Applications of neutron activation analysis

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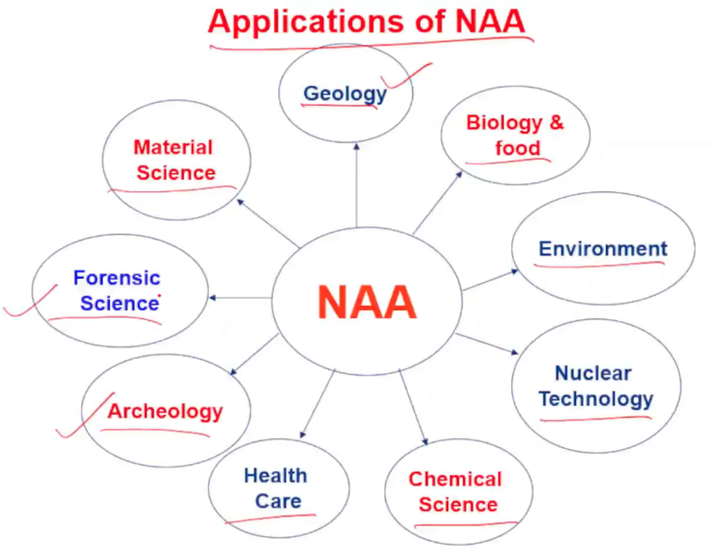
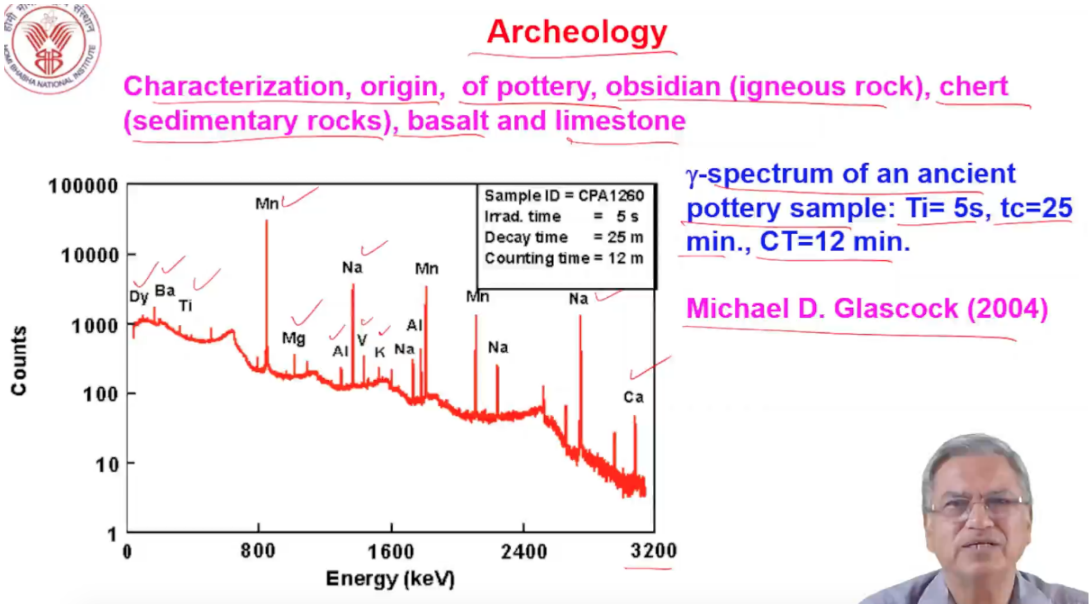
Lecture-17, Module-2

Hello everyone. In the previous part, I discussed the fundamentals of neutron activation analysis technique, very powerful technique for determination of concentration of elements and nearly 70% of the elements in the periodic table are amenable to neutron activation analysis. Different elements have different sensitivity, different detection limits because of their nuclear data. In this part, I will discuss some of the applications of neutron activation analysis.



So neutron activation analysis has found applications in large variety of fields starting from geology, to biology, food and nutrition, environmental sciences, nuclear technology, chemical sciences, even in healthcare, archaeology, forensic sciences and material sciences. So you can see in any area where it is required to find out the concentration of elements, you will find neutron activation analysis is one of the important techniques worth considering.

