one year's worth of fuel for an average reactor (the US average reactor capacity is 1,000 Megawatts of electricity (MW), approximately 550,000 pounds of natural uranium is required. Seven-eighths of this material has the 235-uranium extracted out of it, leaving unusable depleted uranium waste behind. Because thorium does not require enrichment, only one-eighth, or 69,000 pounds of raw material is required for the same energy output. However, there is not even an equivalent energy output because of thorium's enhanced neutron economy and enhanced fissionability characteristics. Therefore, this 69,000 pounds, a full one-eighth of the material required for standard fuel will generate 60% to 200% more energy output.

Thorium creates enormous efficiencies from the micro- to the macroscopic level of fuel, and at virtually every stage in the cycle. Enhanced efficiency translates directly into decreased costs. At the risk of sounding repetitive, cheaper energy provides security benefits the world over.

5.6 Thorium fuel, in existing reactor designs

There are no significant infrastructural impediments whatsoever to using thorium fuels in all existing reactor designs in the immediate present. This is also a s security benefit. Typically, any new energy technology, particularly a nuclear energy technology, must pass through a series of daunting obstacles related to legislation, technology development, regulation, user education and finally market penetration before being implemented. For thorium, the reactors themselves require virtually no modifications, and no regulatory paradigm changes in order to accommodate thorium fuel. So this technology development continuum only applies to the fuel development itself, which is a much easier, faster, safer and cheaper exercise.

5.7 Security of supply

Perhaps the most significant benefit to security is the abundant supply of easily available thorium. Approximately 190 million pounds of uranium is required in 2009 to fuel the 437 reactors in operation globally. However, less than 110 million pounds of uranium will be produced from mining in 2009. The balance must be provided by blended-down weapons material, and from inventories. At the end of 2012, the Russian contract to provide the United States and others with material from their weapons expires, and the Russians have announced that they will not renew the contract. They require the material for their own civil energy program. The uranium shortfall in 2009 that must be filled from inventory is approximately 26 million pounds. By 2016, this shortfall is estimated to be 106 million pounds, and will continue to increase. By 2020, approximately 150 million pounds of uranium will be required from an inventory stockpile every year in order to keep reactors from operating below capacity. These figures take into account new reactors, and new uranium mines. By 2020, the international stockpile will be dangerously depleted, and the material that reactors depend on will either become unavailable, or will skyrocket in price. This partially explains why the price of uranium increased from $7 per pound in 2001 to $135 per pound in 2006. With the retrenchment of oil prices and the global economy in general, the price of uranium has also retrenched to the $40-45 price range. Nevertheless, the problem remains, and it is far more critical than the attention paid to it.

The United States is probably the most vulnerable to this developing uranium supply crisis. At present, the US is forced to import over 90% of its uranium required for reactor fuel. There are new uranium mines being planned, but there are also 19 new reactor builds permitted as of this writing. Each average reactor requires, on average, 550,000 pounds of uranium feedstock. In 2008, the US produced 3.9 million pounds. The supply required for the new facilities alone will be at least 10.5 million pounds, not to mention the 57.2 million or so pounds required for the existing US reactor fleet. There is no question that the United States is facing a serious problem.

Uranium must be mined from underground, typically requiring costly infrastructure. The mining methods are: the In-Situ Leach (or ISL), or the even costlier, more environmentally-obtrusive open pit mining. Because of the technical complexity and because of the extreme environmental impact involved, an extraordinary level of regulation is required to ensure the safety of uranium mining practices. This further increases costs, and slows down new production. A very typical life cycle for a uranium mine will be 10-15 years from discovery to the first year of production. And then the mine's lifespan may only be 5-10 years (as is common).

Uranium typically occurs at very low grade in nature – 1% of weight or less. This makes mining operations themselves expensive, even after the large capital expenditure for infrastructure. Mine operating costs, including the processing, can amount to $25-50 per pound. Once again, this is over and above the typical $50-100 million capital cost sunk into mine construction and development.

Thorium mining is an entirely different proposition. Large supplies of thorium exist in surface mineral sands in nearly every corner of the world. These sands can be mined by dredge mining, which is well-known as being an environmentally unobtrusive mining technique. Without having to go underground, the infrastructure and operating costs are a small fraction of any uranium mining operation. These mineral sands are also highly concentrated with thorium, and can contain tens or hundreds of millions of pounds of thorium per deposit. In short, thorium is readily, cheaply and easily available in large quantities. The US itself has enough easily-extractable thorium to power its reactors for thousands of years.

Thorium can also act as a useful supplement to uranium if necessary. With a secure supply of thorium, a nuclear fuel supply crisis can be averted, meaning that energy supply need not be interrupted.

At present, thorium is not purposely mined anywhere in the world.

6. Waste management

6.1 Radioactive waste

Radioactive waste are the waste materials contaminated by radioactivity above certain level defined In legislation. These are the by- product of nuclear power generation & other application of nuclear fission or nuclear technology. Considering nuclear power generation, we can say nuclear waste is the material that nuclear fuel becomes after it is used in a reactor. It looks exactly like the fuel that was loaded into the reactor -- assemblies of metal rods enclosing stacked-up ceramic pellets.

