Fundamentals of Nuclear Power Generation
Dr. Dipankar N. Basu
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati

Lecture – 01
Introduction of Nuclear Energy

Hello and welcome to this CSS MOOC's course, entitled fundamentals of nuclear power generation; which has been offered under the NPTEL online certification scheme. I am Dipankar N Basu assistant professor in the department of mechanical engineering, IIT Guwahati. And I am going to be your instructor for the entire of this course. Now the as I have already mentioned in the introduction video that the topic of nuclear power generation is a bit of advanced level topic.

And therefore, I would expect the entire audience of mine to be either at the advance level of your analogy curriculum or may be during a post graduate; that is, you must be at least at the 6 semester of your UG course or a may during a master specializing in mechanical, thermal or nuclear or power engineering so that you already have the fundamental knowledge about fluid mechanics and heat transfer. And also, you are aware about the laws of thermodynamics, and also you are quite aware about the differential calculus, or differential equations rather, because we need to make use of those concepts, some of those concepts in different sections of this particular course.

It is quite a bit odd for me that there is no audience in front of me. And I am not a in a position to have direct interaction with you, or have eye contact with you, face your questions directly. But still I would like to keep this course as much interacting as I can so that that means, I would like to follow a more questions as I kind of a pattern. So, and I am sure all of you are going to respond; that is, whenever you have any query or any doubt or you need any clarification, do not hesitate to drop a mail to me. I would try to respond to that at the earliest and for that purpose, while my contact details are already available on the course. So, you should also know the friends; that is, my ts I have 3 PhD students as my ts.

(Refer Slide Time: 02:19)

All of them are quite senior PhD scholar in the department of mechanical engineering, IIT Guwahati, Mister Kiran Saikia who is working in the field of boiling water reactors. And therefore, his PhD topic is quite relevant to the content of this course. Mister Bhaskarjyoti Sharma is working on micro fluidics and heat transfer at microscale. Whereas, mister Milan Sarkar, another senior PhD student he is working on super critical boilers or super critical nuclear reactors; which is again an advanced level nuclear reactor and if possible would like to mention about that sometimes in this course. Their contact details are also available there. So, you can send mail to either of them as well regarding any kind of clarification.

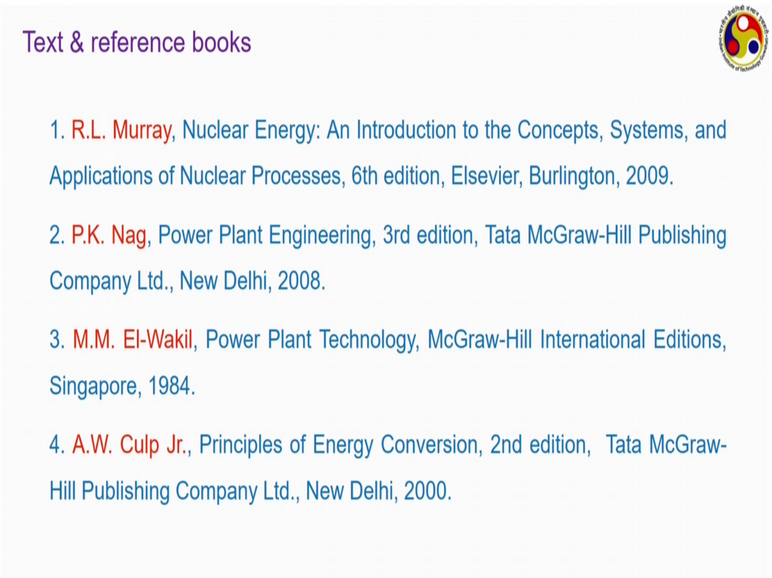
(Refer Slide Time: 03:08)

Now, it is already available the course outline on the course web page. But still I would like to repeat it here. Here this course we shall be starting from the very fundamentals of nuclear power generation; that is, introducing the concept of atomic power generation, discussing about very briefly about the atomic structures, and the source of nuclear energy. And from there gradually shall be moving to more complicated or more advanced topics. Accordingly, the entire content has been divided in to 12 modules. And it is span for 12 weeks.

So, the objective is to cover one module in every week, accordingly each of the modules some of the modules rather it be covered in 2 lectures some of them may require 3 or 4 lectures. And each of the module will be followed by one tutorial. Where the tutorial may contain multiple choice questions, may contain the numerical problems or may have slightly discrete one as well, depending upon the content of that particular module.

Again, as I mentioned hint towards the solution of all this tutorials will be given, and we shall be there for helping you while solving this tutorials. I would also like to solve some sample problems after every module or after any relevant module.

(Refer Slide Time: 04:25)

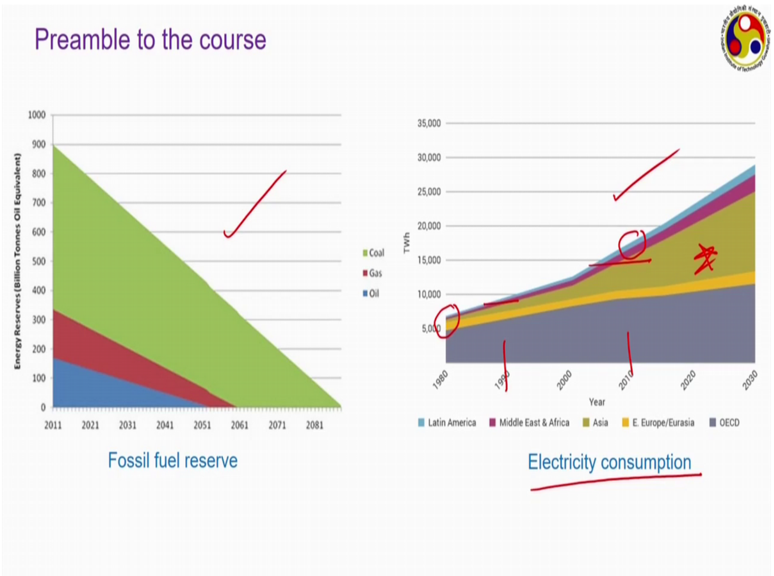


And these are the text books that we shall be following in this course; where I shall mostly be following the book of remand murray. But any of you may not be having direct access to this one. So, you can follow either of the next 2, the book on power planning engineering by professor P K Nag. I think the third edition is the latest one. And also the look by M M El Wakil on power plant technology, another classical book. Both of them has a chapter on nuclear power generation; which is very much relevant, and if I go back to the course outline, both of this books will be sufficient to cover up to module number 8 or 9 for this particular course.

But of course, the rest of 3 modules where we shall be discussing about several advanced topics such as biological effects of radiation, the reactor safety and security, and also the waste management. These are more modern-day topics and they may not be available in the books. You can refer to different materials available on internet and of course, the lectures will be there for your help. Now the topic of nuclear power generation has a quite rich history. Of course, I am in history point of view I am not talking about the way other sources of power generations are invented, and how they came into practice. Rather it has a quite a way of checkered history, because the term nuclear energy where introduced to the man kind only after that (Refer Time: 05:50) at Hiroshima in 1945. And it is quite fascinating to think that in just about 6 7 decades from that point. We are discussing about nuclear power as a possible source of power generation, or is a possible solution for future energy demands.

The term which came to the concept of or came to the knowledge of common people, there is something synonymous to greater destruction. It is only thanks to the contribution of several researches and several scientist, who kept on working on this and didn't just kept it limited to atomic energy do not kept limited atomic energy to the open related options, whether divert it to the commercial power generation. And because of that only 1950's first commercial nuclear power plant was established. And gradually we moved on to get a good share of the global energy production from the nuclear energy.

(Refer Slide Time: 06:53)



Just to justify the need of knowing the nuclear energy, I would like to show you this couple of projection that I have. This particular one, which I am sure all of you are aware that, presently we get the energy needs our day to day energy needs mostly from the fossil fuels like coal petroleum or natural gases; however, as per the considering the present energy reserves available and also the present-day consumption, this talks are not infinite rather they depleting at a very, very fast rate. And just going by this projection the stock of petroleum and natural gas are not expected to last longer than 2050 or 2060. Whereas, coal may survive for 340 years more, but by the year 2100 we are expected to run dry, if we keep on depending solely on this fossil fuels.

And now, if you compare that with the other projection; that is, where I am showing here the global electricity consumption. You can see here the electricity consumption is not only increasing year by year, but it is actually escalating at a very, very fast rate.

Particularly in Asian and middle east related countries; where we can see there is an accelerated growth. If we compare the figures say from 1990 to 2010 over this period of 20 years, the consumption in the Asian countries has become nearly double. Or at least 1.67 times. And in terms of the global figure, if you compare this one and 1980, which was around 6,000 turn or tower we should say, in 2010 it was around 18,000.