And particularly in those areas like nuclear forensic science, archaeology or even the geology where you may like to retain the samples for any future investigation, then this technique scores over other techniques. If the idea is only to determine concentration, there may be techniques like chemical science, material science, you may have other techniques like spectroscopic based techniques, but those samples which are mixed samples and you have to preserve the sample and you are looking for a particular element, then you will find that NAA is the ideal technique, if the element happens to be sensitive to neutron activation analysis. And so people working in different fields have taken NAA for their studies in R&D areas. I will not be able to cover all of them. I will cover some of them like archaeology, forensic science, geology, food and nutrition and healthcare. So let me see how much justice I can do.



Archeology

Characterization, origin, of pottery, obsidian (igneous rock), chert (sedimentary rocks), basalt and limestone

γ-spectrum of an ancient pottery sample: Ti= 5s, tc=25 min., CT=12 min.

Michael D. Glascock (2004)

So archaeology, you know, there are excavations to know the past civilization. There are many, many areas where archaeologists want to find out what is the composition of a particular artifact, which is found out in some excavations. So for example, like I was telling you that you can do dating of the fossils.

So archaeologists would like to know how old the particular place is, for example, there is a temple and you want to find out when this temple was built, you just take a fossil sample, the wood sample from that and you can find out the age of that temple. Similarly, you have the ancient pottery samples from like for example, Mohan Jodaro and Harappa, you get some pottery and you want to know the concentration, you want to understand the kind of technology people had at that time. So nowadays, you know, somebody may claim that this is of that origin. So it is Harappan time. How do you make sure this is of Harappan time which is not a fake? These days there is a lot of adulteration in many things.

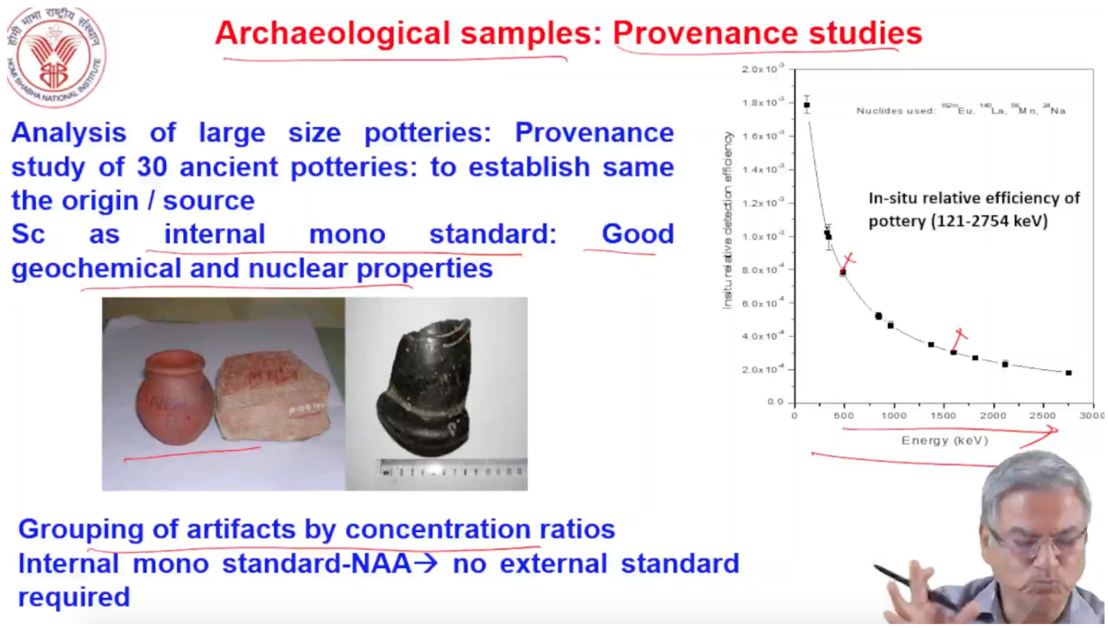
So even suppose somebody is selling an archaeological artifact and earning money, one would like to know scientifically whether it is of that time. So you need to characterize that artifact, you need to find out what is the origin of this. So the ancient pottery, they had well characterized concentration of different elements, they had the signature concentrations of elements. So you can do analysis of this pottery and find out that this is genuine or not. Obsidian type of igneous rocks, you can try to understand the volcanic eruptions that happened, what kind of rocks were generated in the volcanic eruption.

