GUJARAT TECHNOLOGICAL UNIVERSITY

Chandkheda, Ahmedabad

Affiliated

LUKHDHIRJI ENGINEERING COLLEGE

MORBI

A Project Report
On

NUCLEAR REACTOR

Under subject of
DESIGN ENGINEERING – 2B
B.E. Semester – VI

(Chemical Branch)

Submitted by

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Academic Year: - 2015-2016

CERTIFICATE

CERTIFICATE

Date: __________

This is to certify that **Karan Gupta, Mehul Patel, Devarshi Tadvi, Rajesh Parmar,** of B.E. Semester V (Chemical Engineering) has completed their Design Engineering-2A work titled "Nuclear Reactor" satisfactorily in partial fulfillment for requirement of Design Engineering-2A course, Gujarat Technical University, Ahmedabad, in the academic year 2015-2016.

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Chapter 1: Introduction

A nuclear reactor is a device to initiate and control a sustained nuclear chain reaction. The most common use of nuclear reactors is for the generation of electric energy and for the propulsion of ships.

The nuclear reactor is the heart of the plant. In its central part, the reactor core's heat is generated by controlled nuclear fission. With this heat, a coolant is heated as it is pumped through the reactor and thereby removes the energy from the reactor. Heat from nuclear fission is used to raise steam, which runs through turbines, which in turn powers either ship's propellers or electrical generators.

Since nuclear fission creates radioactivity, the reactor core is surrounded by a protective shield. This containment absorbs radiation and prevents radioactive material from being released into the environment. In addition, many reactors are equipped with a dome of concrete to protect the reactor against both internal casualties and external impacts.

Nuclear reactors

A nuclear reactor is a device to initiate and control a sustained nuclear chain reaction. The most common use of nuclear reactors is for the generation of electric energy and for the propulsion of ships.

Steam turbine

The purpose of the steam turbine is to convert the heat contained in steam into mechanical energy. The engine house with the steam turbine is usually structurally separated from the main reactor building. It is so aligned to prevent debris from the destruction of a turbine in operation from flying towards the reactor.

In the case of a pressurized water reactor, the steam turbine is separated from the nuclear system. To detect a leak in the steam generator and thus the passage of radioactive water at an early stage, an activity meter is mounted to track the outlet steam of the steam generator. In contrast, boiling water reactors pass radioactive water through the steam turbine, so the turbine is kept as part of the control area of the nuclear power plant.

Generator

The generator converts kinetic energy supplied by the turbine into electrical energy. Low-pole AC synchronous generators of high rated power are used.

Cooling system

A cooling system removes heat from the reactor core and transports it to another area of the plant, where the thermal energy can be harnessed to produce electricity or to do other useful work. Typically the hot coolant is used as a heat source for a boiler, and the pressurized steam from that one or more steam turbine driven electrical generators.

Safety valves

In the event of an emergency, safety valves can be used to prevent pipes from bursting or the reactor from exploding. The valves are designed so that they can derive all of the supplied flow rates with little increase in pressure. In the case of the BWR, the steam is directed into the suppression chamber and condenses there. The chambers on a heat exchanger are connected to the intermediate cooling circuit.

Feed-water pump

The water level in the steam generator and nuclear reactor is controlled using the feed-water system. The feed-water pump has the task of taking the water from the condensate system, increasing the pressure and forcing it into either the steam generators (in the case of a pressurized water reactor) or directly into the reactor (for boiling water reactors).

EMPATHY MAPPING CANVAS:

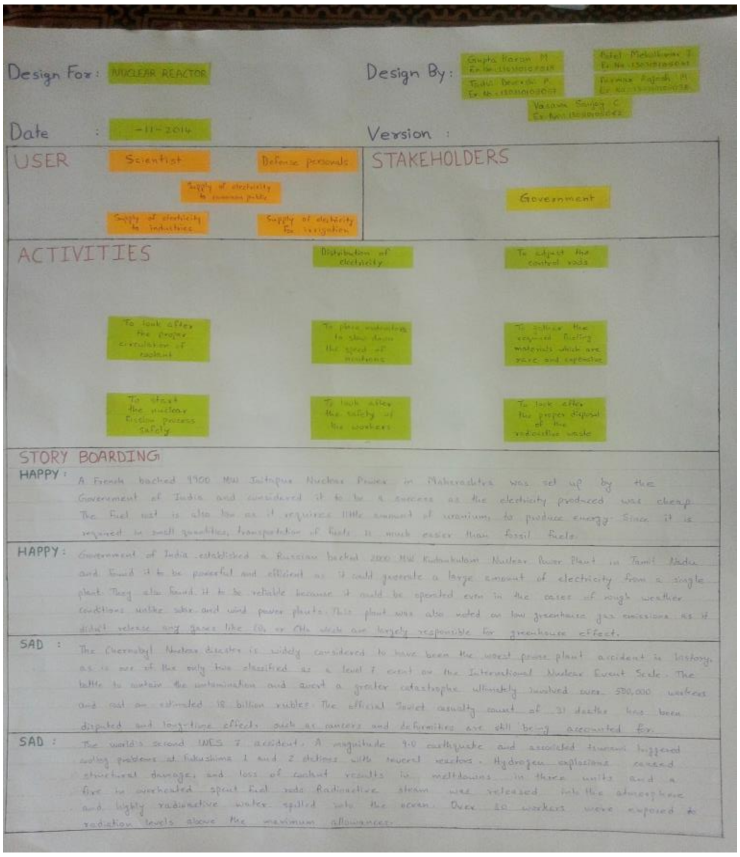

Fig (1.1) Empathy mapping canvas

IDEATION CANVAS:

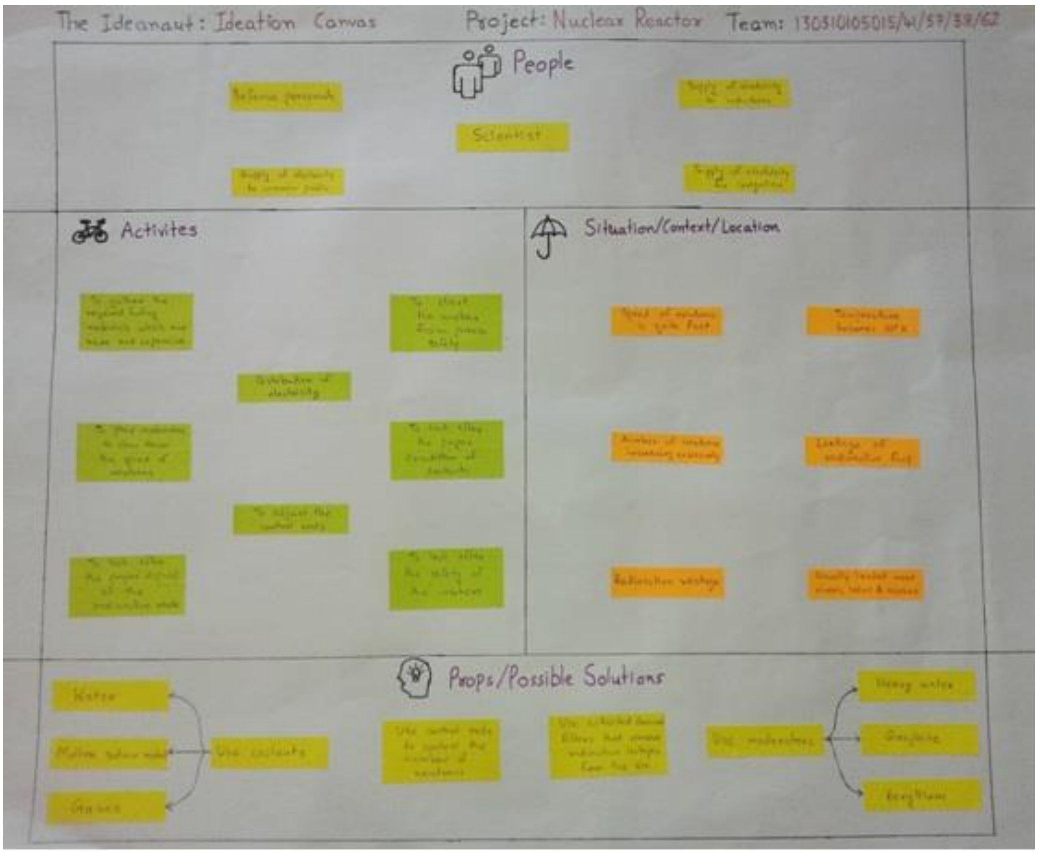

Fig (1.2) Ideation canvas

PRODUCT DEVELOPMENT CANVAS:

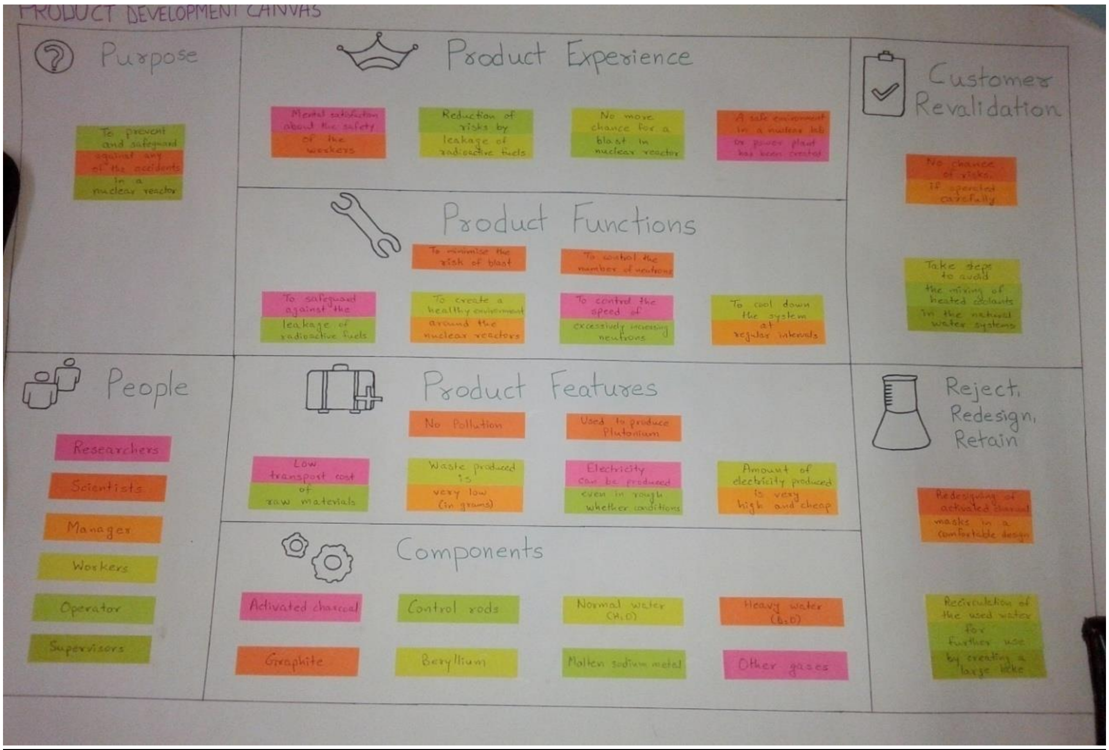

Fig (1.3) Product development canvas

➢ Activities:-

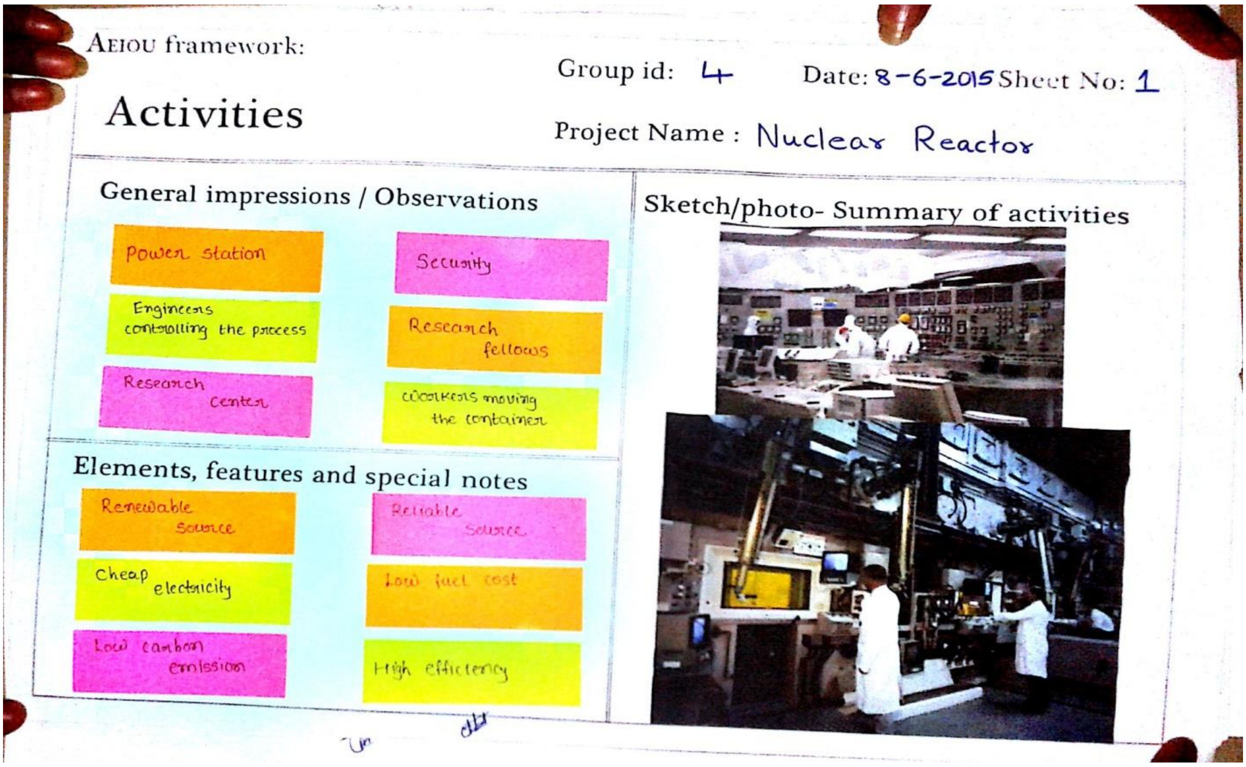

Fig (1.4) Activity canvas

➢ Environment:-

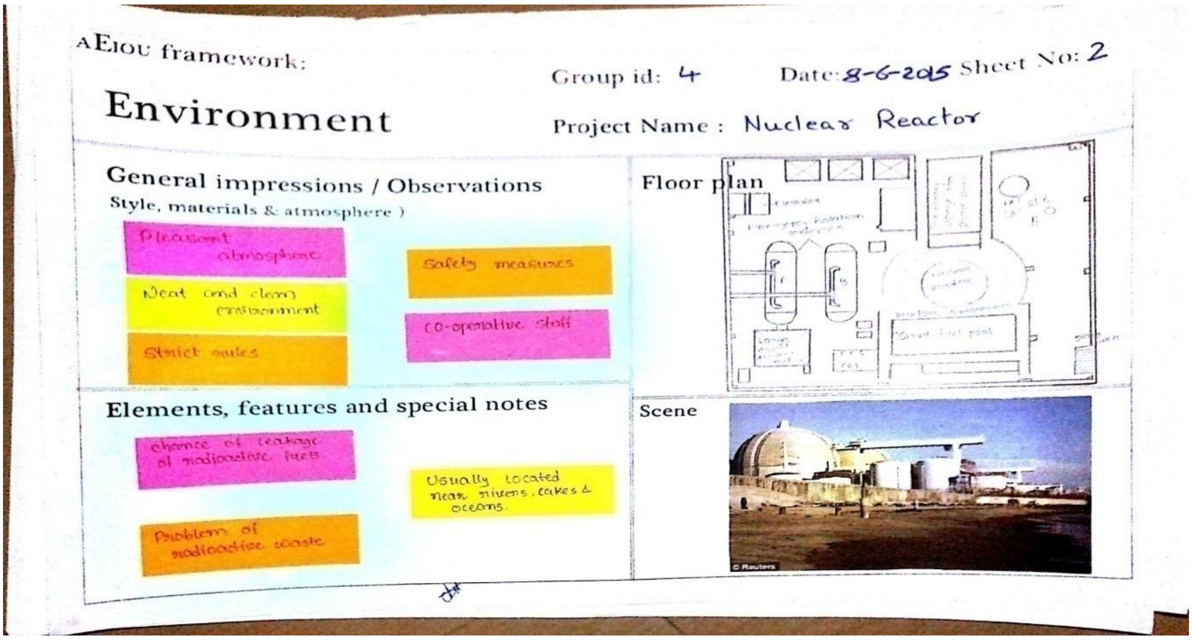

Fig (1.5) Environment canvas

➢ Interaction:-

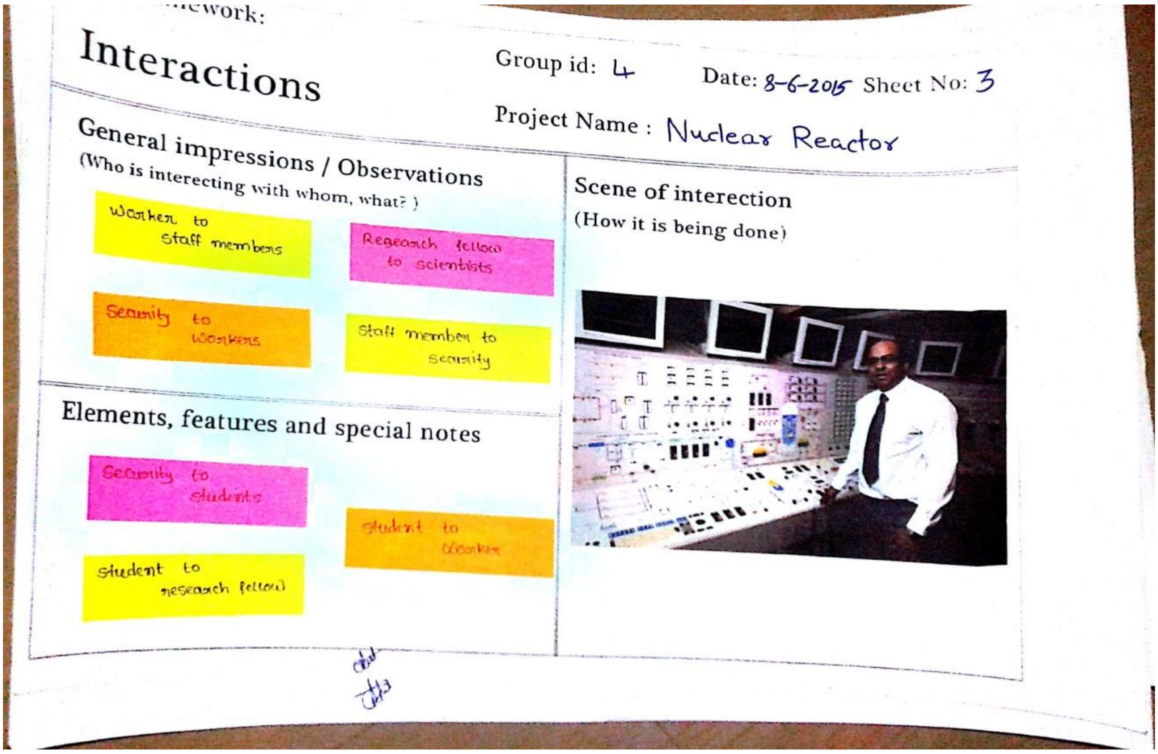

Fig (1.6) Interaction canvas

➢ Objects:-

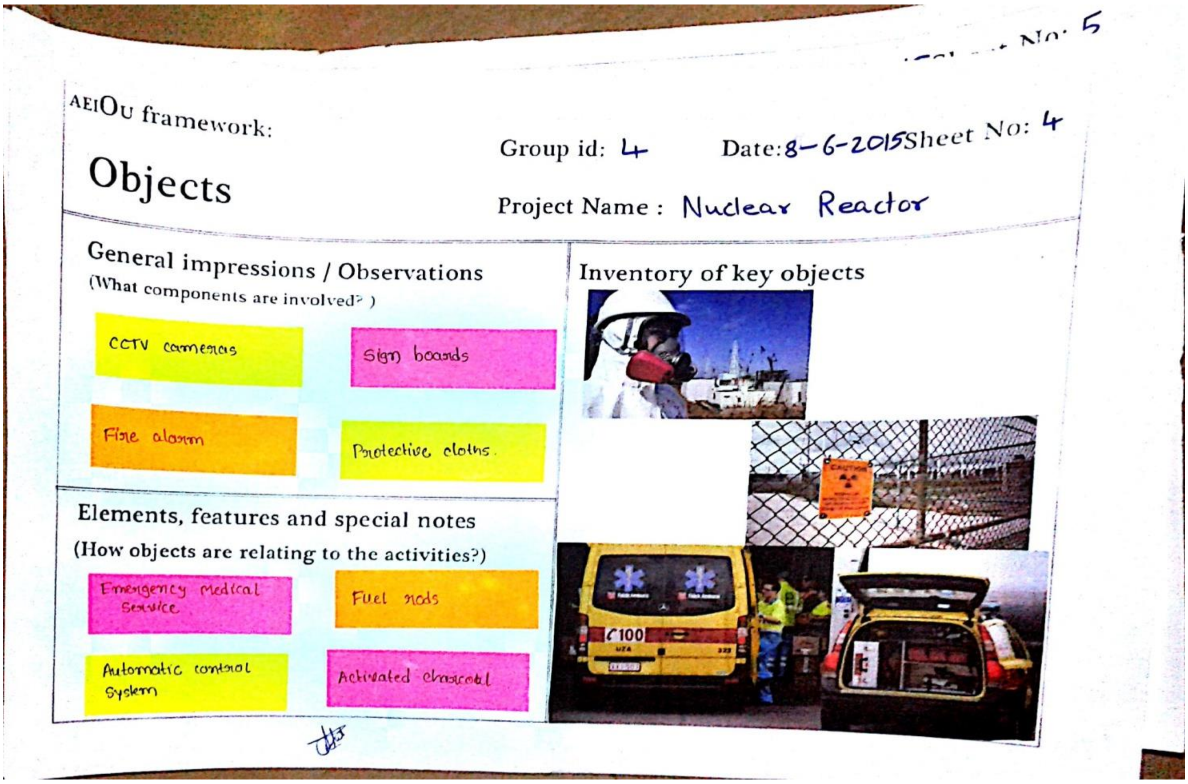