So, a 3 time increase in 30 years. And this electricity consumption is only going to increase at a even faster rate because of several quite well-known reasons; like, our fascinations towards electronic gadgets. We are depending on heavier machineries for solving every day to day needs of ours our fascination towards elimination. And so, several reasons, and therefore, we need to find some other options without instead of adjust continue to depending on the fossil fuels, we have to find some other options of electricity generation. And that is where the renewal and nuclear power comes into the (Refer Time: 09:24)

(Refer Slide Time: 09:24)

Global energy scenario

Regional energy use (kWh/capita & TWh) and growth 1990–2008 (%)									
	kWh/capita			Population (million)			Energy use (1,000 TWh)		
Region	1990	2008	Growth	1990	2008	Growth	1990	2008	Growth
USA	89,021	87,216	− 2%	250	305	22%	22.3	26.6	20%
EU-28	40,240	40,821	1%	473	499	5%	19.0	20.4	7%
Middle East	19,422	34,774	**79%**	132	199	**51%**	2.6	6.9	**170%**
China	8,839	18,608	**111%**	1,141	1,333	17%	10.1	24.8	**146%**
Latin America	11,281	14,421	28%	355	462	30%	4.0	6.7	66%
Africa	7,094	7,792	10%	634	984	**55%**	4.5	7.7	70%
India	4,419	6,280	**42%**	850	1,140	34%	3.8	7.2	**91%**
Others	25,217	23,871	− 5%	1,430	1,766	23%	36.1	42.2	17%
The World	19,422	21,283	**10%**	5,265	6,688	27%	102.3	142.3	39%

Courtesy: Wikipedia

Here I have some numbers to the substantiate the same point. If you compare the figures from 1990 to 2008, we can see the global population has increased by about 27 percent over that period. Where in European countries or a in some advanced nations, the growth rate is quite moderate china has done quite amical because their growth rate is only 17 percent, in middle east and African countries the growth rate is quite high. Over 50 percent and in fact, India is also not far behind, 34 percent increase in the population you can see in period of just 18 years.

Now, if you compare to the energy uses on the last set of data, we can see china has seen 140 percent a staggering number really 140 percent increase in their energy uses. Well, their population growth is only 17 percent. That leads to an 111 percent increase in their per capita energy consumption. Middle east is also not far behind. There the increase in energy consumption is even higher one 70 percent. And so, about 8 percent increase in the per capita energy consumption.

India has seen the energy consumption becoming nearly doubled leading to a 42 percent increase in the per capita of energy consumption. For as the advanced countries has done really good job; like, in a USA or in European countries, we have seen it to be more or less the same. In this others this involves about countries like Australia and others. Here you can see that is in fact, a reduction in the per capita energy consumption.

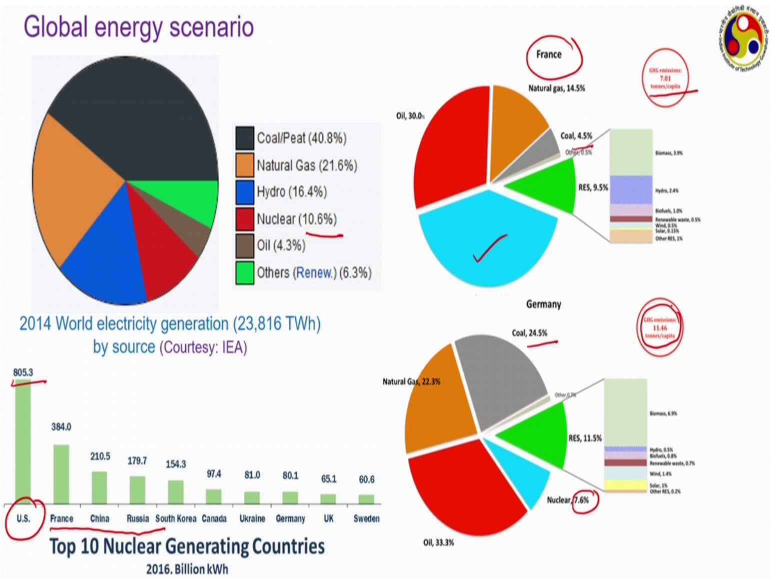
But because of the contribution coming from Asian and middle east countries, we have more than 10 percent increase in the per capita energy consumption over this period of 18 years, and that figure that actually that keeps on increasing. And therefore, we have taken for some newer option to develop a commercial electricity. And that is where the renewal energy and nuclear energy both comes into picture.

Now, renewable while conventionally renewable sources like solar wind biomass they definitely have a great future, there are several issues as well. Particularly they are intermittent in nature, like you know solar energy can supply electricity only during the day time and not at night periods or periods of 0 or insufficient solar energy solution. Wind energy requires a particular wind velocity. And so, they are very much location specific somewhat similar about biomass. And because of all these factors, the renewable energy till date are restricted more towards local scale, or they are more being thought about peak load stations. That is to meet the demand during the periods of the highest consumption.

Of course, effort is on to have base load solar or wind power stations and they are coming, coming up in a different countries at different rate. And that that is only going to increase in future, but there has still several issues to solve. Like in whenever you talk about nuclear, even without knowing anything people always keeps on complaining about the possible effects on the environment etcetera, but the conventional power sources like a coal and (Refer Time: 12:50) can have as detrimental environmental effect as nuclear wind has huge reservation from environmental protection point of view, like station wind powers in fact. And that is where nuclear particularly about that point on base peak load station nuclear course higher than renewable, because it cannot access act as a base load station. It can supply a continuous amount of electricity throughout the year without being bothered about the surrounding or environment or any other demographic issues etcetera.

And therefore, we also need to focus on nuclear. And that is why if you see the global energy scenario I have the data of 2014 here.

(Refer Slide Time: 13:32)

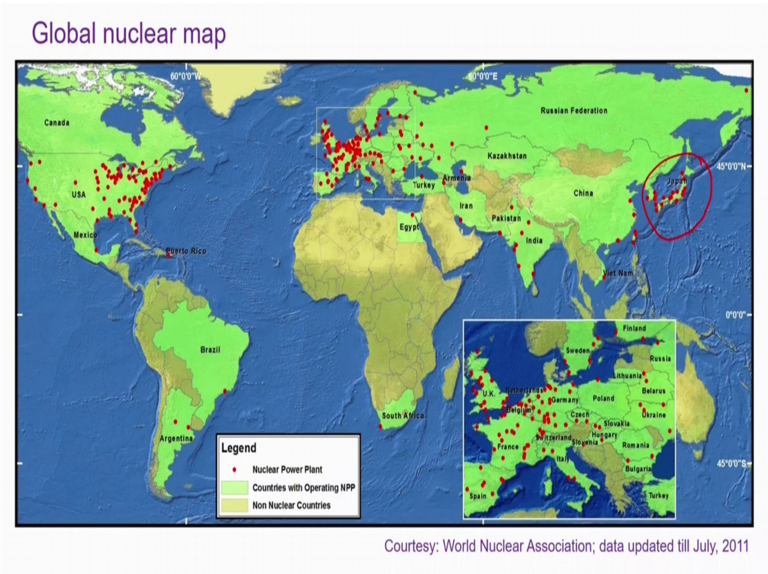


Nucleus still is this quite small fraction. Only 10 percent of the global energy consumption, but this percentage is actually increasing. Despite reservations from different sectors, the nuclear energy is there to exist. Before you see the country, wise scenario USA is the largest contributor. In fact, if you see this figure, this number that is production from us nuclear energy produced from us in the year 2016 is more than combining the next 3 is France china and Russia. But us is the huge country and that requires very large amount of electricity.

So, despite such a large numbers actually nuclear energy is a quite small portion of the total energy produced in us. But there are certain countries like France. France gets a good share of their total energy from nuclear. If you see this figure, nuclear consist of very large fraction in this particular case; which is well above 45 percent in France. The principle reason being the absence of fossil fuels sources in France like they are coal or oil reservoir quite limited compared to other countries. Just compare that to that with their neighbor Germany. Germany has a very decent reserve of coal, and that is why they are getting much larger fraction of their energy from coal which is just about 4.5 percent in France. It is 24.5 percent in case of Germany. And their nuclear share is quite small.

But I would like to attract your attention to another figure. See the greenhouse gas emission in case of France was 7.81, whereas, that for Germany is 11.46. I shall be coming back to this figure after a few slides.