The shards, this is the sedimentary rocks or the sedimentation process took place over a period of time, the basalt and the limestone type of the clays, different geological and archaeological samples you can analyze as a research and development or to characterize and find origins of this artifacts. So this is a particular gamma spectrum of an ancient pottery sample. The sample was irradiated for let us say 5 seconds, the Ti irradiation time, 5 seconds. After the irradiation, they waited for 25 minutes to cool the sample. Cooling means $e^{-\lambda t}$.

So cooling may be required because it may take some time to take the sample out of the reactor to your laboratory. And sometimes you may produce some shorter lived activity which are not of your interest. And then it was counted for 12 minutes. So I have taken this from the reference of Michael Glascock. And you can see here the interesting aspect of this is a typical gamma spectrum from a HPGe detector.

You have right up to 3 MeV. So you can see a large number of elements, their isotopes have suitable gamma rays, this is dysprosium, barium, titanium, manganese, magnesium, sodium, aluminum, vanadium, potassium, and all elements, so sodium and calcium. Sometimes one isotope may have several gamma rays like sodium. So like that, in one shot, one spectrum you can analyze, you can see 1, 2, 3, 4, 5, 6, 7, 8, 9, about 8 into 10, sometimes even it can be more. From a single gamma spectrum, one count of it, one counting of the sample, you can analyze multiple elements in the sample.

So that is the beauty of this and the archaeological samples of varied type, varied sources can be analyzed to find out the source of that particular artifact or you can even do research, you know, how the evolution took place you can understand by neutron activation analysis.



Archaeological samples: Provenance studies

Analysis of large size potteries: Provenance study of 30 ancient potteries: to establish same the origin / source
Sc as internal mono standard: Good geochemical and nuclear properties

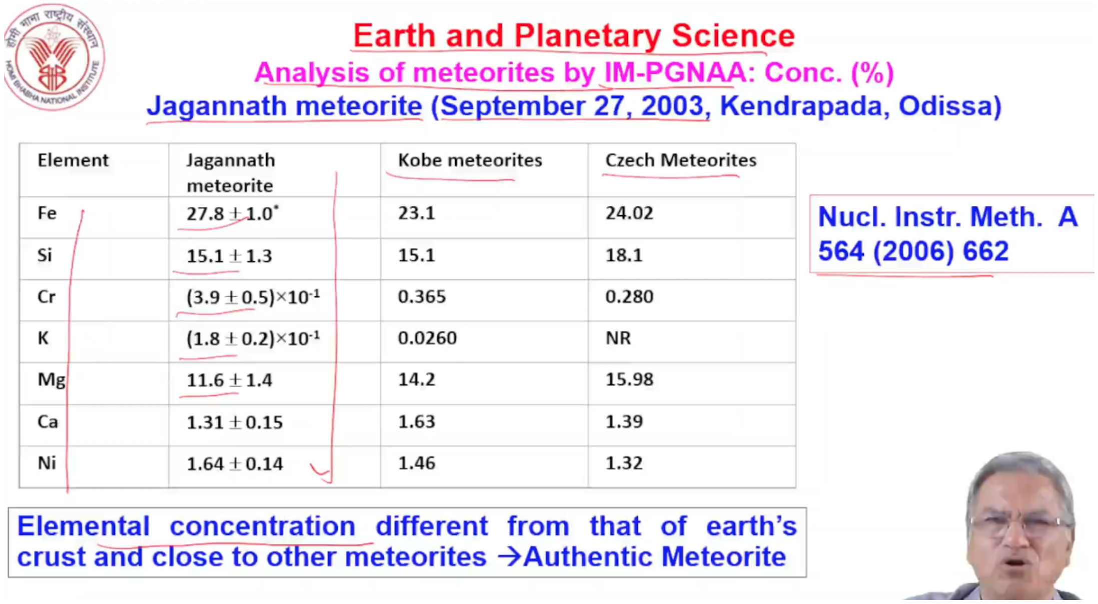
Grouping of artifacts by concentration ratios
Internal mono standard-NAA→ no external standard required

Other classes of this, like sometimes you can do the provenance study of archaeological samples. Again, this is the kind of pottery, you know, large size potteries. So sometimes the archaeologists may like to do some investigation of ancient potteries and to establish their source, where form they came. And so for such samples, in fact, in my department, one of our colleagues is an expert in the neutron activation analysis.