6.2 Classification of radioactive waste

Nuclear waste can be classified mainly into five classes.

a. Low level waste.

b. Intermediate level waste.

c. High level waste.

d. Transuranic waste.

e. Uranium tailings

a. Low level waste: It is generated from nuclear fuel cycle includes paper,rags,filters which contain small amount of short-lived radioactive material.LLW typically exhibits no higher radio-activity than one would expect from the same material disposed of in a non-active area.Some LLW requires shielding during handeling & transport but most LLW is suitable for shallow load burial.

b. Intermediate level waste : Intermediate-level waste (ILW) contains higher amounts of radio-activity.It includes resins,chemical sludge,metal nuclear fuel cladding.It may be solidified in concrete or bitumen for disposal.It can be classified into two types-

1.Short-lived waste(mainly nonfuel material from reactor)

2.Long-lived waste(from fuel & fuel reprocessing)

c. High Level Waste: It is produced by nuclear reactor & contains products & transuranic elements generate in the reactor core.

Properties:

1.Highly radioactive

2.thermally hot

3.Accounts for over 95 percent of the total produced in the process of nuclear electricity generation.

d.Transuranic waste:It is contaminated with alpha-emitting transuranic radioclides with half-lives greater than 20 years.Elements that have an atomic number greater than uranium called transuranic.It arises mainly from weapon production & consist of clothings,tools,rags,residues etc.

e.Uranium tailings: It is the by-product materials left over from the rough processing of uranium bearing core.It contains chemically hazardous heavy metal like lead & arsenic.

A short review of radioactive isotope & their half-live:

Isotope	Half-life
Strontium-90	28 years
Caesium-137	30 years
Plutonium-239	2400 years
Caesium-135	2.3 million years
Iodine-129	15.7 million years

Half-life:It is the time taken by a radio-isotope to loose half of its radio-activity.It varies from fraction of a second to million of year.The rate of decay is inversely proportional to its half-life.

6.3 Amount of waste produced yearly worldwide in nuclear power generation

1. Low & intermediate level radioactive waste:**200000** meter cube

2. High-level radioactive waste:**10000** meter cube

3.A typical **1000** MWe reactor generates **200-300** m^3 low &intermediate level waste& discharge **20** m^3(**27** tons) used fuel per year.

6.4 Waste management

- Nuclear waste management actually deals with the systematic and scientific isolation of waste.
- The main objective of this is managing & disposing of radioactive waste in order to protect people.

Nuclear Engineering (NE) Division researchers has given a model on the basis of the development of waste management and disposal strategies

This specific modeling and analysis activities include:
• Participate in the modeling and assessment of the metal and ceramic waste forms, which incorporate the radioactive wastes generated during electrometallurgical treatment of spent nuclear fuel. These waste forms must be qualified to meet the regulatory requirements on radionuclide release and thermal performance within a geologic repository. Acceptable limits on temperature and radionuclide release must also be met under on-site interim storage and transportation conditions. The qualification relies on both testing and modeling.
• Developing models of the long-term degradation behavior and radionuclide release mechanisms of metallic and ceramic waste forms described above.
This modeling effort focuses on mechanistic interpretation of experimental results of waste qualification tests provided by the waste form development and laboratory testing with the objective of applying these results to the long time scales and environmental conditions of interest in repository performance evaluation.
• Creating and maintaining an electronic database of metal and ceramic waste performance data generated by experimental groups and analysts.
Among other benefits, this database will serve to support retention and ready access to vast amounts of institutional knowledge accumulated over many years in waste form design, optimization, and performance modeling. Access to this database by project personnel will ultimately be via World Wide Web technologies.
Thermal Analysis Results that Demonstrate the Potential Increase in the Amount of Recycle Waste that Could Be Disposed as Compared to Direct Disposal of Spent Nuclear Fuel
• Developing a repository performance assessment model to be used for scoping studies and parameter sensitivity studies. This model is used to perform preliminary repository performance evaluations to support decisions related to strategies regarding the recycling of spent fuel.
• Developing scoping-level thermal models to evaluate the repository thermal response that would result from removing key radionuclides from the waste stream. These models are used to evaluate the benefits that could be achieved with regard to: amounts of waste that could be

emplaced in a given repository, alternative repository design options, and strategic decisions related to the recycling of spent fuel.

• The benefits of recycling spent nuclear fuel as proposed under the GNEP presents an opportunity to re-think the waste management and disposal strategy in both the U.S. and internationally. NE researchers are participating in the development and implementation of an Integrated Waste Management Strategy for the GNEP.

• Developing sub-models for the waste management and disposal for inclusion in system analysis modeling tools.

Principles employed in waste management:

- 1.Concentration & contain.
- 2.Dilute & desperse.
- 3.Delay & Decay.

