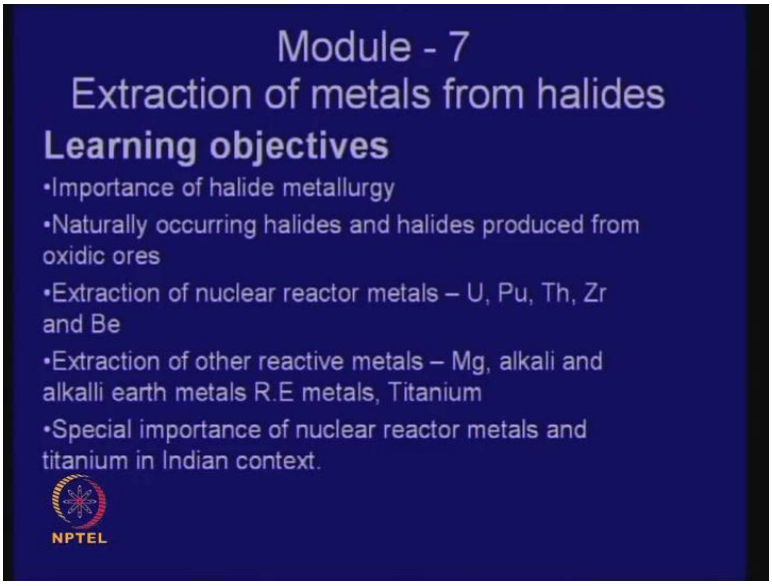
Non-ferrous Extractive Metallurgy
Prof. H. S. Ray
Department of Metallurgical & Materials Engineering,
Indian Institute of Technology, Kharagpur

Module No. # 7
Lecture No. # 26
Extraction of metals from halides, Extraction of reactor metals

Friends, I have so far delivered 25 lectures out of 40 lectures that I am suppose to deliver, which is about nearly two thirds of the lectures essentially during those 25 lectures, we have gone through some interdictory sections familiarity towards on minerals. We are processing some general principles of extraction general principles of refining etcetera, etcetera.

(Refer Slide Time: 00:38)



Module - 7
Extraction of metals from halides

Learning objectives

- Importance of halide metallurgy
- Naturally occurring halides and halides produced from oxidic ores
- Extraction of nuclear reactor metals – U, Pu, Th, Zr and Be
- Extraction of other reactive metals – Mg, alkali and alkalli earth metals R.E metals, Titanium
- Special importance of nuclear reactor metals and titanium in Indian context.

Then, we had moved on to extraction of metals from oxide sources and then extraction of metals from sulphide deposits we are now, coming to the subject of extraction of metals from halite, it does not mean these halides are naturally occurring in all cases we will make a distinction between metals coming from a naturally occurring halides and those that are not coming from naturally occurring halides that from halides, that are made from oxide sources. Why I have put them in this category is because many of these metals like uranium, although they are present as oxide we cannot get it out of the oxide sources, we have to convert it to a halide and from there we have to extract it.

Whereas, in the case of metals like magnesium and sodium we have halides in nature, in the case of magnesium it is in sea water sodium also is in sea water and elsewhere from there we extract the metal. So, there is a distinction, but in both cases we are getting the metal from starting point which is some kind of a halide. Now, by now you should have realized that even though some metals may come from the same kind of ores. The process to be followed are not the same always there are peculiar differences in the properties of the metals or the nature of ores that necessitated to go for appropriate extraction steps and they are different for each metal.

So, we talked about magnesium we got magnesium from dolomite or calcite carbonate of magnesium or magnesium carbonate, you could decompose produce the oxide and then go for carbon reduction this seems this; obviously, seems more rational approach the oxide reduce by carbon, that was done for tin oxides also which come for tin ores very largely also for ferro alloys. In a ferro alloying the ores which are ferro alloying elements basically oxides we could reduce them by carbon, but we had other processes too for example, ferro alloys can be produced by alumino thermic reduction and sometime the advantages there were no carbon in them.

But take case of aluminium easily available as aluminium oxide hydrated bauxite, but then we cannot reduce it by carbon because a carbite is very stable and we have to now, produce pure alumina dissolve it in a fuse salt cryolite electrolytes. So, we have to go for a very different process. Similarly, consider sulphides that the main metals were copper led zinc copper is unique in the sense that we did not have to reduce anything, we had copper sulphide and iron sulphide.

If they were oxidized in a controlled manner iron sulphite oxidize first it was slag out we were left with copper sulphide and some iron sulphide then, further oxidation and removable of iron sulphide we were left mostly with copper sulphide and once it formed C u 2 O then there was reaction between copper sulphide and C u 2 O and copper came out.

So, there was no reduction step anywhere what we did is actually just remove the sulphure out of the system and other things out of the system. You have copper there that does not work for the led sulphide. Now, led sulphide had to be roasted to make led oxide then we reduced it in a blast furnace no problem there. In the case of zinc sulphide also the zinc sulphide was converted to an oxide then pyrometallurgically, it can be reduce by carbon or dissolves in oxide in acid solution and then that solution is electrolyzed after of course, all lot of purification because if we do not have the absolutely purified liquor then zinc cannot be electrolyze from echo solutions, we have discussed the details of these.