He has supplied me this data, Dr. Acharya. So he has used these samples and these samples now you can take a small sample of this artifact and do the neutron ativation analysis. And as I mentioned, that in these samples, it is not known what are the elements, we cannot have the standards for this reference materials are not available. So at that time, the internal mono standard. That means one of the elements in the sample may be used as a reference like scandium. So scandium has got decay characteristics, we can use them. So all elements with respect to scandium, you can determine their concentration. So scandium has good geochemical properties and nuclear properties, the decay characteristics and scandium is chemical to family of rare earths. So scandium, yttrium and then below them are lanthanides.

So chemically they are similar to lanthanides. So this is a typical efficiency graph, because what you require is a good efficiency data. Relative efficiency, efficiency of detection depends upon the gamma ray energy. And so the uncertainties are introduced, because suppose you have this scandium gamma one here, you are using the other gamma here. So ratio of efficiencies becomes important.

If you do not have a good efficiency data, then your analysis may be wrong. So in situ relative efficiency from the same sample, we generate efficiency data because the standard is also in the same sample like scandium. And so you require having the gamma rays, multiple gamma rays in the same sample and internally you can generate the efficiency data with respect to that standard like scandium and determine the concentration of all of the elements. And so you can now do the provenance study, you can generate the data of the concentration of certain group of elements which will characterize the particular pottery. And then this is the kind of study you can do. You do not need any external standards because initially you don't know what are the elements present in that. So this is the kind of research one can do to characterize the samples of ancient origin in earth.



Earth and Planetary Science

Analysis of meteorites by IM-PGNAA: Conc. (%)

Jagannath meteorite (September 27, 2003, Kendrapada, Odissa)

Element	Jagannath meteorite	Kobe meteorites	Czech Meteorites
Fe	27.8 ± 1.0*	23.1	24.02
Si	15.1 ± 1.3	15.1	18.1
Cr	$(3.9 \pm 0.5)\times10^{-1}$	0.365	0.280
K	$(1.8 \pm 0.2)\times10^{-1}$	0.0260	NR
Mg	11.6 ± 1.4	14.2	15.98
Ca	1.31 ± 0.15	1.63	1.39
Ni	1.64 ± 0.14	1.46	1.32

Nucl. Instr. Meth. A 564 (2006) 662

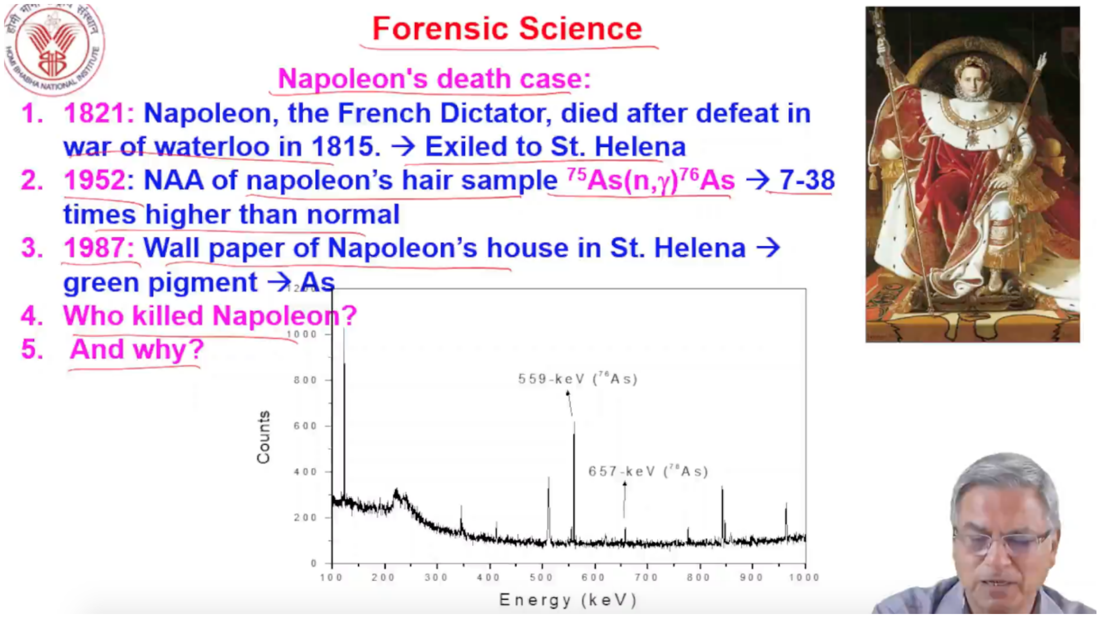
Elemental concentration different from that of earth's crust and close to other meteorites →Authentic Meteorite