Concepts of waste management :

There are a number of concepts about waste management which vary in their usage between countries or regions. Some of the most general, widely used concepts include:

Waste hierarchy - The waste hierarchy refers to the "3 Rs" reduce, reuse and recycle, which classify waste management strategies according to their desirability in terms of waste minimization. The waste hierarchy remains the cornerstone of most waste minimization strategies. The aim of the waste hierarchy is to extract the maximum practical benefits from products and to generate the minimum amount of waste see: resource recovery.

Polluter pays principle - the Polluter Pays Principle is a principle where the polluting party pays for the impact caused to the environment. With respect to waste management, this generally refers to the requirement for a waste generator to pay for appropriate disposal of the unrecoverable material.

Facts to be ensured:

1.Long time protection of people & environment.

2.Have to be done in a open & transparent way.

3.Will be based on sound science.

Limitaions of waste management:

- Extremely long half life of radioactive materials.

- Long term above ground storage,Disposal in outer space,Deep borehole disposal is not implemented.
- Huge time requirement.
- Reliablity of geological desposal is uncertain.
- Reprocessed fuel(used) contain highly radioactive material
- When the uranium in the core of a reactor is used up, you have to take it out . In some cases uranium can be recycled and used again. If you reprocess uranium you can make another dangerous product—plutonium, which is used to make atomic bombs.
- But even though uranium can be used again it finally has to be stored safely. Nuclear waste remains radioactive for thousands of years. Even putting it deep into a mountain would not be completely safe.

6.5 Main sources of radio-active waste:

1.Spent fuel (SF).

2.Power reactor operation.

3.Reprocessing of spent fuel.

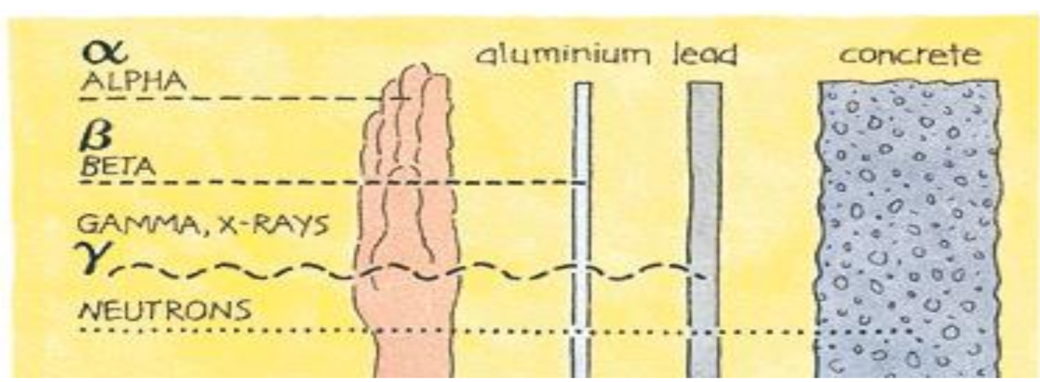
7. Strategies, Reduction methods & Protection

7.1 Protection against alpha, beta, gamma ray

Alpha particles can be stopped by a single sheet of paper.

Beta rays can be absorbed by a few millimeters of aluminum. High energy beta particles are emitted shielding must be accomplished with low density materials, e.g. plastic, wood, water or acrylic glass.

Depleted uranium or thorium[2] are used to prevent Gamma rays.



7.2 Volume minimization of radioactive waste

- Reusing and recycling of materials by separating radioactive components from non-radioactive ones.
- Preventing the contamination of materials by limiting the amounts in radioactive areas
- Assessing technology advances in waste minimization and implementation.
- Introducing supervised pools facilities.
- Storage is mostly in ponds at reactor sites.

7.3 Geological Disposal

Geological disposal involves isolating radioactive waste deep inside a **suitable rock formation** to ensure that no harmful quantities of radioactivity ever reach the surface environment. It is a multi-barrier approach, based on placing wastes deep underground. It is a multi-barrier, multi-phased approach. Geological disposal is based on the concept of multiple barriers that work together to provide containment. The barrier concept prevents deep ground waters, present in almost all rock formations, from rapidly leaching the wastes and transporting radioactivity away from the repository. There are both 'engineered barriers' that are constructed in the repository and 'natural barriers' in the surrounding geological environment. These barriers work together to provide containment and safety:

• The container protects the waste and prevents any water reaching it for at least several hundred years and, in some concepts, for tens or even a hundred thousand years – by this time, most activity will have decayed inside the waste matrix.
•The buffer protects the container, preventing water from flowing around it and absorbing any mechanical disturbance that might be caused by future deep-earth movements (associated with major earthquakes) – if it is highly impermeable, such as clay, it also contains any radionuclides that eventually escape from the container.
• The rock and the geological environment of the repository provide stable mechanical, chemical and water flow conditions around the engineered barriers
for very long times, allowing them to contain radionuclides for much longer than if they were left at Earth's surface – this 'cocoon' effect is due to the very slow rate of natural processes at depth.
• The rocks, soils and waters around and above the repository slow down, or completely immobilise, and dilute and disperse any eventual releases of
activity so that they do not cause a hazard in the natural environment.