Now, very interestingly copper sulphide, led sulphide, zinc sulphide very often they are mixed together they are found at one place, but you cannot apply the same method for all of them fortunately there is now a process called imperials smelting process, wherein, one blast furnace we in we extract at least two metals, you know that we get zinc distill out of the blast furnace and then there is a method of quenching, it in led and separating led and zinc and led comes out from the bottom as a normal blast furnace operation.

It is claimed that if there is copper that also comes out as a separate matte phase, but the imperial smelting process does not work. So, well when there is copper as well. So, it is ideally only for led which comes out at the bottom of the blast furnace and zinc which comes out of the top as vapours. Now, we are now through with metals from oxides and sulphides. We are going to talk about extraction of metals from halides and to start with we will start with extraction of reactor metals, what these are I would explain.

What are the learning objective here? First of all I would like to say few things about the importance of halide metallurgy may be not right at the beginning, but during my lectures I make the distinction once again between naturally occurring halides as a starting point as it is for magnesium and sodium. And halides produced from oxidic ores we will see many examples of that then extraction of nuclear reactor metals. I like to discuss separately these are uranium, plutonium, thorium, zirconium and beryllium.

These are called nuclear metals, reactor metals because they all have important roles in nuclear reactors, you all know that the nuclear reactors will not be nuclear reactors without uranium. Uranium is the most important element and right now the only element from which we can think of producing nuclear energy. Plutonium is a man made material which comes from we will see how from where it comes, it comes from an isotope on uranium. Thorium itself is not one that undergo nuclear fission, but thorium can be converted to a fissile material and we will discuss that.

So, uranium, plutonium, thorium are the elements which will the required in nuclear energy production. Zirconium has a different role it comes in the construction of tubes in which the nuclear metals that will undergo fission will be content, after all we need a place to keep the materials undergoing fission and there we will need zirconium based alloys because zirconium as an advantage, it does not absorb thermal neutrons because if thermal neutrons get absorbed then, they would not be able to carry on the fission reaction.

Beryllium has an opposite role, it is a moderator it can slow down thermal neutrons. So, we will need both this and this in the construction of nuclear reactors. Now, all these are also known as reactive metals because they are very reactive, they produce very stable oxides and because they produce very stable oxides, in theory they can be reduce at high temperatures by carbon, but they all form carbides. So, carbon reduction is not something that we can think of when they are in oxide form that is why, we have to take them into the halide form and see how we can reduce the halide suitably to get the metal.

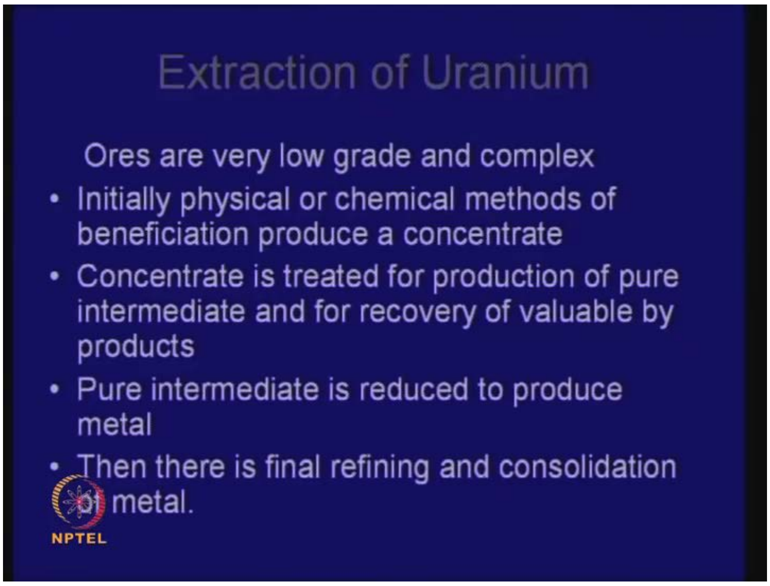
Apart from these reactive metals there also other reactive metals like magnesium, alkali alkaline, earth metals and titanium these are also high up in v m f series, they form very stable oxides they cannot be also easily reduced by carbon for them again, we have to think of some other route and again it is usually the halides will fall upon. Now, the very special importance of nuclear reactor metals, today in Indian context because we want to expand our nuclear energy production drastically, titanium because we have big deposits of Illuminite and we are producing Ti O 2 which goes for paint industry, but we are not producing titanium, whereas, a titanium is a very valuable metal which goes for aerospace alloys all kinds of light metals, where titanium and aluminium alloys are a must.

So, will touch basically all these the books I have referred to earlier will have many details, I will not go into too much of detail, but I would certainly show you some flow sheets and I will again say the when you see a flow sheet do not get scared off. You know this blocks and arrows flow sheets just tell us, what are the essential steps and you are not suppose to remember everything, but you must understand how those steps come one after the other basically, I have to show them to give you the logic or rational of processing of ores and minerals for production of those metals.