Fig (1.7) Objects canvas

➢ User:-

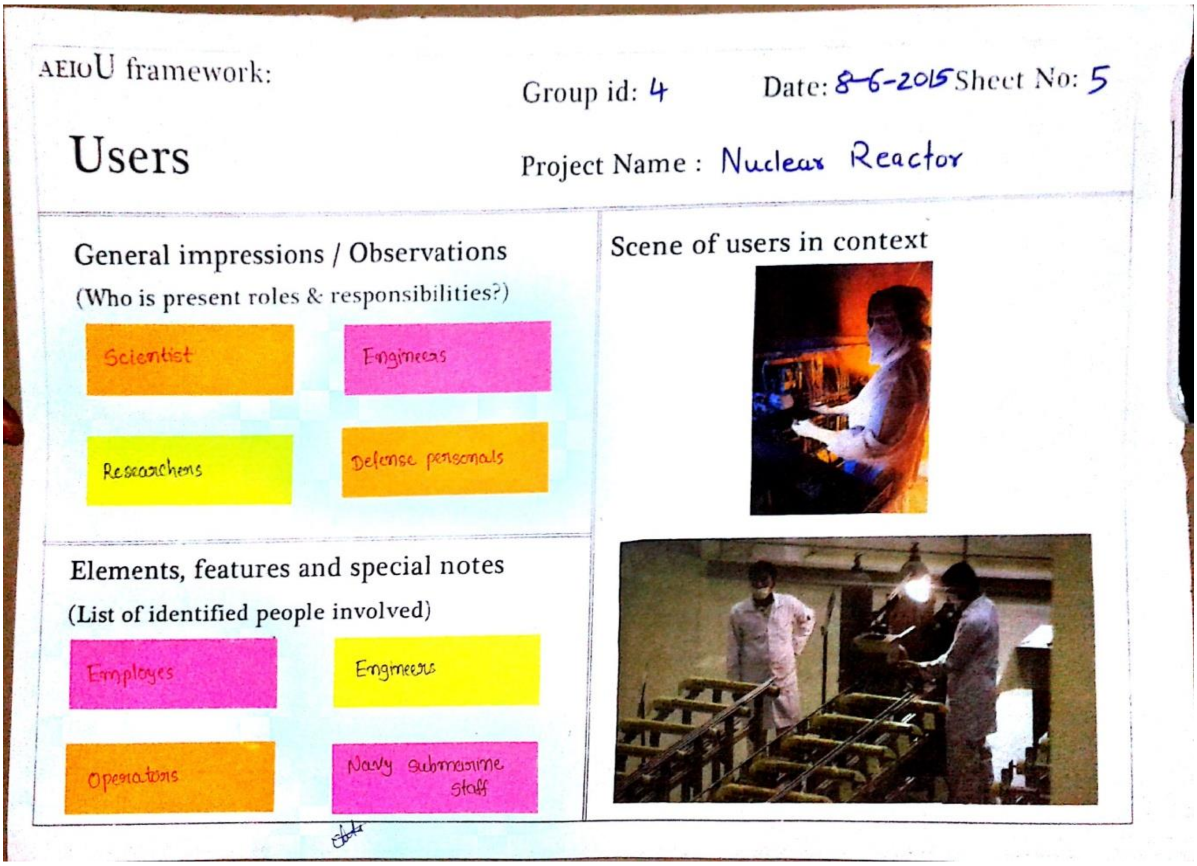

Fig (1.8) Users canvas

➢ Learning Needs Matrix:-

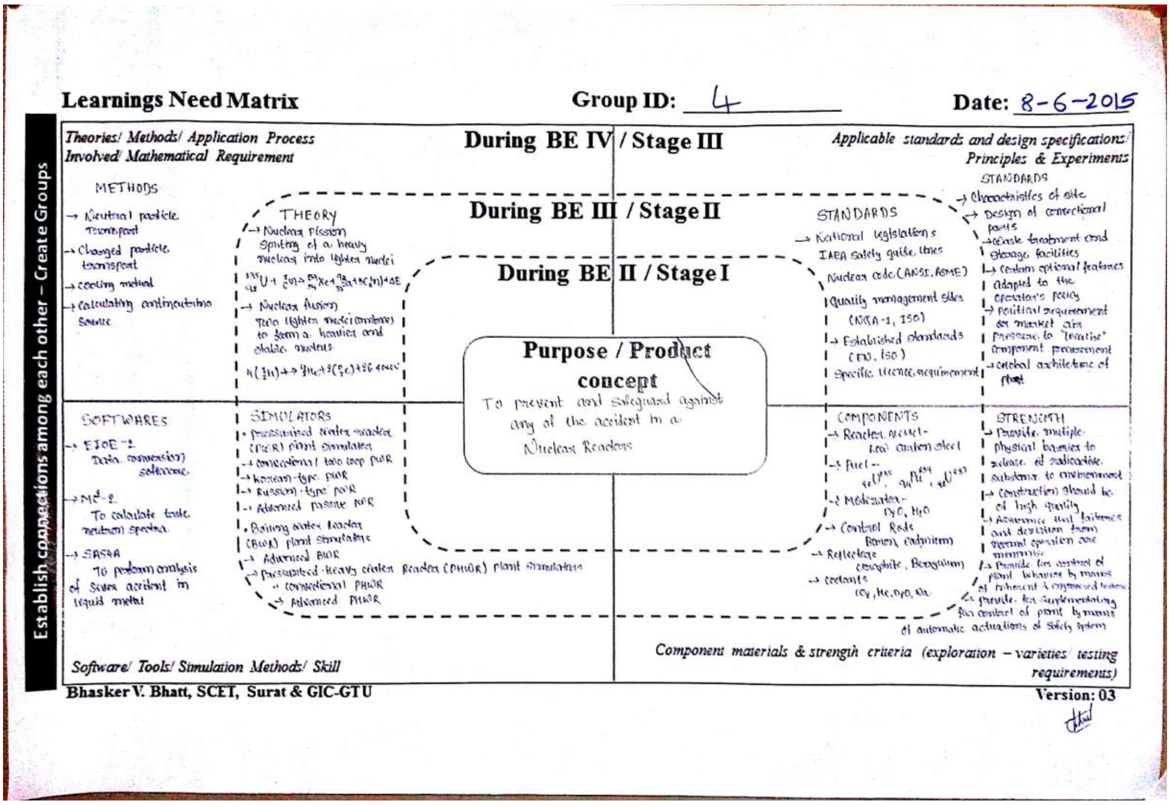

Fig (1.9) Matrix canvas

Chapter 2: Simulation and Analysis (software modeling), Mathematical model: -

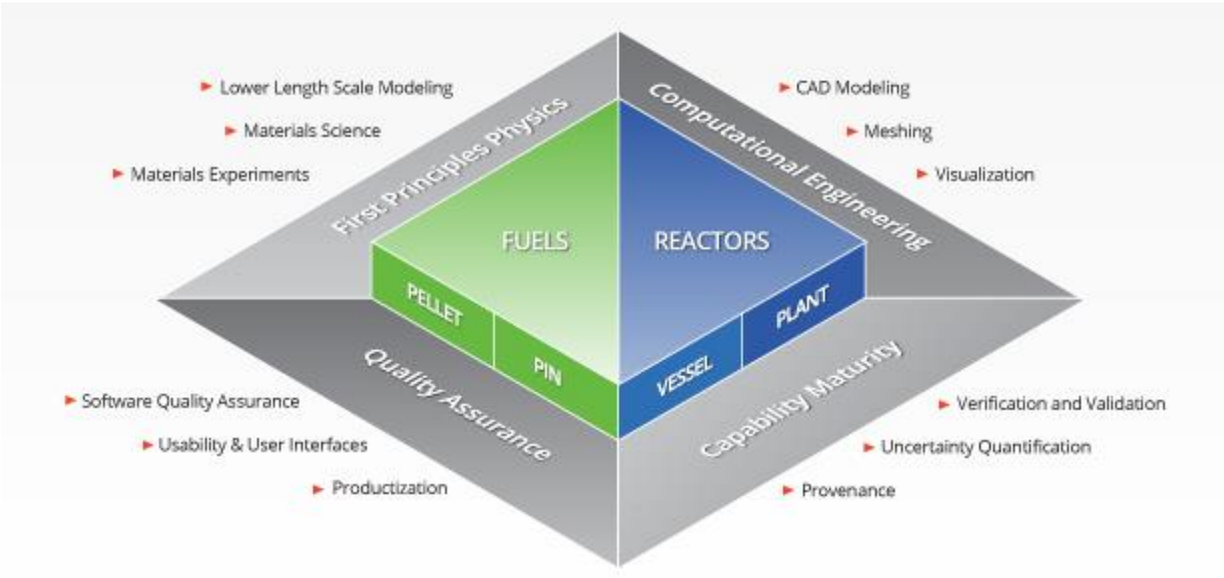

Fig (2.1) Mathematical Model

(2.1) ADVANCING THE STATE OF THE ART

Innovation advances science. Historically, innovation resulted almost exclusively from fundamental theories combined with observation and experimentation over time. With advancements in engineering, computing power and visualization tools, scientists from all disciplines are gaining insights into physical systems in ways not possible with traditional approaches alone.