(Refer Slide Time: 19:35)

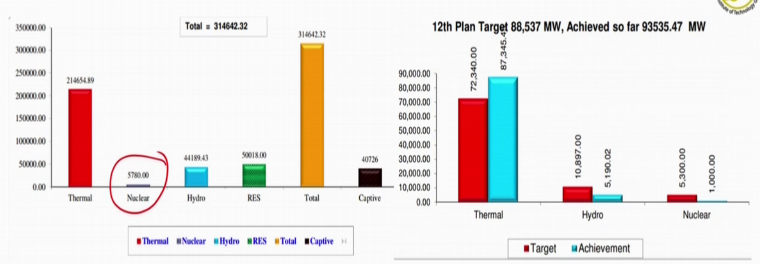


This is a global energy map, slightly old data of 2011. You can see in Europe and US in European countries and US there is a good spread of nuclear energy. And also, in Japan, Japan is a country that depends a lot on nuclear energy despite that Fukushima and associated effects.

India and china has seen an increase in their total nuclear production over a last 1 or 2 decades. And therefore, of course, there are other areas like in Africa or in Latin America there are very, very few nuclear resources. Or in the eastern part of Russia, but the feasible reason being the absence of corresponding uranium or other kind of fuels.

(Refer Slide Time: 16:26)

Indian energy scenario



Courtesy: CEA, Ministry of Power, GoI; data updated till January, 2017

Plan / Year	Thermal				Nuclear	Hydro	RES (MNRE)	Total
	Coal	Gas	Diesel	Total				
End of 6th Plan	26310.83	541.50	177.37	27029.70	1095	14460.02	0	42584.72
End of 7th Plan	41237.48	2343.00	165.09	43745.57	1565	18307.63	18.14	63636.34
End of 8th Plan	54154.48	6561.90	293.9	61010.28	2225	21658.08	902.01	85795.37
End of 9th Plan	62130.88	11163.10	1134.83	74428.81	2720	26268.76	1628.39	105045.96
End of 10th Plan	71121.38	13691.71	1201.75	86014.84	3900	34653.77	7760.6	132329.21
End of 11th Plan	112022.38	18381.05	1199.75	131603.18	4780	+ 11%	24503.45	199877.03
End of Jan 2017	**188487.88**	**25329.38**	**837.633**	**214654.89**	**5780**	[illegible]	**50018.00**	**314642.32**

Now, coming to the Indian scenario, by the year 2017, January 2017 effect; Indian was getting only a small fraction of their total production from nuclear. Just 5780 if you compare that coming from thermal it is extremely small fraction.

But far about that, I would like to again draw your attention to this next figures; where I have shown an year wise or the increase in the consumption of the from different sources increasing the production from sources over different 5-year plans; and now if you see the numbers at the end of the 11th plan, and also till January 2017, the increase in nuclear while it is only about 1000 megawatt. Actually by (Refer Time: 17:22) it is quite small covered to others. But now if we compare that from percentage, over which period hydro energy production has seen only an 11 percent increase. Whereas, nuclear energy has seen 21 percent increase. And as there are several nuclear power plants are planned in India it is expected to increase even more.

In fact, this 21 percent has gone even further because it is database till January 2017, but the latest Indian power nuclear power plant went operational in march 2017; which point where which added another 1000-megawatt capacity to this. And these are the breakup of union nuclear power plant started in as old as 1969 from that Tarapur atomic power plant.

(Refer Slide Time: 18:04)

Details of Indian nuclear power plants

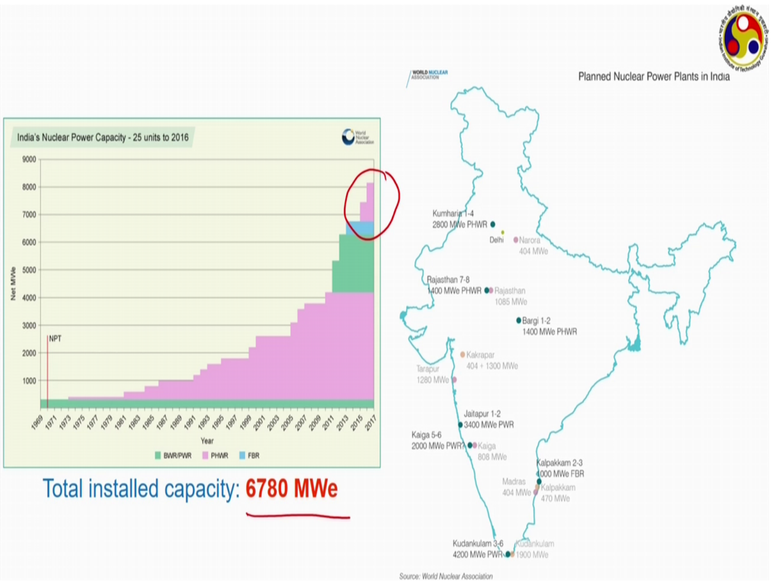
Sl.no.	Plant Name	Date of commercial operation	Location	Gross Power (MWe)	Type
1.	Tarapur Atomic Power Plant-1 (TAPS-1)	Oct-1969	BOISAR, MAHARASTRA	160	BWR
2.	Tarapur Atomic Power Plant-2 (TAPS-2)	Oct-1969	BOISAR, MAHARASTRA	160	BWR
3.	Rajasthan Atomic Power Plant-1 (RAPS-1)	Dec-1973	KOTA, RAJASTHAN	100	PHWR
4.	Rajasthan Atomic Power Plant-2 (RAPS-2)	Apr-1981	KOTA, RAJASTHAN	200	PHWR
5.	Madras Atomic Power Plant-1 (MAPS-1)	Jan-1984	KALPAKKAM, TAMILNADU	220	PHWR
6.	Madras Atomic Power Plant-2 (MAPS-2)	Mar-1986	KALPAKKAM, TAMILNADU	220	PHWR
7.	Narora Atomic Power Plant-1 (NAPS-1)	Jan-1991	NARORA, UTTAR PRADESH	220	PHWR
8.	Narora Atomic Power Plant-2 (NAPS-2)	Jul-1992	NARORA, UTTAR PRADESH	220	PHWR
9.	Kakrapar Atomic Power Plant-1 (KAPS-1)	May-1993	TAPI, GUJARAT	220	PHWR
10.	Kakrapar Atomic Power Plant-2 (KAPS-2)	Sep-1995	TAPI, GUJARAT	220	PHWR
11.	Kaiga Generating Station-1 (KGS-1)	Nov-2000	KAIGA, KARNATAKA	220	PHWR
12.	Kaiga Generating Station-2 (KGS-2)	Mar-2000	KAIGA, KARNATAKA	220	PHWR
13.	Rajasthan Atomic Power Plant-3 (RAPS-3)	Jun-2000	KOTA, RAJASTHAN	220	PHWR
14.	Rajasthan Atomic Power Plant-4 (RAPS-4)	Dec-2000	KOTA, RAJASTHAN	220	PHWR
15.	Kaiga Generating Station-3 (KGS-3)	May-2007	KAIGA, KARNATAKA	220	PHWR
16.	Kaiga Generating Station-4 (KGS-4)	Jan- 2011	KAIGA, KARNATAKA	220	PHWR
17.	Tarapur Atomic Power Plant-3 (TAPS-3)	Aug-2006	BOISAR, MAHARASTRA	540	PHWR
18.	Tarapur Atomic Power Plant-4 (TAPS-4)	Sep-2005	BOISAR, MAHARASTRA	540	PHWR
19.	Rajasthan Atomic Power Plant-5 (RAPS-2)	Feb-2010	KOTA, RAJASTHAN	220	PHWR
20.	Rajasthan Atomic Power Plant-6 (RAPS-2)	Mar-2010	KOTA, RAJASTHAN	220	PHWR
21.	Kudankulam Nuclear Power Station-1 (KKNPS-1)	Dec-2014	KUDANKULAM, TAMILNADU	1000	PWR
22.	Kudankulam Nuclear Power Station-2 (KKNPS-2)	Mar-2017	KUDANKULAM, TAMILNADU	1000	PWR

Courtesy: AERB, India; data updated till Aug-15, 2017

And that kept on increasing at a faster rate particularly see in 2000 onwards, you can see there are several plants coming on, and the last one as I have mentioned in march 2017 another 1000 megahertz capacity was added which gives a total 6780 megawatt electrical of install capacity of nuclear power plant in Indian.

And there are several other plans proposed like the map here shows quite a few such locations. And by 2020 whereas, several other plans.