Please remember a very important saying of Einstein and I saw it near the airport in Kolkata as you come of that there is a big wording in which it is written and it said that I do not need to know everything, I just need to know where to find it when I need it. So, in much of your studies you should know what is where and once you know that when you need to study you go there. So, these lectures that I am delivering some references that I am showing you just gives you the idea that, in case you need to know more details where you should go to and you pick up the details, but then it helps if you know the logic if you follow the steps, why they come one after the other, what are the tricks of the trade in each step.

And once you get familiar with the subject you will get to know that, the many things that the metallurgies do have come from many, many years of experience knowledge of fundamental chemistry and in principle they are actually quite simple and certain things are repeated again and again, in different extraction processes and that knowledge will come to you, as you study the subject and stop getting scared of the flow sheets. Flow sheets are nothing for repetition of certain what we call steps that, that are carried out in different extraction processes.

(Refer Slide Time: 15:58)



Extraction of Uranium

Ores are very low grade and complex

- Initially physical or chemical methods of beneficiation produce a concentrate
- Concentrate is treated for production of pure intermediate and for recovery of valuable by products
- Pure intermediate is reduced to produce metal
- Then there is final refining and consolidation of metal.

With that let me proceed now, we have to talk about nuclear reactor metals. Now, in the case of all these metals the ores are actually very low graded and complex, if we talk about uranium ore, you cannot find then uranium ore like iron ore or aluminium ore where the aluminium or iron percentage is very high it is not. So, you will see later on an uranium ore means an ore, where uranium content may be less than one percent or even smaller.

So, we are at essentially would be dealing with low grade and complex ores which will require equally complex mineral beneficiation processes some of which I have touched in the initial stages of mine during my lectures. There have there would be initially a physical or chemical method of beneficiations and we will produce a concentrate this is now true of many, many metals and their ores and its becoming even more important as time goes by because ores and minerals are becoming gradually low grader.

Now, there was a time when those were in the business of producing metals could go to a mine and handpick certain parts of the mines, which apparently were richer in the metal content, but that is no longer allowed today because if we were to pick and choose the particles, which are richer in metals content then you are living behind a deposit which is now poorer in grader. So, you have extraction process for the future generations will become more difficult.

So, the general government policies that you take what you get you do not select from the mines this particle or that particle they looks of which tell you, they are richer in that particular metallic value that is not allowed. So, you have to mine the whole thing and develop your process that will suitable for dealing with low concentration of the metallic value.

Now, once you got a process like that standardized then it will apply for the rest of the ore body also which is also pure grade. So, you are not doing anything special for a selected batch or selected sample. So, essentially we need physical and chemical methods of beneficiation some of which we have, I have discussed earlier there are many physical methods, you know in the case of sulphide deposit we found we can do floatation and in one step an ore body which had one percent will produce a concentric 25 percent or 30 percent of copper same with zinc or lead.

In the case of oxide that we dealt initially, we did not have to worry about concentration so much because ores were very concentrated, but when we come to reactor metals, we will find we will need greater application of mineral beneficiation techniques, we have to think of magnetic separation because many minerals are magnetic of different susceptibilities, some can be removed by weak magnetic force, some would require stronger magnetic force some even stronger.

There can be methods based on size, density, shape. We discussed once a method which we called a spiral that using a spiral from beach sands, we can separate different fractions depending on density, shape, as well as particle size that kind of thing would be required here incidentally there are many more methods, where minerals are separated based on density, shape and size using essentially the same principle that their are the way they would settle would differ from one mineral to other.

So, in the case of spiral certain properties were used we can have tabling you may have seen tabling we have cyclones hydro cyclones, there are other methods there can be electro static separators, where they moves up the electro electrical charges are giving and based on the charges acquired they can be separated. So, magnetic separation electrostatic separation, the separation based on density, particle size and there are other metals also, if you go to the books you will get all the details, how they are done I will not go into the details of this.

Then there are chemical methods of separating one mineral from the other, which are sometimes much more selective like if you have a complex over body with many minerals, we can chlorinate take out a volatile chloride of one particular metal only then change conditions get another metal as a volatile chloride or a liquid chloride and this is your third metal.

More frequently we try to beneficiate by selecting leaching, that we leach out one metallic value living others unleached in the residue and from there again, there will be further leaching process for getting others and once we leach from that we can precipitate or we can go through solvent extraction, iron exchange for purification the idea will be to produce a pure compound and once we have produced a pure compound we will move forward.

So, we can have chlorination, fluorination, leaching which can be acid leaching or alkali leaching these will be chemical methods. Then once we produce a concentrate our goal will be to treat the concentrate to produce a pure intermediate. Now, we call that when we talked about purification of metals, I had said basically we fallow two approaches when we comes to refining.