Another is the geology, earth and apart from earthly objects, you can do the meteorites that are coming from the planets. So these meteorites that are coming to earth and you would like to know from which planet or from where it has come, what is the source of this meteorite. So the geology people, they are trying to characterize the different meteorites present and you can even compare with other meteorites.

So one of the studies was analysis of meteorites by internal mono standard prompt gamma neutron activation analysis, suppose you have a big chunk of meteorite, so in prompt gamma as I mentioned, the neutron beam is out of the reactor hall and then you can expose the entire sample to the neutrons and then the gamma rays are detected by the Germanium detector. So in Odisha, in September 27, 2003, a meteorite fell on the earth and that is named as Jagannath meteorite. So this Jagannath meteorite was characterized by my colleagues at the BARC and it is published in journal. I have taken the data from Dr. Acharya and you can see here the elements that are present iron, silicon, chromium, potassium, magnesium, calcium, nickel.

Jagannath meteorite concentrations you can see in terms of the percentage, all of them are in percentage, 27%, 15.1, 0.39, 0.18, and 11.6 and so on. And you can also compare them with other meteorites elsewhere published by other colleagues, other researchers on Kobe meteorites, Czech meteorites and then you can find out whether it is an authentic meteorite or what is the origin of this, whether it is different from this meteorite. So what was found that the elemental concentration of this meteorite was found to be different from that of the Earth's crust and it was found to be close to these other meteorites. So essentially, they wanted to confirm first of all that it is an authentic meteorite. you know, somebody may take a rock and say this is the meteorite. So sometimes people may do business also, they just sell this meteorite, it is from other planet.

So to make sure that it is an authentic meteorite and also to compare it with other meteorites and you can do R&D. So what are the sources of these meteorites. So this kind of study, one can do in the field of Earth and planetary science.



Forensic Science

Napoleon's death case:

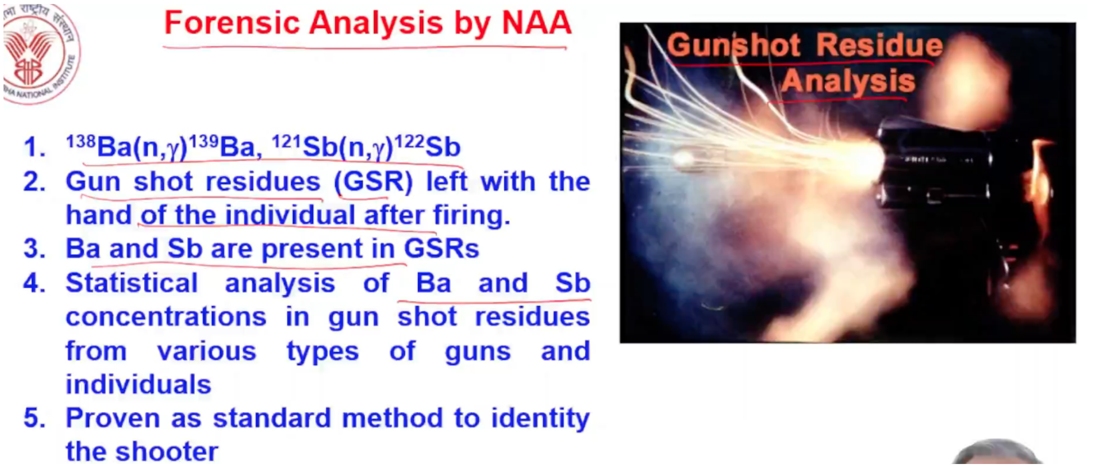
1. 1821: Napoleon, the French Dictator, died after defeat in war of waterloo in 1815. → Exiled to St. Helena
2. 1952: NAA of napoleon's hair sample $^{75}As(n,\gamma)^{76}As$ → 7-38 times higher than normal
3. 1987: Wall paper of Napoleon's house in St. Helena → green pigment → As
4. Who killed Napoleon?
5. And why?