(Refer Slide Time: 18:25)

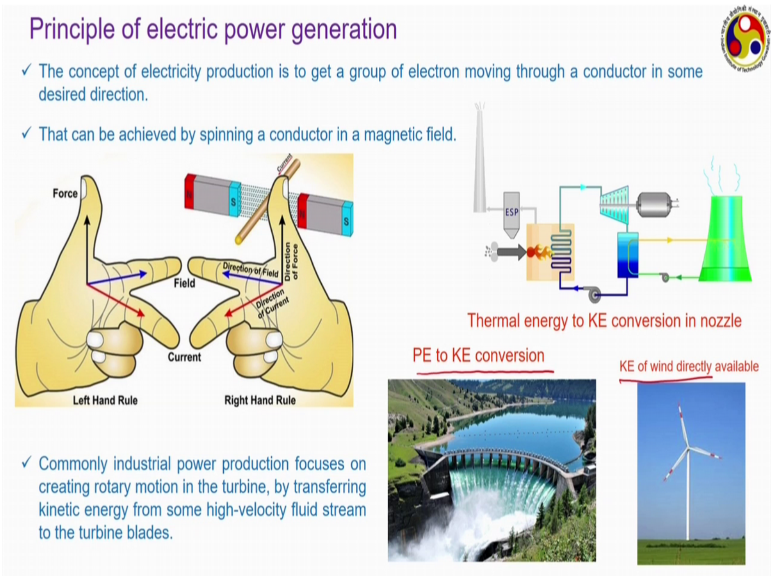


Which are expected to becoming operational giving or giving a project data generation capacity of 8,000 megawatt electrical or actually slightly more than that.

Therefore nuclear energy is here to stay. And hence we need to have a detailed idea about this. Now you must be aware that, whenever there is a talk of setting up a new nuclear power plant, there will be lots and lots of deliberations and discussions and arguments compared to any conventional power stations.

I personally feel that, most of that can be ascribed to the lack of knowledge about the technology. People are not properly aware about exactly about how this technology works, exactly how energy is harnesses from the atoms, exactly how we use the fuel or on how we can protect the surrounding from radiation hazards. Exactly, what are the nature of this radiation hazards that we always keep on discussing. How we discovered the spent fuel, or how we disposed the waste fuel. If we have proper knowledge about them, then probably we shall be in a much better position to discuss whether we should go for nuclear energy or not. And I am sure that successfully completion of this course will allow you to participate in those discussions and put on your own points for this.

(Refer Slide Time: 20:08)



So, let us start with very 3 basic principles. Today we shall not be discussing too much about the nuclear power generation as a topic; whether we shall be discussing more about some introductory points, about how energy is produced. What are the points where nuclear is separate from the conventional sources, what are the advantages and disadvantages of nuclear energy. And also, would like to plan a very briefly into the history paying out homage to several great minds who have contributed to the development of this particular field. And finally, shall we look into the atomic structure so that we can prepare our self to though more in-depth discussion on the nuclear energy generation.

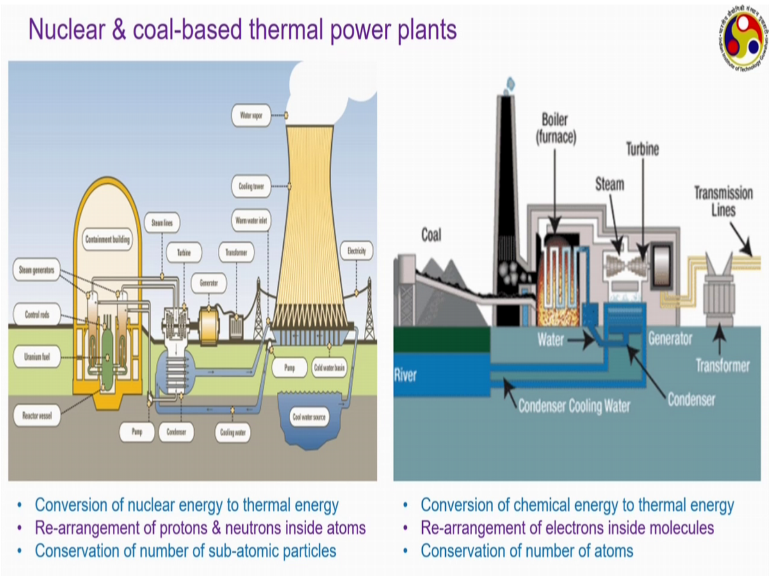
So now here we have the principle of electrical power generation; which I am sure all of you are aware about. The electricity production is achieved when a group of electron is availed to move through a conductor by some that some desire direction, and that movement of electron is generally achieved by spinning a conductor in a magnetic field. Now up to that part, more or less all power stations or conventional power stations have the same kind of working principle, but how to create this motion of the conductor? There is a difference. In most of the common power stations you will find a turbine which has several blades and mountains on it and the turbine itself is mountain and on a shaft.

We create the rotary motion of the turbine by heating the turbine blades with some high velocity fluid stream so that the kinetic energy of the fluid steam is transferred to the blades, and subsequently to the shaft. And alternator is mounted on the same shaft which gives us the electricity as the output. Now the difference between different kinds of power stations is the way of producing that high velocity fluids stream. Like, in case of a coal based thermal power plant, we have thermal energy to kinetic energy conversion in the nozzle.

Basically, coal or such kind of fuel like any gas, etcetera is burnt in a boiler so that the heat of combustion is used to generate stream by supplying that to water we get a high energy or high enthalpy stream of steam; that is, taken through a nozzle and it pass through the nozzle the thermal energy is converted to kinetic energy which is subsequently taken into the turbine. Whereas, in case of hydroelectric power stations, here we know that water from a higher energy elevation is allowed to fall through there by converting it is potential energy to the kinetic energy, and when this high velocity water jet strikes the blades of the hydraulic turbine, then waste is the same. And this kinetic energy is readily available in case of wind turbine. Because the we need a certain velocity of wind, which we will be avail to move the turbine blades by a certain magnitude and certain rpm, rather and that we will subsequently lead to the production of electricity.

Now, there can be 2 types of this high stream energy or high velocity energy generation we can divide in 2 categories; one like this hyrdoller wind where we either directly get the kinetic energy or convert potential energy into kinetic energy. The other where thermal energy involved like coal, where we generate thermal energy by burning some fuel or by some other means, and that thermal energy is used to raise stream and then raised through the nozzle and the turbine. And nuclear is in this letter category. That is, it is quite similar to the coal-based power stations.

(Refer Slide Time: 23:52)

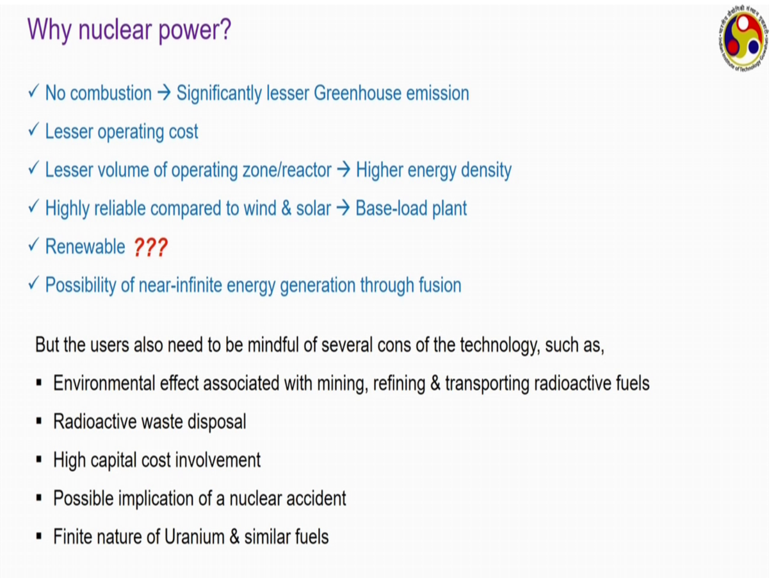


In both the cases several components are same, like you will be having the same kind of nozzels and turbines, a stream generator where energy is supplied from some fuel to produce stream. Then you may have a condenser and boiler keep on and all those associated accessories. But their difference is, how we supply the energy to the stream in that stream generator. Like, in case of coal-based power stations, we have chemical energy of fuel converted to the thermal energy.

Now, there we have basically a chemical reaction. And any chemical reaction means rearrangement of electrons inside the molecules so that the number of atoms are conserved, but atoms combine in different way to form different kinds of molecules. So, the total number of molecules may not be conserved, but total number of atoms and electrons will be conserved.

But in case of a nuclear, we have conversion of nuclear energy to the thermal energy; where not electrons or we are not at all talking about atoms and molecules whether we are going inside the atoms, and we are into the nucleus where the protons and neutrons they will be rearranged to form a new nucleus giving words to a new atom. And therefore, total number of the sub atomic particles that is protons and neutrons will be conserved, but total number atoms may not be conserved. Yes, we shall be discussing about this in more detail.

(Refer Slide Time: 25:28)



Then I have to justify why should we go for nuclear power, and here I have dotted out a few points. Some of those will be discussed in more detail later on.