In the case of pyrometallurgy the goal was to produce a whole lot of metal as much as we can as quickly, as we can irrespective of water impurities coming. So, the idea was to produce the impure metal in bulk, then go for purification like we did in the case of lead and elaborate purification in the case of zinc, in the case of copper. The other method will be to produce first a very pure compound which means, we do not want to produce whole lot of that metallic value with impurities. We start with enough care to produce a pure intermediate and once you got a pure intermediate, from there what you produce the metal will be very pure.

This is will be the essential approach in the case of nuclear metals, reactive metals as well as other metals that we are getting from halides. So, once we have recover pure intermediates and we will also recover valuable byproducts from which you will get other things, this pure intermediate is reduced to produce metal and that metal will be pure. Of course, very often even if you take a pure metal, pure intermediate we may be able to produce a metal which may be pure, but it may not be physically in a form that is acceptable.

Like suppose, we have a method and we reduce and we end up with very pure fine powder. Now, these are very reactive metals mind you so if there is a fine powder, they always the danger of them getting reoxidized even if you keep it under inert atmosphere, under vacuum even the slighted partial pressure of oxygen will produce oxides at least from the surfaces of the powder.

So, once you get a powder we cannot lead it as such we will have to go for a final refining and consolidation of the metal, we have discussed some methods for that it could be vacuum mark melting essentially, if you remelt it under vacuum ensure that all gases are removed and once we make a consolidated metal in bulk form its surface area would be low. So, the chances of reactivation would be low.

So, please remember these are the standard steps we will need in the case of most of them, start with the low grade complex ore go through physical or chemical methods of producing a concentrate then from the concentrate, we will produce a almost pure intermediate from, pure intermediately produce a pure metal then although it is pure metal it may not be in the correct physical form or it may have some gases impurities. So, we go for refining and consolidation this is what we will do.

Let me start with uranium. Now, before I start with uranium I like to impress upon you the enormous importance of uranium today. Uranium we need because we need nuclear energy, nuclear energy is a highly debatable subject unfortunately we will also have many wrong notions about nuclear metallurgy. I do not know how many of you know, there is specially in some states of India where there is an inbuilt bois against a nuclear metallurgy West Bengal is one of them, they were proposals to have nuclear reactors in Sundarban area. Now, there is a proposal to have summer near in Purulia area they have all been very strongly opposed by many people political parties as well as many intellectuals.

There fears are not all wrong after all we have had Chernobyl in Russia and that created a tremendous fear about nuclear reactors, there are been some accidents in one or two other places also, but then many people have argued that look at France, France does not have its coal they cannot have thermal power plants unless they import coal they do not have oil fields. So, they cannot have thermal power plants based on imported oil they do not have natural gas the England is very lucky, they have the north sea oil fields which produce gas also france does not have it. So, what that France do?

French have gone in a big way for nuclear energy 80 percent of their demand countries, demand is met by nuclear energy alone and they are the leaders there has been no accident in France. So, far it does not mean it may not happen, it hasn’t happened. The other objection so, the about safety I can also say if you go for any other source of power nobody guaranties your safety if suppose, you go for hydroelectric projects they have heard about the dams collapsing because of earthquake or collapsing because with age, the strength has gone down and dams have burst and remember do you know what it means when the dam bursts.

We talk about thermal power plants, thermal power plants today is a serious threat in terms of climate change, it is causing slow poisoning and the amount of Co 2 the thermal power plants are throwing out in the air is causing millions of death, it may not be an immediate death, but it is a matter of concern. So, people are thinking of taking Co 2 and putting it somewhere in the ground, store it in the ground and there are processes which are operating power plant.

This brings me to the other fear about nuclear power that after undergoing fission. What you do with a nuclear waste you know, it is a very complicated subject the waste is radioactive. So, first of all it has to be taken into some kind of a glass a glass because the glass does not easily get leached then it has been put in steel containers may be 1, 2, 3 and they have to be put under rocks or in the sea.

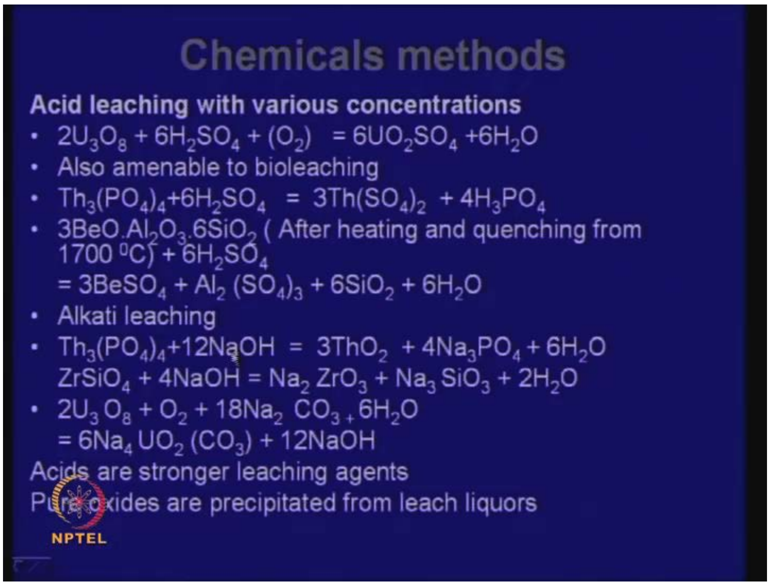
Now, the experts who know they say they have now done enough work for safe disposal of nuclear waste. So, the question of disposal of nuclear waste has been addressed nuclear reactor accidents should also not happen. If you know how to maintain and nuclear reactors are now going to expand everywhere, even in those countries where there is enough oil, enough coal think of Iran today Iran is not going to for nuclear reactors only to a making bombs at least they are claiming they also need nuclear power.