7.3.1 Materials used in geological disposal

Glass waste forms, Ceramic waste forms, and Nanostructured materials

7.3.2 Safety assessment of geological disposal

1.The methodology for carrying out safety assessment is now thoroughly developed and tested – indeed, it is a routine exercise used regularly, at various programme stages, to compare alternatives: designs, layouts, materials,geological environments and repository sites.Safety assessment looks at the behaviour of the whole disposal system to evaluate possible radiological impacts
on people.

2.Process models that describe materials behaviour in a repository need to consider all of the driving mechanisms– thermal, chemical, hydraulic and mechanical ('TCHM') resulting from the radioactive decay heating of the wastes, the chemical composition of materials and pore waters, and the rock stresses. These can each be affected by external events, too – for example, in the distant future, some European countries will be covered by thick ice sheets in a new ice age – with thermal and mechanical load impacts being transmitted even torepository depths and changes in groundwater flow and chemistry.

3.Any radionuclides that do escape from the rock and deep groundwaters could find their way into the biosphere.Pathways for radionuclides through surface waters,soils, plants and animals to people are complex.Nevertheless, the ability to identify and evaluate them is a key aspect of safety assessment as the biosphere pathways and processes ultimately control the potential human radiation doses we calculate and these are compared with regulatory standards to decide whether a repository provides sufficient safety. The biosphere is a very complex and constantly changing natural system, especially when looked at over thousands of years – not least, as a result of changing climate and human habits. Consequently, there are numerous uncertainties about future biosphere states. Safety assessors seek to get round this problem by identifying present- day biosphere models that can act as reference states covering the main environmental conditions that could occur over the nexthundreds of thousands of years.

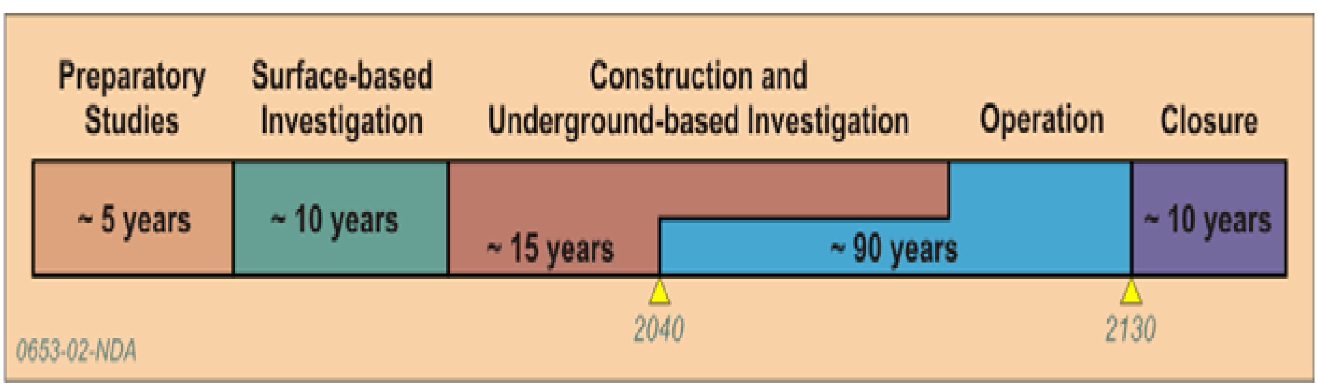
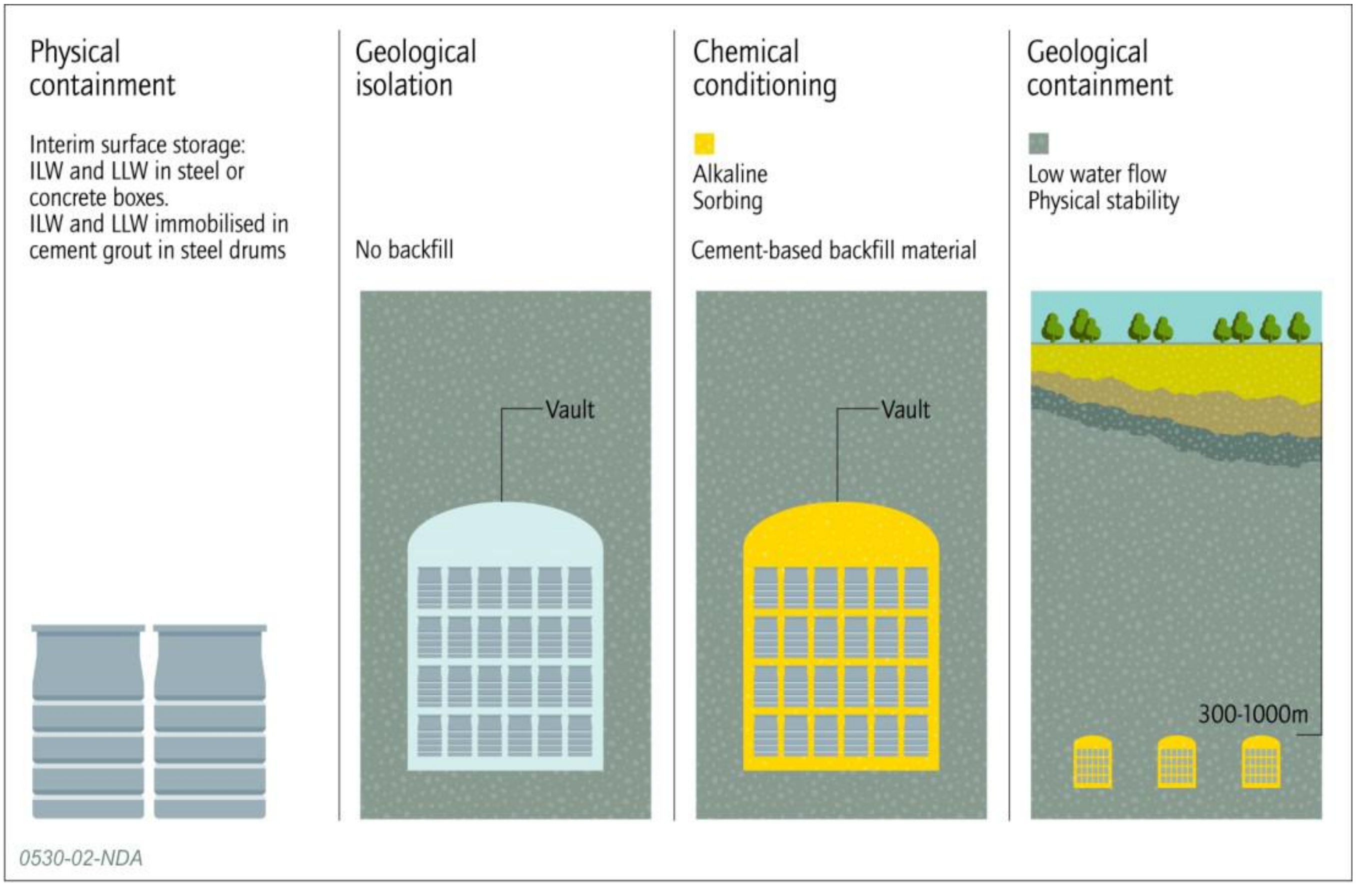