The first one is no combustion. Of course, in case of incase of coal-based power stations, we bound the fuel and the exhaust gases are allowed to escape to the surrounding, leading to environmental pollution, and such kind of greenhouse emission is absent in case of nuclear because there is no chemical reaction involved. Whatever happens that is happening at the atomic level only, and green house emission will therefore, be significantly lesser. I have a shown you couple of numbers for France and Germany earlier, if you remember in case of Germany the amount of greenhouse gas emission was at least 50 percent more compare to France. And one primary reason being this, because

Germany depends a lot on coal-based power stations or power generation, and similarly oil based that is combustion related technologies. Whereas, France gets the significant share from nuclear. So, nuclear definitely is in much cleaner technology compared to coal.

The operating cost is generally much lesser, then lesser volume of operating zone per reactor or higher energy density. This point I shall be discussing in more detail during the next lecture. It is also highly reliable compare to wind and solar as I have mentioned. They the amount of electricity or energy that we get from nuclear plant is independent of the surrounding condition and the demographic details. And therefore, they are excellent as based load power stations. They are not suffered too much by the fluctuations in the environmental conditions and therefore, they are easier to control in a way also.

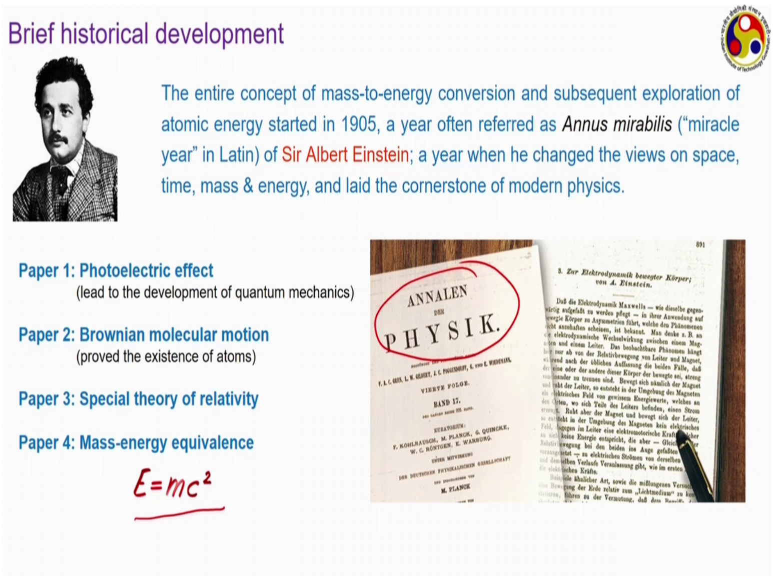
Next point may raise some eye brows renewable. Now renewable conventional we attach this terms to solar wind and biomass, but here I am using that on renewably nuclear also. Well I shall be coming back to this after a few lectures. But in certain situations, nuclear energy can also be termed as renewable and then possibility of mere infinity energy generation through fusion reaction. Again, I shall be coming back to this later on, but just into the perspective. A projection shows that while the reserve of coal and other kind of fossil fuels may not last for more than 50 60 years, common nuclear fuels like uranium and thorium, they also may not last more than 100 years. But if we use the fusion reaction and if you are able to master this technology, that can provide energy for about 300 1000 years.

So, how that of course, we shall be discussing later on, but everything is not rosy about this nuclear power, because there are several factors that we need to be mindful of like the environmental effect that everyone discusses about, it is particularly with the handling of radioactive fuels mining refining and transportation of the same. There is possibility of radiation hazards. In module number 10 we shall be discussing about this radioactivity, and radioactive hazardous. And possible ways of getting us protected from that. The radioactive waste disposal the topic of the last module and another very highly devoted topic. The high capital cost involvement, nuclear power plant as that requires several layers of protection to protects us from the contentment, and other kind of radiation related issues. Generally, the capital cost involvement is much higher than fossil fuel-based plants.

The possible implication of nuclear accidents, while so far in the history there are only 3 incidents where a accidents happened in some nuclear power plant. The 3-mile island in us in 1979, the Chernobyl incident I think in 1985 or 86 in the farmer Soviet Union. And the very recent one at Fukushima power stations. We shall be try to discuss a bit about the details of each of them, and try to see how or they happened on whatever reasons behind each of those accidents. And what are the factors we need to be careful learning from them. The finite nature of uranium and other fuels that is similar to the fossil fuels that can also be a concern.

So, with this factors in mind, let us now try to the see a bit about historical development of the nuclear power generation.

(Refer Slide Time: 29:55)

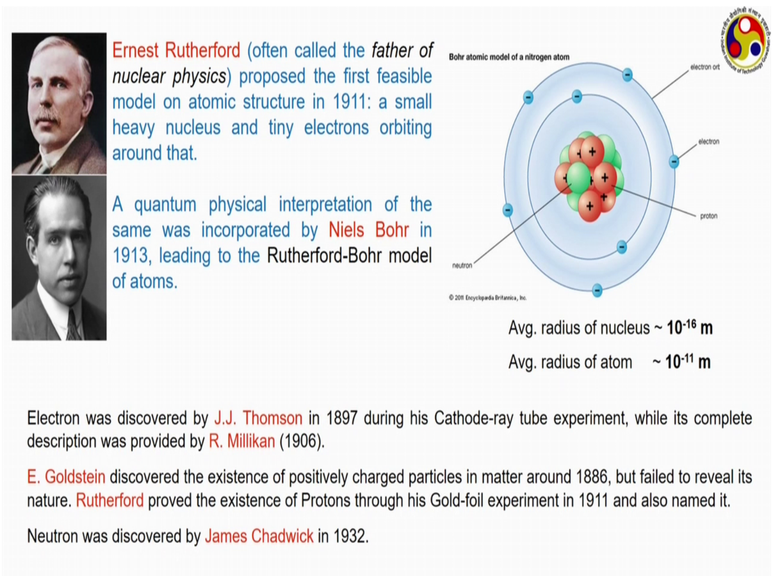


These being a fundamental portion of physics, there are contributions from several great minds. And I am going to mention only a very few of them; which without mentioning this actually we cannot proceed with any discussion on nuclear power. And the first homo (Refer Time: 30:17) we must pay to sir Albert Einstein. Because this entire concept of nuclear energy generation or mass to energy conversion, etcetera they all started probably in 1905 while the topic of radio activity was already identified and proved before that. But it was only in this year's 1905 which is often refer as the Annus Mirabalis; that is, the miraculous year of sir Albert Einstein that everything related to the nuclear power generation that started.

Because this is the year when he published 4 research papers, and totally changed the concepts of space time mass and energy. And basically, the entire journey of modern physics started from that year onwards. All of his papers where published in this particular general, Annalen Der Physic which is one of the oldest publishing researcher general which is still active now. I cannot remember probably I think it started it is journey in 19 sorry, 1799 and it is a still a very popular one. On this particular journal in the year 1905 he published 4 papers. The paper one was on photoelectric effects; which lead to the development of the quantum mechanics later on.

It may be a surprise to many of you, and the noble prize that sir Albert Einstein received later on was actually related to his work on photo electric effect or not, because of the much-celebrated theory of relativity. In his section paper, he discussed about the Brownian molecular motion; which undoubtedly proved the existence of atoms. And the third paper special theory of relativity nothing to mention about. In a later year probably in 1912 or 13 he published the generalized theory of relativity and the paper 4 which is related to this mass energy equivalence. And that gave to this widely used and very, very popular relation E equal to m c square; where m is mass and c is the velocity of light in vacuum. And e is the corresponding energy. So, c being generally a constant, this particular one gives the mass to energy conversion or vice versa.

(Refer Slide Time: 32:28)



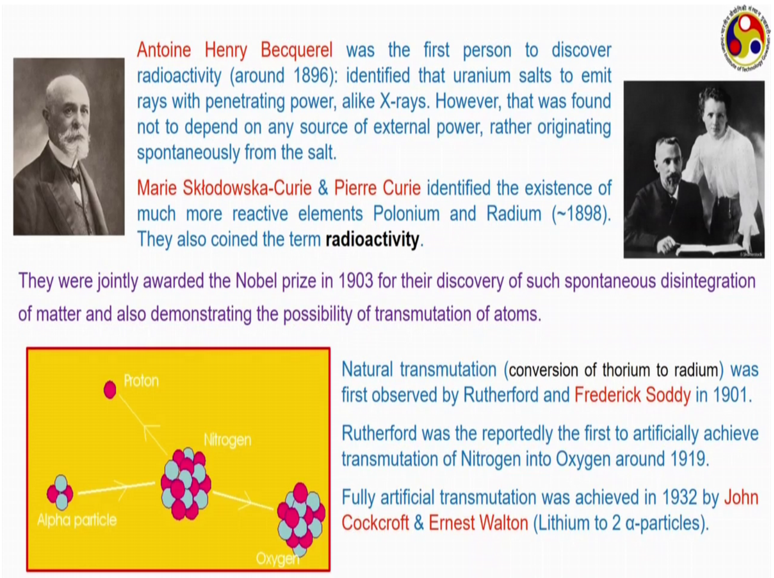
Emest Rutherford was the person which is often referred as the father of nuclear physics. He proposed the atomic structure to give the first feasible modular of atomic structure in 1911, which is quite similar to the solar structure that we have over solar system. Where we have a heavier mass at the center, and all the electrons are orbiting around that in elliptical or hemispherical or I should now say hemispherical, semicircular kind of orbits. The heavier nucleus was identified to be positively charged. And the mass of the nucleus was found to be much, much larger compared to the electrons.