China they have a lot of coal, but they are also going in a big way for nuclei reactors and they are proposing an big expansion in a number of nuclear reactors, I will come to the subject towards the end of this course when I discuss environmental problem. India started up very early, but we have kind of following behind as of now, we are producing just about 3 to 4 percent of energy, 3 to 4 percent of our total energy divide, but there are plants to take up to 20 year. So, in forcible future And by a large planners are approving of these this thing.

Now, the problem is without uranium we cannot get started I will tell you why I am using the word get started something will come later, but need uranium to start with we do not have enough uranium in the country and that is the basis of all these things, we had between America and many other countries all the peripheral action treaties and many countries have almost accepted India into the club and there are countries coming forward to give us uranium.

I read recently Australia which has large reserves of uranium are also now beginning to see merit in supplying uranium to India, India does not have much uranium there are some small deposits and I will come to that later on there is search is on as to where we can find the ways.

(Refer Slide Time: 34:40)



Chemicals methods

Acid leaching with various concentrations

- $2U_3O_8 + 6H_2SO_4 + (O_2) = 6UO_2SO_4 + 6H_2O$
- Also amenable to bioleaching
- $Th_3(PO_4)_4 + 6H_2SO_4 = 3Th(SO_4)_2 + 4H_3PO_4$
- $3BeO.Al_2O_3.6SiO_2$ (After heating and quenching from 1700 ^0C) + $6H_2SO_4$ $= 3BeSO_4 + Al_2(SO_4)_3 + 6SiO_2 + 6H_2O$
- Alkati leaching
- $Th_3(PO_4)_4 + 12NaOH = 3ThO_2 + 4Na_3PO_4 + 6H_2O$
  $ZrSiO_4 + 4NaOH = Na_2ZrO_3 + Na_3SiO_3 + 2H_2O$
- $2U_3O_8 + O_2 + 18Na_2CO_3 + 6H_2O$ $= 6Na_4UO_2(CO_3) + 12NaOH$

Acids are stronger leaching agents

Pure oxides are precipitated from leach liquors

So, now leaving it there let me come to the subject as to why uranium is. So, important, but before that let me quickly go through if we had uranium what we will do. What will do is what we will do in the case of many other reactor metals, will produce a concentrate and then we would leach it and after leaching, we will try to produce a pure compound.

In the case of uranium for example, U 3 O 8 is the oxide you are aiming at it can be leached by sulphuric acid take in into solution as a sulphite incidentally, this is also amenable to bioleaching remember I had mentioned one there are all kinds of bacteria, which can speed up natural process of sulphuric acid leaching of oxide deposits.

This work is also going on in our country where there are low grade uranium ores, we can identify some bacteria and those bacteria if left there they will leach automatically because it will be very much suitable for low grade ores because it will produce a leach liquor, we would not have to go through elaborate processing, but that is a long term process.

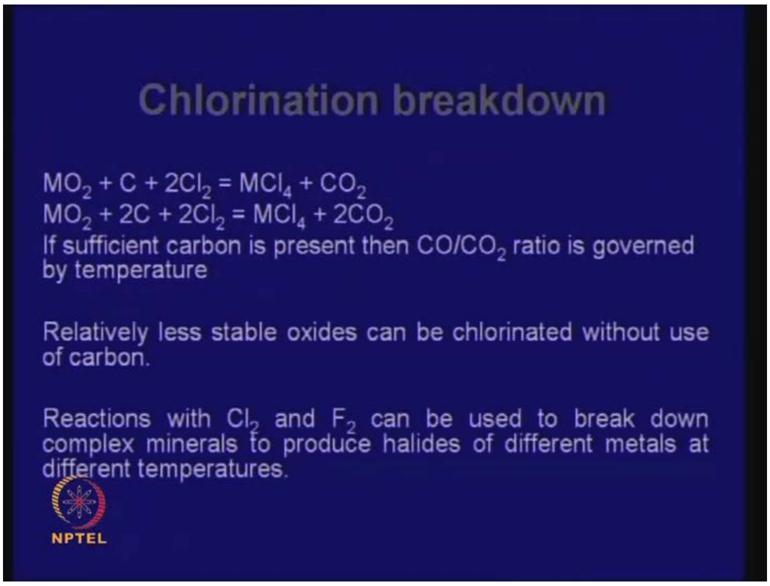
Now, same thing kind of would be applied for when we come to thorium, we will say we produce thorium concentrate that can also be leached by sulphuric acid taken into solution. If we start with a beryllium ore which is written like this can also be leached by sulphuric acid to take beryllium in the solution. Now, these are three examples of acid leaching, there are also alkali leaching processes for all these like thorium can be leached by sodium hydroxide, zirconium. Sodium hydroxide, uranium can also leached by an alkali to produce uranium in solution.