Figure : Geological Disposal Programme timeline indicating phases

UK geological disposal concept for intermediate level waste / low level waste



7.4 Initial treatment methods:

a. Radioactive waste processing

1.Incineration: Incinerators burn waste at high temperatures. The main purpose of incinerating radioactive waste is to reduce waste volume, since a large proportion consists of bulky items. Incineration of waste that is a mixture of chemically hazardous and radioactive materials, known as "mixed waste," has two principal goals: to reduce the volume and the total chemical toxicity of the waste. Infact,it is a disposal method in which solid organic wastes are subjected to combustion so as to convert them into residue and gaseous products.

2.Compaction: Compaction systems are offered for the size reduction of solid Low Level Waste (LLW) and Intermediate Level Waste (ILW) including Plutonium Contaminated Material (PCM**).**

The ILW Supercompaction systems are suitable for the volume reduction of Beta/Gamma waste and Plutonium Contaminated Material (PCM). These Supercompaction systems are equipped with drum and puck recovery systems. The drives and actuators are placedoutside the cell and the system is specially designed for operation in a non-man accessible environment.

Solid Radwaste Treatment Solutions :

Fontijne Grotnes built the world's first Supercompactor. From this, the technology developed into a reliable technology for the reduction of radioactive waste.

The following are processes to prepare nuclear waste for long term storage or final disposal:

• Drum infrastructure

• Sorting

• Pre-compaction

• Supercompaction

• Optimizing

• Grouting

• Design studies

b. Re-use of waste (**cesium-137, strontium-90**)

1.Radioisotope thermoelectric generators

2.Food irradiation

c. Packaging

- High level wastes can be converted into glass blocks,known as **vertification.**
- Intermediate level waste is **combined with cement** or **solidified** inside a **stainless steel container.**
- Low level wastes are compacked in drums,placed in boxse & encased within concrete.

7.4.1 Methods of treating & disposing of nuclear waste

1**.**Deep geological repository.

2.Dry cask storage

3.Ducrete

4.Ocean floor disposal.