Modeling and simulation has a long history with researchers and scientists exploring nuclear energy technologies. In fact, the existing fleet of currently operating reactors was licensed with computational tools that were produced or initiated in the 1970s. Researchers and scientists in NEAMS are developing new tools to predict the performance, reliability and economics of advanced nuclear power plants. The new computational tools will allow researchers to explore in ways never before practical, at the level of detail dictated by the governing phenomena, all the way from important changes in the materials of a nuclear fuel pellet to the full-scale operation of a complete nuclear power plant. For efficiency and practicality, the NEAMS program organizes its development activities into two distinct categories: the Fuels Product Line and the Reactors Product Line. Teams concentrating on the Fuels Product Line investigate the materials that comprise and surround nuclear fuel. The Reactor Product Line team focuses on developing design tools to study the full reactor system. These tools give the models and codes credibility and certainty needed for real world situations. By providing the capability to couple the Fuels and Reactors Product Lines, entirely new classes of problems can be tackled with fidelity never before attained. In this regard, the NEAMS Toolkit provides the designer with a truly predictive capability that spans the “pellet to plant”.

Chapter 3: Engineering Economics of Design:-

(3.1) Cost Estimation:-

The total cost of a mask is estimated to be approximately Rs.800/-

It includes the buying of materials, the cost of molding these materials as per our requirement, the cost of manufacturing the mask in appropriate thermal conditions and under appropriate pressure, the cost of labors and the overhead cost incurred.

(3.2) Labor, Material and Overhead cost:-

(3.2.1) Labor cost:

The cost of labor is high in such processes, and it is hence assumed to be Rs.30/- per mask manufactured.

(3.2.2) Material cost:

The materials required for manufacturing this type of mask are activated charcoal, membranes to be used as filters, and the cost of other materials used for its construction. The amount of activated charcoal powder required for manufacturing of one mask would be approximately one kilogram. And for the filtration part, we use Nano-filters of 0.001-0.0001 pore size and an operating pressure of 50-300 psi. Here, Nano-filters are used as the membranes for filtering the activated charcoal particles from the pure air.

Cost of one kilogram of activated charcoal is Rs.450/-. The cost of membrane filters that would be used in manufacturing of one mask is estimated to be Rs.250/-. The cost of other various materials to be used in lesser proportions is Rs.20/- per mask.

Hence, the total cost of materials comes out to be the additive summation of cost is mask. That means a total of Rs.720/- is required to gather the materials to be used in one mask.

(3.2.3) Overhead cost:

Those general charges or expenses in any business which cannot be charged up as belonging exclusively to any particular part of the work or product as where different kinds of goods are made, or where there are different departments in a business called also fixed charges establishment charges, or (in a manufacturing business administration charges selling charges, and distribution charges, etc.

The selling and distribution charges incurred for manufacturing one mask is assumed approximately Rs.50/-.

(3.2.4) Total cost:

Thus, the total cost incurred for manufacturing one mask is the additive summation of labor cost, material cost and the overhead cost.

Total cost = (labor cost) + (material cost) + (overhead cost)
= 30 + 720 + 50
= Rs.800/- per mask manufactured.

Hence the cost estimation comes to be:

(3.3) The Time value of Money:-

The time value of money (TVM) is the idea that money available at the present time is worth more than the same amount in the future due to its potential earning capacity. This core principle of finance holds that, provided money can earn interest, any amount of money is worth more the sooner it is received.

If we want to reduce the climate impact of electric power generation in the United States, there are less costly and risky ways to do it than expanding nuclear power. A 2011 UCS analysis of new nuclear projects in Florida and Georgia shows that the power provided by the new plants would be more expensive per kilowatt than several alternatives, including energy efficiency measures, renewable energy sources such as biomass and wind, and new natural gas plants.

Public financing for energy alternatives should be focused on fostering innovation and achieving the largest possible reduction in heat-trapping emissions per dollar invested—not on promoting the growth of an industry that has repeatedly shown itself to be a highly risky investment. The industry has failed to prove that things will be different this time around: soaring, uncertain costs continue to plague nuclear power in the 21st century. Between 2002 and 2008, for example, cost estimates for new nuclear plant construction rose from between $2 billion and $4 billion per unit to $9 billion per unit, according to a 2009 UCS report, while experience with new construction in Europe has seen costs continue to soar.

Chapter 4: Design for Use, Reuse and Sustainability:-

(4.1) Design for Use – How long this design will work

(4.1.1) Reliability

Nuclear power is the most efficient and reliable source of large-scale, around-the-clock electricity. High reliability and dependability mean that electricity is available on the grid whenever needed, all the time. This is particularly important during periods of extreme heat or cold. Another part of reliability is the energy-intensive nature of uranium fuel. A single uranium pellet, slightly larger than a pencil eraser, contains the same energy as a ton of coal, three barrels of oil or 17,000 cubic feet of natural gas. Each uranium fuel pellet provides heat for up to five years to make steam for power generation, making uranium an important part of base load fuel diversity that ensures grid stability. Nuclear plants are built to run all the time and provide full power when it is most needed. A third of a reactor's fuel is replaced every 18-24 months during short, scheduled spring and fall refuelling outages. This means America's nuclear energy plants can supply large amounts of predictable, reliable electricity through virtually every period of extreme heat and cold.