Now, there is no agreement as to what will be best will it by acid leaching or alkali leaching. There are many countries which have which go for acid leaching, I will see later on that in India. So, far as uranium is concerned and many others we go for alkali leaching. Now, here is a general principle acids are usually much stronger leaching agents by stronger I mean, they will act quickly they will leach more in a shorter time, but they would leach a whole lot of other things also, not only uranium they will take into solution some of the other metallic values, you do not want even you try to control the conditions.

Whereas in the case of alkali leaching, the leaching is a milder process it can be more selective. So, you can have a selection step during leaching itself provided you settle for longer duration or lesser recovery in a given time. Now, some people will opt for this some people will opt for a stronger leaching and worry about the impurities subsequently, it depends on who likes to do what.

We will give examples of both. So, essentially from leach liquors we will try to produce a pure oxide this is the whole game. So, the thing take a concentrate leach by acid or by alkali take the metallic values in solution, they rejects go for recovery of byproducts which are also variable and finally, finally try to produce pure oxides from the leach liquor, From that oxide again we will have to convert it into some halide chloride or fluoride because from oxides we cannot go to the metal metallic state, we will go to the halide or fluoride and we proceed further.

(Refer Slide Time: 39:09)



Chlorination breakdown

$MO_2 + C + 2Cl_2 = MCl_4 + CO_2$
$MO_2 + 2C + 2Cl_2 = MCl_4 + 2CO_2$
If sufficient carbon is present then CO/CO_2 ratio is governed by temperature

Relatively less stable oxides can be chlorinated without use of carbon.

Reactions with Cl_2 and F_2 can be used to break down complex minerals to produce halides of different metals at different temperatures.

Now, one very general method that is applied in many cases is to take an oxide and convert into a chloride, which could be a liquid or it could be a gas. If it is a volatile chloride then the gas will be taken out and condensed if it is a liquid of course, the liquid would be drenched out.

Now, if there are many, many metallic values one can control the chlorination temperature and or partial pressure of chlorine to recover one metallic value at a time means, you take out metal one as a chloride first, then the change condition take out another metal as another chloride either, vapour or liquid and 3, 4 can be taken out from a mixture of several chloride.

Now, if you recall I had discuss the thermodynamics of chlorination and pointed out that there are two kinds of chlorination. When we chlorinate just taken MO 2 and react with Cl 2, you produce a chloride is called direct chlorination this happens in the case of oxides, some oxides which can directly form a chloride, but some do not do that we have to bring in a reducing agent carbon and this we call chlorination in presence of carbon.

There are thermodynamic reasons why need carbon essentially, it is for those where the oxide is very stable. The carbon kind of is reduces to metal, metal reacts with chlorine and produces the chloride. If sufficient carbon is present then CO by CO 2 ratio is governed by temperature. So, the temperature is a the crucial parameter and as I have said relatively less stable oxides can be chlorinated without use of carbon, but many oxides cannot be directly reduced chlorinated by chlorine unless there is carbon in the system.

Now, we can do similar things with chlorine or fluorine to break down complex minerals to produce halides of different metals at different temperatures, this is done from the whole bunch of things and very often these ores are very, very complex we can separate. So, this is an example of chemical beneficiation.

(Refer Slide Time: 42:12)

Reduction of metal halides

- Metallothermic reduction of halides allows oxygen free operation and, therefore, superior metallic product.

  Choice of reduction method will depend on
- Thermodynamic feasibility and kinetics
- The heat balance
- Melting and boiling points of constituents
- Densities of metal and slag

Now, once we have produced a halide this way, then there is a very logical thing to go for Metallothermic reduction of halides by Metallothermic reduction means, you bring in a reducing metal which will form more stable halide very often it can be calcium or magnesium.

Why want to go for Metallothermic reduction of halide because then we are not using any oxygen in the environment, we will get a superior metallic product which will not react with any oxygen in the environment and a choice of reduction metal will depend on many, many parameter. So, it will depend on thermodynamic feasibility in kinetics; obviously, at what temperature you will do it will depend on that and it will depend on the reducing agent we are using calcium or what ever.