5.Saltcrete

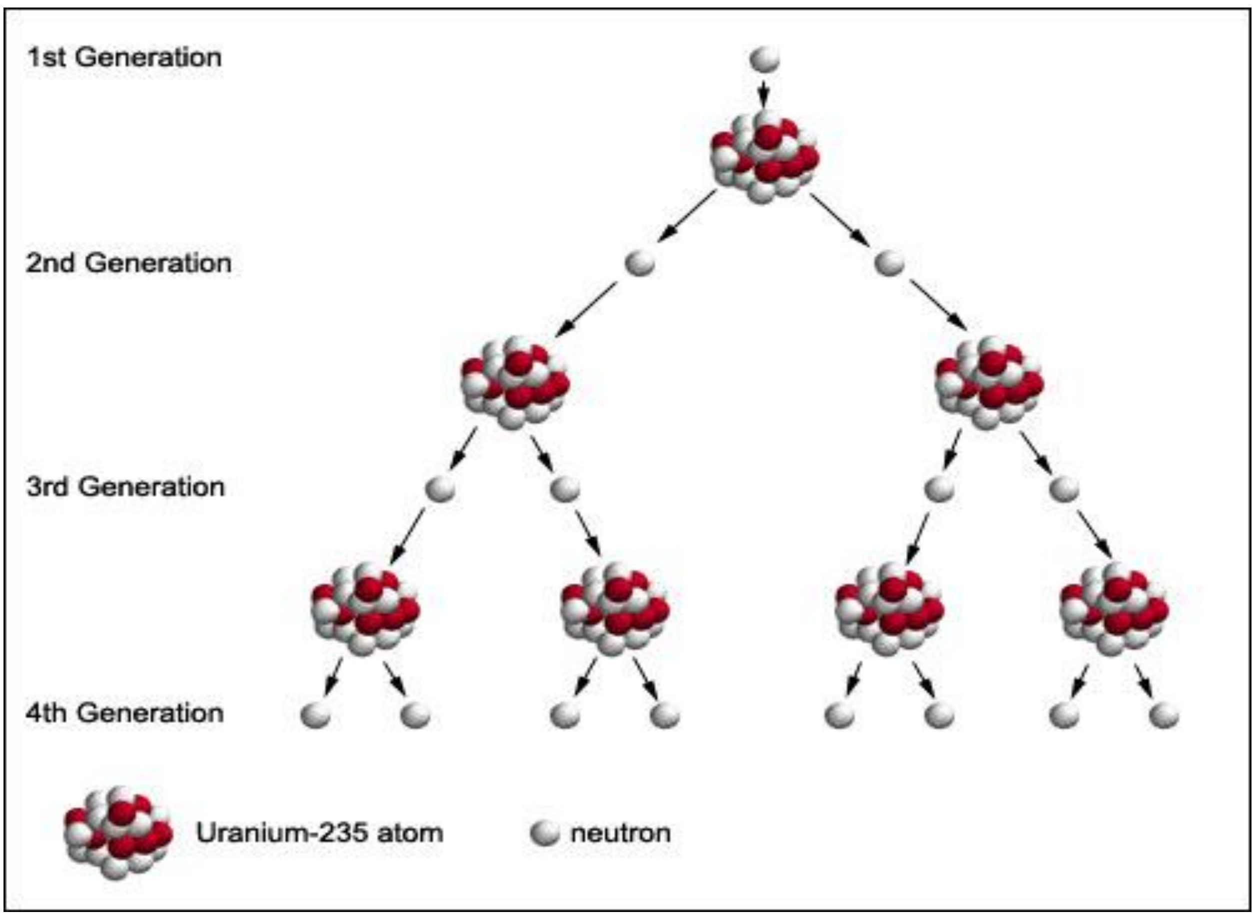
6.Spent fuel pool

7.Spent nuclear fuel shipping cask

8. Waste ionization Pilot plant

9.Deep borehole disposal

7.5 Nuclear Chain Reactions



Explanation of Chain reaction

Reaction: U235 + n → fission + 2 or 3 n + 200 MeV

- Each neutron releases two more neutrons, so the number of fissions doubles each generation.
- In 10 generations there are 1,024 fissions and in 80 generations about 6 x

10^23(a mole) fissions.

- Control rods are put into the reactor and control the chain reaction.
- By raising or lowering Control rods into the core chain reaction may be quicker or slower respectively.

7.5.1 How radioactive waste produced from nuclear fission

- Nuclear fission produces radioactive isotopes of krypton, strontium, cesium and barium.
- Fission products also dilute the fuel.
- Reaction slows down & concentration of uranium-235 is too low for fission

  to continue the fuel must be replaced & used fuel is the spent fuel .

- Moreover fission products give out three types of radiation, alpha (a), beta (b) and gamma (g) known as ionizing radiations.
- During reactor operation Control rod become hot fasts chain reaction & radio active isotope are formed.

7.5.2 Facts inside a power plant

A nuclear power plant must be safe, otherwise radiation could get into the air. They have a containment - a building around it that is made of concrete and steel. In the core of the reactor uranium is formed into long rods which are put into water. This water cools the rods when they get too hot.

Control rods are also put into the core. They take up the neutrons and control the chain reaction. They can be raised or lowered into the core. If you raise them the chain reaction goes on quicker , the core gets hotter and more energy is produced. If you lower them they absorb free neutrons and the chain reaction is slowed down.