(4.1.2) Maintainability

Experience has shown that maintenance and operability aspects must be addressed in the design work. ABB Atom has since long an ambition of achieving optimized, overall plant designs, and efficient feedback of growing operating experience has stepwise eliminated shortcomings, and yielded better and better plant operating performances. The records of the plants of the latest design versions are very good; four units in Sweden have operated at an energy availability of 90.1%, and the two Olkiluoto units in Finland at a load factor of 92.7%, over the last decade. The occupational radiation exposures have also been at a low level. The possibilities for implementing 'lessons learned' in existing plants are obviously limited by practical constraints. In Finland and Sweden, significant modernizations are still underway, however, involving replacement of mechanical equipment, and upgrading and back fitting of I and C systems on a large scale, in most of the plants. The BWR 90 design focuses on meeting requirements from utilities as well as new regulatory requirements, with a particular emphasis on the consequences of severe accidents; there shall be no large releases to the environment. Other design improvements involve: all-digital I and C systems and enhanced human factors engineering to improve work environment for operators, optimization of buildings and containment to decrease construction time and costs, and selection of materials as well as maintenance of operating procedures to reduce radiation exposures even further. The BWR 90 design was offered to Finland in the early 1990s, but development work continues. It has been selected by a number of European utilities for assessing its conformance with the European Utility Requirements (EUR), aiming at a specific EUR Volume 3 for the BWR 90.

(4.2) Design for Reuse

- Used nuclear fuel has long been reprocessed to extract fissile materials for recycling and to reduce the volume of high-level wastes.
- Recycling today is largely based on the conversion of fertile U-238 to fissile plutonium.
- New reprocessing technologies are being developed to be deployed in conjunction with fast neutron reactors which will burn all long-lived actinides, including all uranium and plutonium, without separating them from one another.
- A significant amount of plutonium recovered from used fuel is currently recycled into MOX fuel; a small amount of recovered uranium is recycled so far.

Fig (4.1) Tin cans of nuclear fuel as waste

(4.3) Design for Sustainability

Nuclear energy plays an integral role in providing clean energy for global sustainable development. The world has seen the successful international development and expansion of nuclear technology for energy, agriculture, medicine, food preservation, hydrology, industry and ecology in support of sustainable development.

The World Business Council for Sustainable Development recognized nuclear energy's contribution to clean air and sustainable development in its March 2007 report "Policy Directions to 2050":

Three key technologies will be required to deliver sufficient scale of electricity generation and greenhouse gas reduction: renewables, nuclear power and clean-coal technology.

The U.N. World Commission on Environment and Development created the classic definition of sustainable development in its report, "Our Common Future":

> "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Chapter 5: Prototyping:-

A prototype is an early sample, model, or release of a product built to test a concept or process or to act as a thing to be replicated or learned from. It is a term used in a variety of contexts, including semantics, design, electronics, and software programming. A prototype is designed to test and try a new design to enhance precision by system analysts and users. Prototyping serves to provide specifications for a real, working system rather than a theoretical one. In some workflow models, creating a prototype (a process sometimes called materialization) is the step between the formalization and the evaluation of an idea.

Two prototypes have been made by our team for this project on “Nuclear Reactor”. One is of the demo model of nuclear power plant located near the water bodies. As per our suggested solutions in Design Engineering – 1A, we have kept a small lake as water body, so that the hot water from the reactor may be cooled in the lake and the same water can be re-circulated and re-used into the reactor for further condensation.

In the prototype the main building is near the reactor so as to control the functions of the power plant. There are three reactors in our prototype, behind which, there is a power generation unit consisting of the turbines, generators and electricity distribution channels. The raw materials for the nuclear power plant come into the same unit. As discussed above, the heated water from the reactor is passed to the cooling tower, where water is cooled up to some extent. And now, this water containing the traces of nuclear cannot be released in to the water bodies like rivers or oceans, as it may destroy the marine life. Thus, this water from the cooling tower is sent to the artificially created water body (lake), where it is stored and cooled by natural process. It is then sent for re-use in the nuclear reactors.

Another prototype made for this project is a mask for the safety of labourers, workers, scientists, lab supervisors and other working staff, in case of radiation leak from the reactor or from the nuclear waste. This mask is made up of activated charcoal as a primary filter and membrane filters as the secondary filter. Nano-filters are used as the membrane filters with a pore size of 0.001-0.0001 and pressure of 50-300 psi, to avoid the passage of activated charcoal particles. This mask made up of activated charcoal as primary filter adsorbs the radiated molecules on its surface and passes only the air through it. This is the working principle of the second prototype, activated charcoal mask.

Chapter 6: Test the Prototype:-

The prototypes of nuclear power plant made by us, as well as the activated charcoal mask for the safety of laborers, supervisors and working staff cannot be tested within the nuclear power plant premises for the safety reasons. So it was not possible for us to do this step.

Chapter 7: Measuring Instrument/ technique – knowledge and use, manufacturing/ fabrication process, electronic circuit/ boards, open source tool:-

(7.1) There are five methods for detection and measurement of radioactivity:

(7.1.1) Cloud chamber: - This technique is used for detecting radioactivity. The chamber contains air saturated with water vapor. When the piston is lowered suddenly, the gas expands and is super cooled. When alpha and beta particles of water condense, the trail or cloud thus product marks the track of the particle. The track can be seen through can be seen through the window above and immediately photographed. The bubble chamber method gives better photographs of the particles tracks.

(7.1.2) Ionization Chamber: - This is simplest device used to measure the strength of radiation. An ionization chamber is fitted with two metal plates separated by air. When radiation passes through this chamber, it knocks electrons from gas molecules and positive ions are formed. The electrons migrate to the anode and positive ions to the cathode, giving the strength of radiation that passes through ionization chamber.

In an ionization chamber, thus a small current passes between the plates. This current can be measured with an ammeter, and called Dosimeter, the total of electric charge passing between the plates in a given time is measured. This is proportional to the total amount of radiation that has gone through the chamber.

(7.1.3) Geiger Muller Counter: - This device is used for detecting the rate of emission of alpha or beta particles. It consists of a cylindrical metal tube and a center wire. The tube is filled with argon gas at reduced pressure. A potential difference of about 1000 volts is applied across the electrode. When an alpha or beta particles enters the tube through the mica window, it ionizes the argon atoms along its path.

The argon ions are drawn to the cathode and electrons to anode. Thus for a fraction of a second, a pulse of electrical current flows between the electrons and completes the circuit around.

Each electron pulse marks the entry of one alpha particle into the tube and is recorded in an automatic counter. The number of such pulses resister by a radioactive material per minute, gives the intensity of its radioactivity.

(7.1.4) Scintillation Counter: - Rutherford used a spinthariscope for the detection and alpha particles. The radioactive substance mounted on the tip of the wire emitted alpha particle, each particle on striking the zinc through the eye-piece. With this device it was possible to counter alpha particle from 50 to 200 per second. A modern scintillation counter also works on the above principle and is widely used for the measurement of alpha or beta particles. Instead of the zinc sulphide screen, a crystal of sodium iodide with a little thallium iodide is employed. The sample of the radioactive substance contained in a small vial is placed in a well cut into the crystal. The radiation from the sample hit the crystal wall and produces scintillation. These falls on a photoelectric cell which a pulse of electric current for each flash of light. This is recorded in a mechanical counter. Such a scintillation counter can measure radiation up to a million per second.