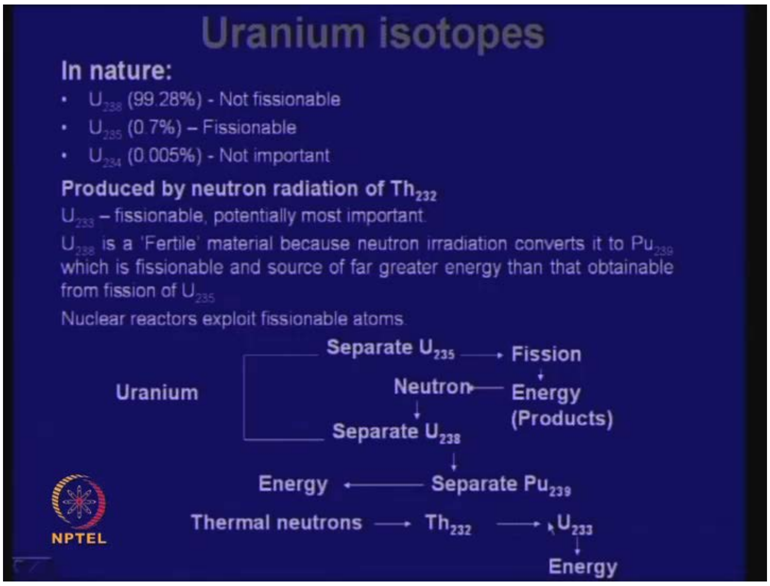
It will depend on heat balance we would like to go for those reactions, which produce lot of exothermic heat. The reaction will become easier we will able to melt either the metal or the slag or one or both melting boiling points of the constituents are very important supposing we see that we need a temperature, we make the reducing agent that we want to use needs to be a gas then you have to have a bomb, you have to have a reactor which is closed and which is to under high pressure.

This too complicated we do not want that we want a process, which will take place at a temperature where the reducing agent will not have to be under pressure as gas if it is there is a solid or a liquid fair enough then, we also have to worry what were the product. the product comes out as a gas then again we have a problem that how do you collect it.

So, the what will happen to the required at the required temperature to the physical states of reaction products becomes also a criteria for choosing the Metallothermic process and of course, the densities of the metal and slag are important because we need a metal slag separation. So, you see you simply cannot go like we can do that in chemistry that this reaction and will take place this reduces that this will be produce.

Now, we are talking about practical considerations it may be in theory, will it be in practice will practice allow this process. This becomes a very important criterion in metallurgy because we are talking about actually handling a raw material producing a concentrate, producing a compound then actually produce in a metal. So, we need to have conditions which suite practical operations I will try to touch on these here and there.

(Refer Slide Time: 45:42)



Uranium isotopes

In nature:

- U_{238} (99.28%) - Not fissionable
- U_{235} (0.7%) – Fissionable
- U_{234} (0.005%) - Not important

Produced by neutron radiation of Th_{232}

U_{233} – fissionable, potentially most important

U_{238} is a 'Fertile' material because neutron irradiation converts it to Pu_{239} which is fissionable and source of far greater energy than that obtainable from fission of U_{235}

Nuclear reactors exploit fissionable atoms

Uranium

Separate U_{235} → Fission

Fission ↓ Energy (Products)

Neutron ← Energy

Neutron ↓ Separate U_{238}

Separate U_{238} ↓ Separate Pu_{239}

Energy ← Separate Pu_{239}

Thermal neutrons → Th_{232} → U_{233}

U_{233} ↓ Energy

Now, let me start with uranium and let me re-emphasize the importance of uranium. You are not going to be a nuclear metallurgies unless you join B A R C, but in today as a metallurgist you must know some fundamental principles. So, far as production of nuclear metals are considered why they are important, what are the issues that are important you must know otherwise, I do not think you can be called a metallurgist. Now, in nature uranium has 3 isotopes one is uranium 238 which is the bulk of the substance 99.28 percent then, you have uranium 235 which is only 0.7 percent.

(( ))

Same term, this isotope is fissionable. Fissionable means if it is bombarded by thermal neutrons then, if it absorbs one neutron it will absorb more than one neutron. So, that they will that neutron again bombarding, it will produce more neutrons this is the basis of nuclear metallurgy that you gradually increase the neutrons as through fission reactions.

There is a another isotope U 234.005 percent it is not important we are not interested, but now it might same to you that uranium 235 is not that important 0.7 percent though its fissionable and you might think that, well if this is not fissionable what is the use of 99.28 percent try to understand now some very interesting things. Uranium 235 which is 0.7 percent is definitely very important, but there is another isotope which is uranium 233 which can be produced by neutron radiation of thorium 232 this is actually, the most important isotope of uranium that man can produce artificially from thorium 232.

So, thorium becomes very important an India has thorium deposits, but to come to that stage we have to start first with uranium. Normal uranium and uranium 235 and will come to this later. This another interesting thing is you might think uranium 99.28 percent which is not fissionable is not important that is not true, this isotope is a fertile material fertile material means, it can be converted to plutonium 239 which is fissionable.

So, uranium see the beauty uranium 99.28 percent which is not fissionable can be converted to plutonium, plutonium 239 which is fissionable. So, it is called fertile material by itself is not fissionable, but it keeps rise to fissionable material. Why it is fertile again let me repeat its fertile material because neutron irradiation converts it to plutonium 239, which is fissionable and source of far greater energy than obtainable from fission of uranium 235, it should be obvious uranium 235 is in 0.7 percent, but we have uranium 238 which is 99.2 percent.