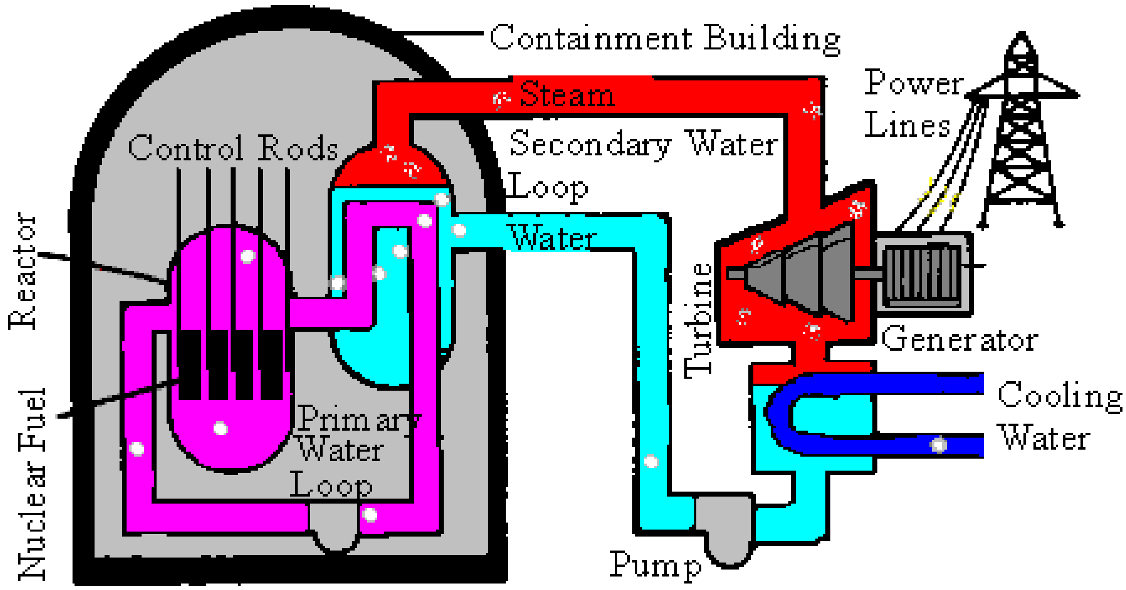


Figure: Inside a power plant

7.8 Nuclear Power Standards according to IEEE standards association

7.6.1 Standard Criteria for Class IE Electric Systems for Nuclear Power Generating Stations

This standard applies to those parts of the electric systems in stationery single-unit and multi-unit land-based nuclear power generating stations that provide electric power to the Class IE electric equipment. The electric systems included are comprised of the following interrelated systems" (!) alternating-current power systems, (2) direct-current power systems, (3) vital instrumentation and control power systems. These systems consist of power supplies (e.g., connections to the station switchyard, stand-by generators, batteries), distribution equipment and components (e.g, transformers, switchgear, bus cable, battery chargers, inverters), and instrumentation and controls (e.g., relays, meters, switches, control devices). This standard does not apply to the unit generator(s) and their buses, step-up and auxiliary transformers, switchyard, transmission lines and transmission network.

7.6.2 Standard Criteria for Accident Monitoring Instrumentation for Nuclear Power Generating Stations:

Criteria are established in this standard for variable selection, performance, design, and qualification of accident monitoring instrumentation, and include requirements for display alternatives for accident monitoring instrumentation, documentation of design bases, and use of portable instrumentation.

7.7 Recent technologies

Acceleration driven system:

- ❑ Make long-lived radioisotopes into shorter-lived.
- ❑ Run nuclear reactors powered by thorium.

Fusion-fission hybrid system:

- ❑ Use fuel pellets of deuterium and tritium to produce energy sufficiently greater than the input.

Deep –burning system:

- ❑ Destroy weapon usable material.
- ❑ Burn the spent fuel.

4th generation , Fast & High temparature reactor:

- ❑ Adopt uranium/plutonium from fuel & minimizes waste.

8. Waste management & Bangladesh perspective

8.1 About waste management

- Russia will supply nuclear fuel in the form of fuel assemblies & take the spent fuel back.
- Geological disposal has been being constracted.
- Bangladesh Atomic Energy Commission will manage the low & intermediate level waste.

8.2 Experts views about safety issues of Rooppur nuclear power plant

- ➢ The water-water energy reactor (VVER or WWER)-1200, which would be installed at the Rooppur nuclear power plant to produce 1,000 MW of electricity, would ensure that the plant has the highest safety measures supervised by the International Atomic Energy Agency (IAEA).
- ➢ The nuclear power plant (NPP) would be built in accordance with the most contemporary Russian technologies, conforming to all international safety requirements
- ➢ The plant's power unit will have a double protection layer of the reactor, able to withstand the fall of a plane of up to 200 tonnes, an earthquake up to 8 point on the Richter scale, and a heavy wind with a speed of up to 56 miles per second," said Igor P Korolchenko, head of the construction division of the NPP in Bangladesh.