The it was followed by the interpretation of news board following the quantum physics well quantum physics. And therefore, this mode is often referred as the Rutherford more model of atoms. There work established that inside the atoms there is a huge amount empty space, because the average radius of nucleus was measured to be in the range of 10 to the power minus 16 meter. Whereas, that average radius of atom is of the order of 10 to the power of minus 11 meter. And these huge amount of space inside was occupied only by very, very tiny electrons.

This empty space is very, very important which we shall be discussing later on. There are several sub atomic particles which are present inside the nucleus particularly in the present age of gravitational wave. We should mention about positrons and neutrinos. But here I am not going to mention about those, because in this particular course we shall be restricting ourselves only to this 3 well known sub atomic particles; proton, neutron and for course electron. Electron was discovered by J J Thompson in 1897 during his cathode ray experiments. And the complete description of electron, particular the measurement of idea about it is mass and energy was given by R Millikan in around 1906.

Golfstein was the researcher how discovered the existence of positively charge particle, inside the matter it was around 1896. But he failed to reveal the nature or completely he was not able to completely describe the nature of this positively charged particle. Rutherford prove the e existence of protons, through his gold foil experiment in 1911. And also, he gave the name proton. But it has also identified that nuclears does not constitute only a protons, but there it is possible to have some other heavy subatomic particle, which probably is neutral. And from the discovery of that neutron element was done by James Chadwick in 1932. And it was name neutron. And this particularly discovery has far reaching implication on a development of nuclear physics.

(Refer Slide Time: 35:27)



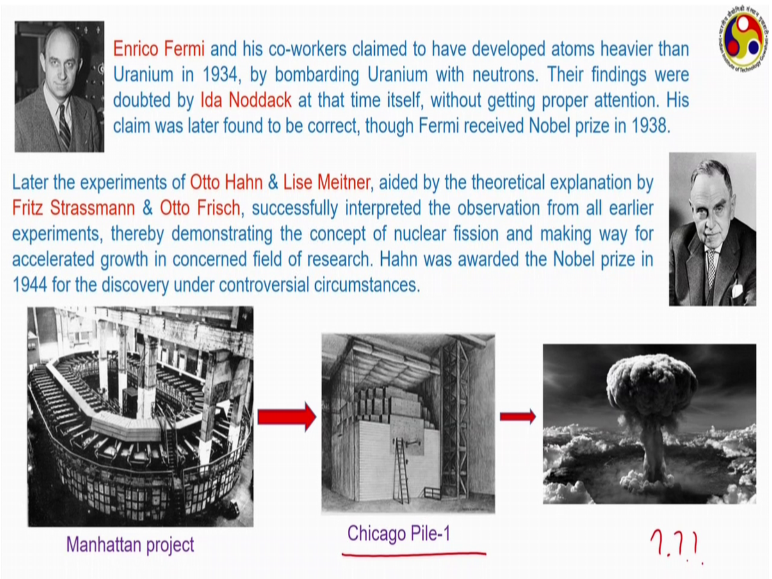
A Henry Becquerel was the person who first discovered the concept the radioactivity around the 1896, when he identified that uranium salt can emit rays with penetrating power; which are quite similar to x rays, but they do not need any kind of external power to produce that rather that was found to be coming out more spontaneously from the salt.

Simultaneous experiments were also done by the curie family; that is, the Madame curie and Pierre curie they identified the existence of much more reactive elements. They were the persons who coined the term radioactivity. And they also identified 2 reactive elements which are found to be much more reactive compared to uranium, and they gave the name polonium and radium. Radium was discovered around 1898, the name polonium actually refers to Poland; which was the birth place of madam curie. Both Becquerel and curie family together received the noble prize in 1903 for the discovery of the radioactivity or spontaneous disintegration of mater.

But this was only the natural phenomenon or spontaneous disintegration; natural transmutation of atoms that is conversation of one atom to the other that was first observed by Rutherford and Frederick Soddy in 1901. Rutherford repeatedly was reportedly Rutherford was the first person to achieve artificial transmutation of nitrogen to oxygen around 1919, but fully artificial transmutation was achieved in 1932 by john Cockcroft and Emest Walton, when they were able to convert lithium to 2 helium atoms;

which lead to several groups actively working on this topic of transmutation that is converting one atom to another, and there by releasing the energy stored in the atom.

(Refer Slide Time: 37:25)



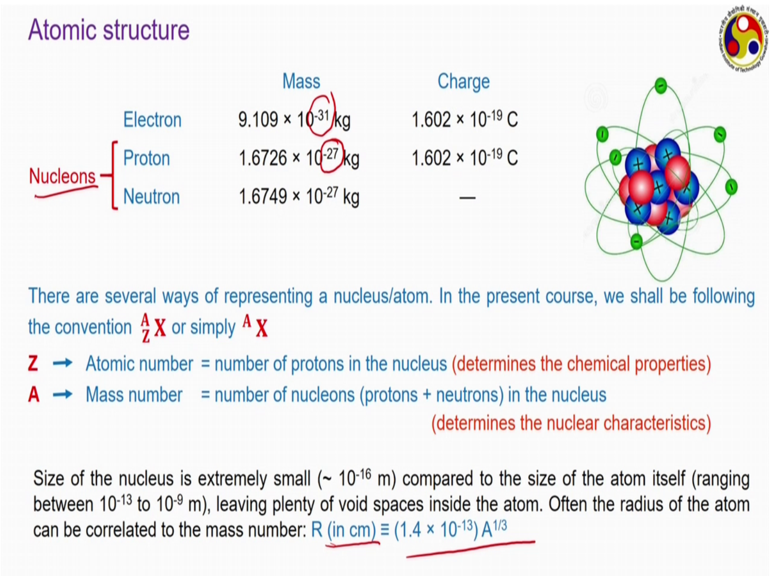
Envico Fermi there his coworkers where the group who first claim to have developed atoms heaver then uranium in 1934, because, till that time uranium was the atom known as to was identified as the atom with the heavier the mass or the highest amount of mass. But Fermi claimed that they have discovered atoms higher then this by bombarding uranium with neutrons. Their claim was neutron has absorbed the uranium or sorry, uranium has absorbed the neutron, there by converting it to much heavier atom, and developing a newer atom. But their claim was doubted by (Refer Time: 38:05) that the same time itself, but that failed to attract proper attention. His claim led to led to the noble prize in 1930, but later on it was proved that Fermi's experiment were wrong or rather Fermi interpretation of experimental observation was wrong.

The experiments Otto Hohn Lise Meitner they aided to the they for contributed or they continue to work on this particular field for several years. And they were the first group added by the theoretical explanation provided by Fritz Strassman and Oto Frisch. They successfully interpreted the observations from all earlier experiments including that from Fermi and their coworkers. And were able to achieve a proper nuclear reaction under control condition and also liberate the energy that is stored in the atom.

Their work led to the noble of prize of Otto Hahn in 1944; which was given under quite controversial circumstances, because this noble prize was awarded or announced in the later part of 1945 post the second world war; where the atom bomb at Hiroshima and Nagasaki was already history. And Otto Hahn was also under the locker or I should say he was in jail. And that it is also quite un fair to give the noble prize only to the Otto Hahn, because Meitner and Strassman contributed equally to experiment, but still Hahn was the person who received the noble prize for this. And the result of their interpretation led to the Manhattan project, then Chicago pile one the first ever nuclear reactor develop by mankind, and then the unmentionable at the Hiroshima in 1945.

Thank fully scientist did not stop their rather they continued working on this, and in an restrict nuclear energy only to the weapons whether started thinking about using this huge amount of energy source for the benefits of the mankind and there by producing commercial electricity from that. The first commercial nuclear power plant started working in early 50's in the (Refer Time: 40:33) Soviet Union whom followed by United States. And other countries started slowly following that which has give us a good platform about nuclear power generation, standing at this point. And there are several generations of nuclear reactors, that has been designed and used by the mankind starting form first generation moving to second and third and presently you are leaving in the mod of 4 generation nuclear reactors, and looking for a bright future of nuclear power generation.