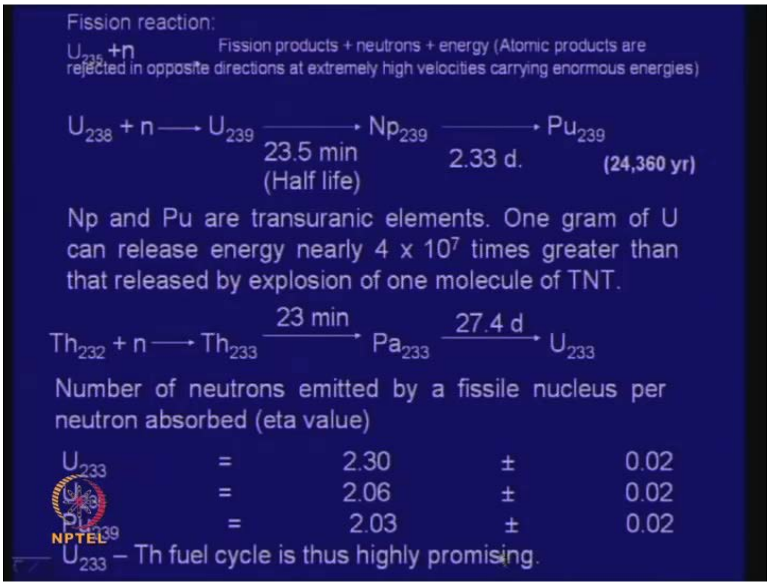
So, what we can convert it to plutonium we will have lot more fissionable material. Unfortunately there is a problem uranium 238, when convert it to plutonium 239 does not all become plutonium 239 only very tiny fractions of uranium 238 after irradiation produces plutonium 239 and there is a great deal of problem in recovery with that plutonium 239.

Very elaborate chemical engineering processes anyway let us go through all this once again, you have uranium one has to find a method of separating the isotopes how will we do it, I will very briefly discuss later. We will have to separate uranium 235 and uranium 235 is the one which can undergo fission, which is fission then when bombarded by thermal neutrons it will break into 2, 2 products fission products of equal mass which will go at very high velocity in different directions and it will produce neutrons.

It will produce more neutrons than it has consumed and those neutrons would again bombard U 35 and produce more neutrons and so the energy goes multiplying. So, after fission there is a energy in the products, which have gone fly in the opposite directions then, there are thermal neutrons these neutrons can be used to bombard U 238. This U 238 will get converted to plutonium 239 which is have to separated out and in that we will produce energy.

So, in the first generation we will have a reactor working on uranium 235 then we will go to next generation, where those thermal neutrons would be use to produce plutonium actually, in any reactor whenever a fission reaction is taking place plutonium is always been produced and that, that is the plutonium extraction becomes very critical process. Similarly, the thermal neutrons can convert thorium 232 to uranium 233 which is a fissionable material, this is an isotope which comes out of thorium 232 by thermal reaction with thermal neutrons.

(Refer Slide Time: 53:35)



Fission reaction:

U_{235} +n Fission products + neutrons + energy (Atomic products are rejected in opposite directions at extremely high velocities carrying enormous energies)

$U_{238} + n \longrightarrow U_{239} \xrightarrow[\text{(Half life)}]{23.5\ \text{min}} Np_{239} \xrightarrow[2.33\ \text{d.}]{} Pu_{239}$ (24,360 yr)

Np and Pu are transuranic elements. One gram of U can release energy nearly 4 x 10^7 times greater than that released by explosion of one molecule of TNT.

$Th_{232} + n \longrightarrow Th_{233} \xrightarrow{23\ \text{min}} Pa_{233} \xrightarrow{27.4\ \text{d}} U_{233}$

Number of neutrons emitted by a fissile nucleus per neutron absorbed (eta value)

U_{233} = 2.30 ± 0.02

U_{235} = 2.06 ± 0.02

Pu_{239} = 2.03 ± 0.02

U_{233} – Th fuel cycle is thus highly promising.

These are the fission reactions uranium 235 bombarded the neutron produces fission products, more neutrons and energy atomic products are ejective in opposite directions at extremely high velocities carrying enormous energies, we have to find a way of extracting those energies. In the case of uranium 238 which is a fertile material neutron U plus uranium 235plus neutron will give uranium 239, which has a half life of 23.5 minutes then Np 239 half life of 2.33 days finally, it converts to plutonium 239 which is stable half life is 24360 year.

So, uranium 238 has now been converted to a man made element which is stable. Neptunium and Plutonium are transuranic elements one gram of uranium can release nearly 4 into 10 to the power 7 times energy as from one molecule of TNT. So, you see how much of energy there is one gram of uranium. Now, coming to thorium 232 reaction is plus n thorium 233 half life 20 minutes in palladium 27.4 days finally, uranium 233 which is stable this will be efficient.

Now, finally, number of neutrons emitted by a fissile nucleus per neutron absorbed it is called eta value, we will find uranium 233 gives 2.30 number of neutrons per neutrons absorb U 235 2.06 plutonium 239 2.03 therefore, the uranium 233 which comes from thorium fuel cycle is most highly permissible. I will stop here now I continue with it in the next lecture thank you.