Then, one of the most important areas wherein the neutron activation analysis finds lot of applications, is forensic science. So I will just share one of the stories from, not a story, the actual research that happened in the case of investigating the death of Napoleon Bonaparte.

Napoleon Bonaparte was the French dictator in the 19th century and he was actually defeated in the war of Waterloo by the British Army in 1815 and then he was exiled to a place called St. Helena and there in exile Napoleon died. So there were a lot of speculations about how Napoleon died, whether he was poisoned or not. And so you see 1821 is a long time passed but still since he was an emperor and so some scientists wanted to investigate whether he died of poisoning or he died of natural death because he was not very old at that time. So then in 1952 the hair sample of Napoleon was collected from that place St. Helena and this hair sample was subjected to neutron activation analysis by neutron capture reaction on arsenic-75. Arsenic is monoisotopic so you get ^{76}As by (n, γ) reaction. And what was found that the activity of arsenic-76 in this Napoleon's hair sample was found to be 7 to 38 times higher than what you get in the normal hair. So it was no doubt that Napoleon's hair had very high concentration of arsenic than in the normal hair. The question was whether Napoleon was poisoned with arsenic or not.

In 1987 this investigation was going on. They wanted to investigate where from the arsenic came into the hair and so they found that there was a wallpaper in Napoleon's house in St. Helena and the pigment in that wallpaper it contained arsenic. And arsenic is known to form volatile compounds. So the green pigment contained arsenic and it is possible that under the environmental conditions, arsenic might get airborne and arsenic is known to form complex with organic molecules and then it could have been inhaled by Napoleon and that might have killed him.

So there was a theory going on that time that Napoleon was poisoned slowly by giving him arsenic laden food but it was not known who killed Napoleon. And of course what was the motivation for killing Napoleon because he was already in exile but it generated lot of interest among the community. Historians, they wanted to know whether he was really poisoned by arsenic, we do not know. Lot of research went and the neutron activation played an important role in coming to this conclusion that Napoleon's hair contained large concentration of arsenic than what is present in normal people. You can see here, this is the gamma spectrum of arsenic-76, 559, and 657 keV gamma ray. So we can, selectively find out the peak area of these peaks and find out the concentration of the arsenic in the sample.



Forensic Analysis by NAA

1. ^{138}Ba(n,γ)^{139}Ba, ^{121}Sb(n,γ)^{122}Sb
2. Gun shot residues (GSR) left with the hand of the individual after firing.
3. Ba and Sb are present in GSRs
4. Statistical analysis of Ba and Sb concentrations in gun shot residues from various types of guns and individuals
5. Proven as standard method to identity the shooter