(Refer Slide Time: 41:09)



I would like just touch upon briefly on the atomic structure before closing the shot today. As per the Bohr Rutherford model, any atom of comprises of a heavy nucleus; which is generally positively charged, and electrons tiny electrons orbiting around that in hemispherical or electrical orbits. The electrons are extreme small in terms of their mass as you can see here their mass is of the order of 10 to the power minus 31 kgs. Whereas, the nucleus comprises of proton and neutrons; who are having nearly similar mass, and the it that is of the order of 10 to the power of minus 27 kg, which is 10 to the power of 4 kg higher then electrons. And therefore, whenever we shall be doing any calculation from now onwards using the mass of proton and neutron, the mass of the electron will invariably will neglected.

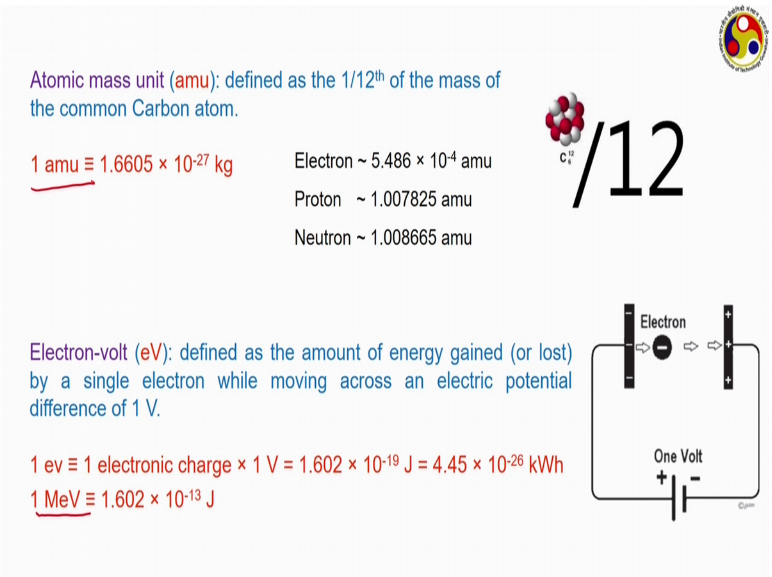
Neutron is positively charged whereas, proton is having equal amount of charge as the electron which is 1.602 into 10 top the power minus 19 coulomb. But the charge of proton and electron are of opposite sense. And therefore, they are given opposite signs conventional proton is called positively charge whereas, electron is called negatively charged. And proton and neutron as both of them comprise the nucleus they together are often called nucleons.

Now, there are several conventions by which we can represent a nucleus or an atom. In the present course we shall be following this particular concept, is it x? Or a exist? Here is z is the atomic umber, which is equal to the number of protons present in the nucleus. So, atomic number is the number of protons present in the nucleus; which of course, is equal to the number of electrons rotated in the orbits to keep an atom electrically neutral. And it is the proton which it generally determines the chemical properties of any particular nucleus. And therefore, atomic number is associated with the chemical properties. A on the other hand is the mass number, which is the total number of nucleons. That is number of protons plus neutrons present together inside the nucleus. It determines the nuclear characteristics; which we shall be repeatedly discussing in this course. So, the atomic number we can write that the mass number is related to the atomic number, plus the number of neutrons is often represented by the symbol n.

Now, the size of the nucleons is extremely small as I have mentioned it is of the order of 10 to the power of minus 16 meter, whereas, the size of the atom ranges from 10 to the power of minus 19 10 to the power of 13 meter. Leaving plenty of voice (Refer Time: 43:52) inside the atom. Quite often the radius of an atom is correlated to the mass number, by a very much empirical relation like this. 1.4 into 10 to the power of minus 13 into a to the power one third. But this an empirical nature nature relation of empirical nature, and the radius that we get from atom that is in centimeter. So, please be careful about the unit of this radius.

Now, both the as we have seen in the previous slide, here we are talking about extremely small mass. Of the order of 10 to the power of minus 27 kgs or 10 to the power of minus 31 kgs, which are quite odd to discuss about using from a point of view of our day to day life.

(Refer Slide Time: 44:42)



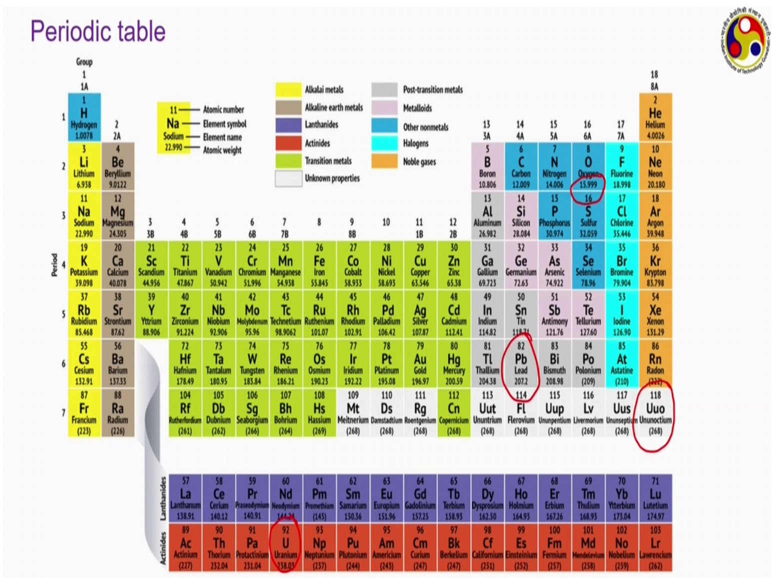
And then therefore A new unit of mas is required to be proposed and that unit is called atomic mass unit or amu; which is defined as one twelfth of the mass of the common carbon atom.

Proper measurements say that one amu is equal to 1.6605 into 10 to the power of minus 27 kgs; which subsequently gives the mass of electron proton and neutron as like this. So, from now onwards we shall be using amu as the mass per energy. While amu is the commonly used unit for this, but in some books, you will also find this small U is used to define the mass of these atomic sub atomic elements.

We shall also be proposing an unit for energy which is electron volt it is defined as the amount of energy gained or lost by a single electron as it passes through an electoral potential barrier of one volt. One electron passing through a potential barrier of one volt then the amount of energy gained by the electron are amount of energy required to make to move is called one electron volt.

So, corresponding amount of energy you will be one electronic charge multiplied by one volt giving 1.602 into 10 to the power 19 joule. And electron volt generally being a small unit, on MeV is mega electro volt; which is 1.602 into 10 to the power of minus 13 joule. We have to repeatedly make use of this particular one. So, from now onwards we shall be using amu as the unit for mass. And MeV as the unit for energy, unless otherwise required.

(Refer Slide Time: 46:25)

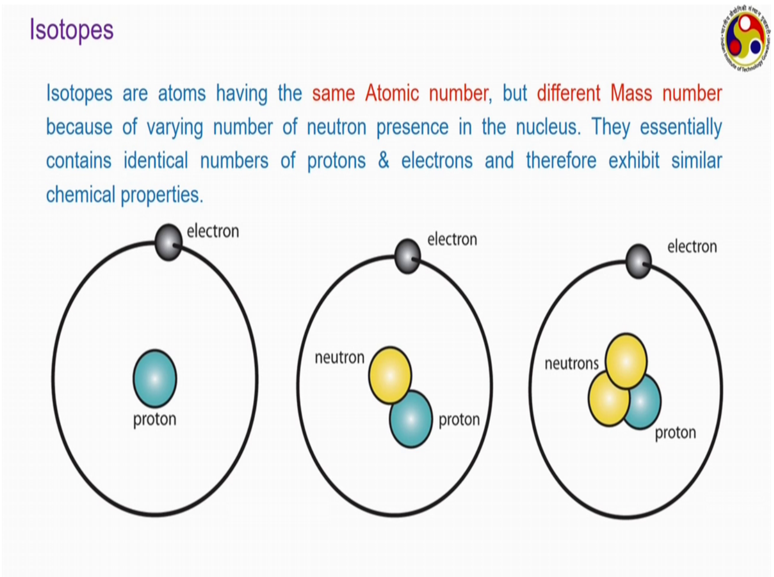


This is a structure of modern periodic table, where means this particular one shows elements up to an atomic number of 118, but truly speaking up to atomic number of 92, which is uranium beyond that basically all of them are artificial that is produced in the laboratory via some kind of nuclear experiments or nuclear reactions. But till 92 all the elements are naturally available. Hydrogen is the smallest one or with the first one in the series; which is having an atomic number of one and also a mass number of one, because it is nucleus contains only a single proton and no neutron.