(7.1.5) Film Badges: - A film badges consists of a photographic film encased in a plastic holder. When exposed to radiation they darken the grain of silver in photographic film. The film developed and viewed under a powerful microscope. As alpha or beta particles pass through the film they leave a track of black particles. These particles can be counted. In this way the type of radiation and its intensity can be known. However alpha radiation darkens the photographic film uniformly. The amount of darkening tells the quantity of radiation. A film badge is an important device to monitor the extent of exposure of persons working in the vicinity of radiation. The badge film is developed periodically to see if any significant dose of radiation has been absorbed by the wearer.

Chapter 8: Comparison of existing material, methods, tools and equipment for your project and justify your selection of materials, methods, tools and equipment etc.:-

We have seen that uranium-235 is used as a reactor fuel for producing electricity. But our limited supplied of uranium-235 is predicated to last only for another fifty years. However, no fissionable uranium-238 is about 100 times more plentiful in nature. This is used as a source of energy in the so-called breeder reactor which can supply energy to the word for 5,000 years or more.

Here the uranium-235 core is covered with a layer or ‘blanket’ of uranium-238. The neutrons released by the core are absorbed by the blanket of uranium-238. This is then converted to fissionable plutonium-239. It undergoes a chain reaction, producing more neutrons and energy.

$_{92}U^{238} + {_0}n^1 = {_{94}}Pu^{239} + 2\ {_{-1}}e^0$

$_{94}Pu^{239} + {_0}n^1 = {_{38}}Sr^{90} + {_{56}}Ba^{147} + 3\ {_0}n^1$

The above reaction sequence produce three neutrons and consumes and only two. The excess neutron goes to converted more uranium to plutonium-239. Thus the reactor produce or ‘breeds’ its own fuel and hence its name. Several breeder reactors are now functioning in Europe. However, there is opposition to these because the plutonium so obtained can be used in the breaded H-bomb.

This deadly device makes use of the nuclear fission of the isotopes of hydrogen. It consists of a small plutonium fission bomb with a container of isotopes of hydrogen. While the exact reaction used is a strictly guarded military secret, a fusion reaction between H-2 and H-3 may be the possible source of the tremendous energy released.

The fusion bomb produces the high temperature required for nuclear fusion triggers the H-bomb. The explosion of such a bomb is much more powerful than that of a fission bomb or atomic bomb. Fortunately, the H-bombs have been tested and not used in actual warfare. If they are ever used, it may mean the end of civilization on earth.

The material used in the mask for the safety of the workers is made up of activated charcoal. Silica gel is not used for this material formation as it is a drying agent, as compared to activated charcoal which adsorbs the radioactive gases on its surface and does not allow it to pass.

Any types of metal or alloy are not preferable to be used in the shielding of the nuclear reactor because the extreme heat of the reactor can affect the shield material by melting. Thus instead of using this, a strong concrete shield is made on the outer surface of the reactor, which is not affected much by its heat.

Chapter 9: Conclusion & future scope:-

With the melodramatic history of nuclear energy in America, it's no wonder people look at it with skepticism. But while industry management was lacking, the technology has not disappointed. New concepts now in development will not only help us through the current energy/environmental crisis, they will answer long held concerns about nuclear energy.

Nuclear power is a highly efficient and dense source of energy with no greenhouse emissions and an abundant supply of fuel. But the industry has been plagued by poor management and a communication strategy of tech-babble. There are some valid concerns about safety associated with nuclear energy, but many of the most popular ones are not justified.

Many people are concerned about the radiation risks of living near a nuclear reactor. Thankfully, these risks are overstated. The amount of radiation you get from walking past an X-ray room in a hospital would not be acceptable for workers at a nuclear plant.

What if someone crashes a plane into the reactor? That would be terrible, but not because of radiation leaks. All nuclear plants in America have been retrofitted with redundant safety systems, including ones that make them passively safe. This means even if everybody at the plant is asleep when something terrible happens, natural forces will cause the reaction to shut down.

What about the Three Mile Island accident in 1979? In the worse nuclear reactor "disaster" in our nation's history, the physical plant failure released no radiation thanks to redundant safety systems, but the communication failure was catastrophic. Authorities did little to explain to the public what had happened. And the resulting safety measures put in place in all reactors were largely ignored. This incident was the beginning of the end of open discussion about nuclear energy.

Periodic stupid decisions by plant operators about how to deal with low-level waste have also damaged the credibility of the entire nuclear industry.

The concerns about high-level waste in Yucca Mountain are valid. We can't say what is going to happen in a thousand years. And with current technology, all we can do is sit on it. But that's not to say we don't have a plan.

The Generation IV International Forum (GIF) comprises scientists from 10 nations cooperating on development of advanced nuclear reactors. These concept reactors were designed with several goals in mind including proliferation resistance, improved safety, elimination of high-level waste, and sustainability.

Several of the Gen IV concepts are called fast reactors. These reactors will eliminate the production of high-level waste by using it as fuel. Fast reactors, such as the Sodium-cooled Fast Reactor (SFR), will be able to consume spent fuel from other reactors, and conceivably the waste now stored in Yucca Mountain. The resulting low-level waste will completely decay in much more manageable time frames.

Another Gen IV concept reactor is called the Very High Temperature Reactor (VHTR). The high temperatures in this reactor will allow it to excel at applications other sources of energy would be ineffective at, such as high volume production of hydrogen to be used in vehicles and home heating, and manufacturing steel and aluminum.

These concepts include built-in redundant active and passive safety systems. The life cycle of nuclear fuel will ensure that weapons grade material will never be isolated to minimize proliferation of nuclear weapons.

Gen IV reactors could be ready for commercial use as early as 2030, depending on funding of research. Intermediate designs can be implemented before that. Fortunately, these concepts have received vigorous international support so far.

Nuclear energy will be most effective as part of a broad portfolio of energy sources. Wind and solar energy have the potential to be very affordable and portable solutions. Nuclear can meet needs other sources would be poorly suited to, such as efficiently producing hydrogen, metallurgy, and efficient production of electricity on large scales.