- Need a huge quantity of water to cool the reactor. For that purpose, two big reservoirs will be built to preserve water.
- Regarding the disposal of nuclear waste, The intergovernmental agreement of 2011 provides for return of the nuclear waste to Russia, which could also be viewed as an element of safety. We would use a special system to transport nuclear waste to keep the environment free of pollution.
- The NPP will implement an efficient combination of active and passive (operating without human participation, based on natural forces of nature) safety systems. In particular, the plant will have a passive heat removal system intended for long-term removal of residual heat of the reactor without any auxiliary power supply source, including emergency ones.
- Rooppur plant will be well-ventilated and accumulation of hydrogen gas will be prevented to preclude any such disaster.
- The plant will have five tiers of engineered features and administrative measures to protect these barriers and ensure that their effectiveness is retained, in particular, for protecting the public.

8.3 Limitations towards implementing nuclear power plant in Bangladesh

- Bangladesh has no technical expertise or skilled manpower to undertake such a complex and high tech project.
- The country has no industrial infrastructure and the transport system is absolutely rudimentary. Most of the materials to be used in the plant such as the quality assured high grade stainless steel, pipes, valves, pumps and other components will have to be imported and the cost will simply be prohibitive.
- Bangladesh has no institutional and regulatory framework to undertake a complex project like this and consequently safety standards will be seriously impaired.
- The VVER-1000 is quite outdated. Its safety standards fall so short that even in Russia the construction of one of the VVER-1000 plants was cancelled in 2008.
- No site selection procedure or environmental impact assessment was ever conducted.River Padma is now heavily silted due to extraction of as much as 75 per cent of water during the lean summer months by India using Farakka Barrage only 40km upstream of the proposed site. The remaining amount of water is woefully inadequate to meet the plant cooling requirement for even one 1000MWe plant! This would increase the risk of nuclear accident as in Fukushima (loss of coolant accident) to an unacceptable level.

9. Observation & Proposal

- Have to make technical expertise & skilled manpower to undertake such a complex and high tech project.
- Using generation IV Reactors or Liquid Fluoride Thorium Reactors.
- Developing a deep repository for high-level radioactive waste disposal.
- Initial treatment technology have to be developed.
- National framework is to be set to maintain boundaries for safe operation.
- The materials to be used in the plant (high grade stainless steel, pipes, valves, pumps etc) have to be constructed in Bangladesh.So industry with modern facility have to be built.
- Have to ensure adequate water to meet the plant cooling requirement for preventing nuclear accident.
- Institutional and regulatory framework as well an affluent transport system have to be ensured.

10. Conclusion

Nuclear power is essential to address the global issues of energy sustainability ,environmental pollution, acid rain, availability of safe drinking water and particularly to address the issue of climate change. The world Energy Council in its 20th World Congress held in Italy in November 2007. Concluded,” Nuclear power will be an important and growing share of the energy mix.”

The developed world is also changing the attitude Italy just reversed a 22-year freeze on nuclear power plants. Countries like China, India, Japan and South korea are taking ambitious nuclear power expansion program.

A serious accident in a nuclear power plant, however, can spread radiological contamination to the areas surrounding the plant and security of a nuclear power plant, safe guards of nuclear materials are the issues of serious concern of not only of the state concerned but of the world communities as well Nuclear proliferation is bothering the developed world from the perspective of global terrorism.

The key issues related with nuclear safety, security, safeguard, proliferation, waste management, occupational protection etc. have to be addressed effectively and efficiency with transparency and global cooperation and understanding.

Stringent and effective nuclear regulatory regime is essential for safe and secure nuclear power program. World nuclear power operators and regulations have been performing their responsibilities efficiency. The performance of nuclear power plants so far has been proved to be by far the safest. The licensed life of a nuclear power plants is now being extended to even 60 years compared to 30 years economic life of a coal fired power plant.

Regulatory regime is continuously evolving with changing perceptions and attitude, new scientific knowledge and technological inventions and innovation for better plant performance and safety. Fourth generation nuclear power plants have been already been designed and are now being constructed.

Nuclear power is essential for Bangladesh to fulfill the constitutional obligation of reaching quality electricity at an affordable price to every citizen of the country. Strong political will , commitment and continuity of actions will be required by the present and subsequent governments considering this as a national issue.

Strong political will, support of the concerned authorities, provision of adequate fund, qualified manpower and logistics as well as national and international collaborations will be necessary.

Bangladesh should seriously study and analyze the development trends of nuclear power programs of some of the successful countries: India, South Korea, Japan. The country will have to develop independent regulatory body and enact new laws and regulations and take necessary steps to implement the same if it has to pursue nuclear power program.

Study of the US, Indian and South Korea legal systems might also help. The IAEA, as per its statutory responsibility, assisted in the past and will help at future dates too.

The subject is too vast to be covered by a lecture or two. It is, however, believed that the concerned and interested persons will be able to explore the subject further by using the references cited in the presentation.

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