The next one is helium which contains 2 which contains protons and 2 neurons, and that goes on this way. As we are discussing about radioactivity and nuclear reaction in this course are interest will mostly be starting from the elements after lead. Lead is more or less in nuclear I should say it is neutral from nuclear experiments point of view, but all those elements after that like this polonium and radon, and radium, uranium, thorium, plutonium, they all are highly radioactive.

Of course, their radioactive level varies, but generally our discussion. At least in the first part of this course will mostly be around mostly be around this materials after lead. But that is means here of course, we are showing the means you can see here, each of this symbols are followed by one number. Like, if you take say oxygen, here below the symbol we are presenting the mass number of common oxygen nucleus in terms of amu, which is 15.999, but this is only the common nucleus. But a any atom can have multiple nucleus which we call as isotopes.

(Refer Slide Time: 48:37)

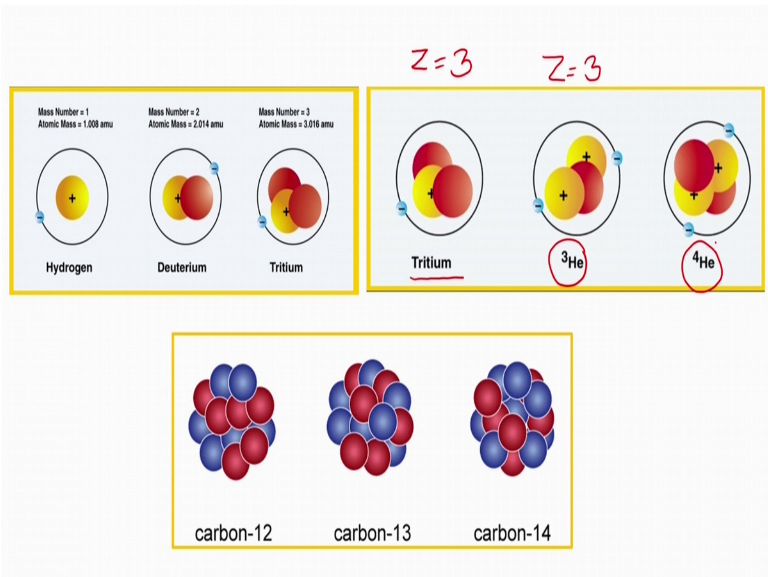


An isotopes are atoms which of the same atomic number. But may have different mass number that is they have the same number of proton in the nucleus, but may have varying number of neutrons. And as we have already seen that protons are related to the chemical nature. So, their chemical properties will be even more already the same. But the number of neutrons or number of nucleons that decides the nuclear nature. And therefore, different isotopes of the same element may have different nuclear nature, while they are expected to have more or less the same chemical nature.

So, in an nutshell by varying the number of neutron in the nucleus, we can produce different isotopes of the same element, and can vary their nuclear properties. Like here you can see 3 different isotopes of hydrogen, the first one which is a common one which has only a single proton. And therefore, one electron orbiting around that no neutron in a nucleus, but in the second one which is called deuterium, it has one neutron and one proton. So, the atomic number remains one, but the mass number is 2 in this case and the third one, which has atomic number of one again, but a mass number of 3 because it has 3 neutrons.

In all the cases there is only a single proton in the nucleus, there will be only a single electron in the orbits also.

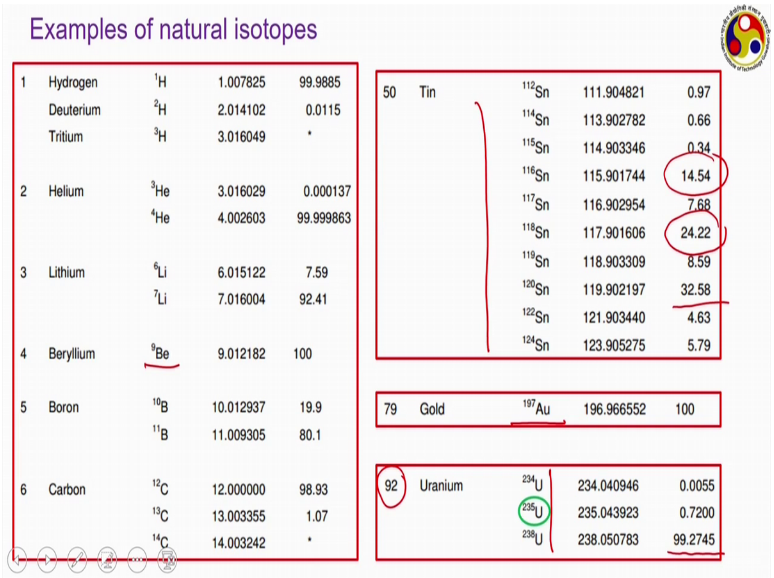
(Refer Slide Time: 49:59)



These are some further examples of a some isotopes like carbon can have 3 common isotopes c 12 13 and 14. In all the cases we are having 6 protons in the nucleus. But number of neutrons varies respectively 6 7 and 8. And as a result of that, it is also possible to have the nucleus of 2 different elements; which are having different atomic number, but the same mass number.

For example, just compare tritium; which is the third isotope of hydrogen. Having one proton and 2 neutron, it is having mass number of 3. Now you compare that with 3 helium or 3 He. It is having an atomic number of 2 because there are 2 protons, but a single neutron it is also therefore, having a mass number of 3. So, both tritium and 3 He they are having the same as number, but different atomic numbers. Of course, the common isotope of helium is helium 4 which has 2 protons and 2 neutrons.

(Refer Slide Time: 51:13)



Examples of natural isotopes

1	Hydrogen	^{1}H	1.007825	99.9885
	Deuterium	^{2}H	2.014102	0.0115
	Tritium	^{3}H	3.016049	*
2	Helium	^{3}He	3.016029	0.000137
		^{4}He	4.002603	99.999863
3	Lithium	^{6}Li	6.015122	7.59
		^{7}Li	7.016004	92.41
4	Beryllium	^{9}Be	9.012182	100
5	Boron	^{10}B	10.012937	19.9
		^{11}B	11.009305	80.1
6	Carbon	^{12}C	12.000000	98.93
		^{13}C	13.003355	1.07
		^{14}C	14.003242	*

50	Tin	^{112}Sn	111.904821	0.97
		^{114}Sn	113.902782	0.66
		^{115}Sn	114.903346	0.34
		^{116}Sn	115.901744	14.54
		^{117}Sn	116.902954	7.68
		^{118}Sn	117.901606	24.22
		^{119}Sn	118.903309	8.59
		^{120}Sn	119.902197	32.58
		^{122}Sn	121.903440	4.63
		^{124}Sn	123.905275	5.79
79	Gold	^{197}Au	196.966552	100
92	Uranium	^{234}U	234.040946	0.0055
		^{235}U	235.043923	0.7200
		^{238}U	238.050783	99.2745

Mostly all-natural elements can have several isotopes; like, I have listed here some of them, boron can have 2 lithium can have 2, some of the substances such as the beryllium or gold. They are having just one known isotopes, we can artificially produce several others in the laboratory. But in nature we generally found only one of them. Whereas, some of the elements can have several; like, you can see here 14, it has several isotopes starting from mass number of 112 to 124. And all of them are quite prevalent in nature. Because you can see where Sn 120 appears about 32 percent, this is also appearing 24 percent and this appears 14 percent.

So, all of them are quite prevalent in nature. And primary interest here is uranium, uranium commonly has 3 isotopes. U 234, U 235 and U 238 all of them are having the same atomic number which is 92, but the number of neutrons have is U 238 is the most common one which comprises 99.3 percent about; the of the uranium ore that we extract form iron. But it also contains very small amount about 0.7 percent of U 235 and very little amount of 234, very little amount of 234.

So, different isotopes of the same element, can have different number of neutrons, and accordingly their nuclear characteristics can be completely different; like, we shall be seeing later on, while the difference between U 235 and U 238 is only the presence of 3 extra neutrons in the nucleus for U a 238; their nuclear nature is completely different. While U 235 can be used as a nuclear fuel U 238 cannot.

We shall be taking this discussion forward in the next class. So, I would like to summarize whatever we have discussed today. Today you have got a brief introduction to the course. So, where discussed about the course content, we planned a little bit in the history by paying homage to the some of the scientist. And very briefly we have discussed about the topic of atomic structure and isotopes. And the measure completion that we are having from today's lecture is that, most of the natural elements can have several isotopes, because of the presence of different number of neutrons and the nucleus. And accordingly, with the nuclear characteristics may vary.

I would like to stop here for the day. We shall be starting in the next class by seeing different kinds of nuclear reaction, and discussing the source of nuclear energy, and the mode of harnessing that one.

Thank you. Bye for the day.