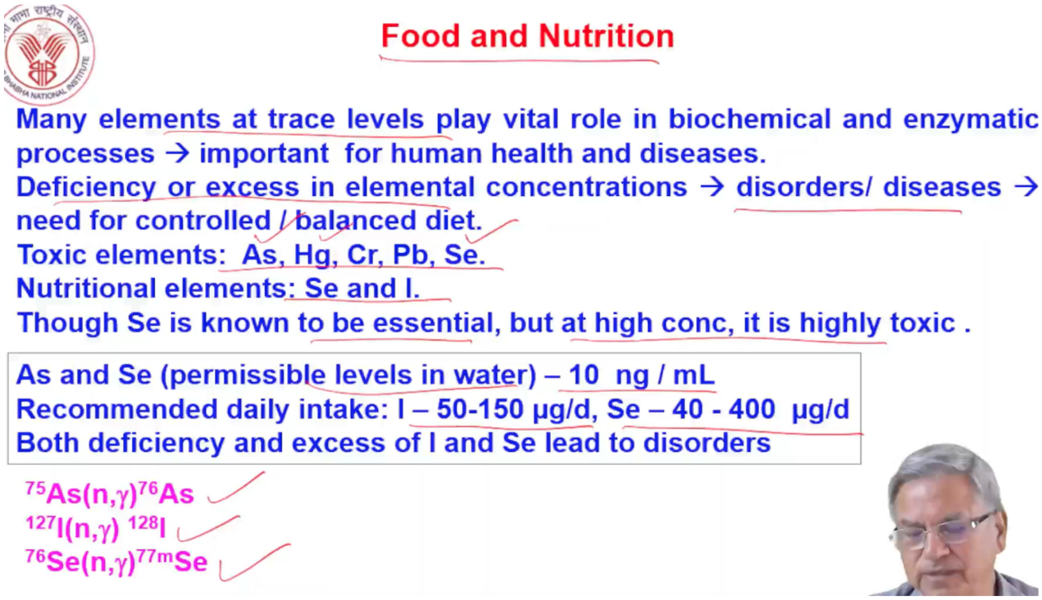
Gunshot Residue Analysis

Another area in the forensic science where the neutron activation analysis is used is the gun shot residue in a crime investigation. Somebody fires a bullet and the bullet is recovered from the site but then you want to know who fired that bullet. So the culprit, you have to unambiguously prove. So see in many places, you go by the witness. The witness says, I have seen this person firing but the witness may turn hostile after some time. The statement of a witness, it can vary and you cannot rely on the witnesses for the final judgment. So always, forensic science relies on the scientific evidence of the culprit. So you have to correlate with the weapon and the culprit. So how do you do that? What was found that this gunshot residue, if somebody fires a gun, then that person's hand contains the residue of the powder, gun powder.

So you can analyze the gun powder from the hands of the culprit. Of course, by the time if the culprit has washed the hands, then you cannot do anything. But if you can catch the culprit and you can get some sample from that hand of the culprit, analyze those samples for the particular elements. So in this case, barium and antimony are the two elements which are not very common in the soil samples or dust samples. So these are not very commonly available. Like commonly you will get iron, scandium, aluminum and so on, magnesium and so on. So what was found that this gunpowder and gun shot residue contained barium and antimony. And they were actually taken as signatures of the bullets, the gunpowder that is used. And so if a person's hand was found to be contaminated with these elements, he is a prospective suspect. The gunshot residues, GSR to be abbreviated, left with the hand of the individual after firing can be used as a scientific evidence for correlating with the person who did the crime.

The barium and antimony are present in these residues. And so what essentially you do the different types of guns, you can collect the data, the kind of concentration ratios of barium and antimony from different types of guns and the different individuals, you can generate a database. And then you can pinpoint that suppose you recover the gun that was from the crime scene and you have 10 people who are suspects. So you can analyze the sample from the persons and correlate. This is the person whose sample is matching with the gun recovered from the site.

So that is the kind of scientific evidence generated. And scientifically you can nail the culprit, then one cannot escape, they have to accept. This is the kind of analysis people do in the forensic investigations.



Food and Nutrition

Many elements at trace levels play vital role in biochemical and enzymatic processes → important for human health and diseases.
Deficiency or excess in elemental concentrations → disorders/ diseases → need for controlled / balanced diet.
Toxic elements: As, Hg, Cr, Pb, Se.
Nutritional elements: Se and I.
Though Se is known to be essential, but at high conc, it is highly toxic .

As and Se (permissible levels in water) – 10 ng / mL
Recommended daily intake: I – 50-150 μg/d, Se – 40 - 400 μg/d
Both deficiency and excess of I and Se lead to disorders

^{75}As(n,γ)^{76}As
^{127}I(n,γ) ^{128}I
^{76}Se(n,γ)^{77m}Se

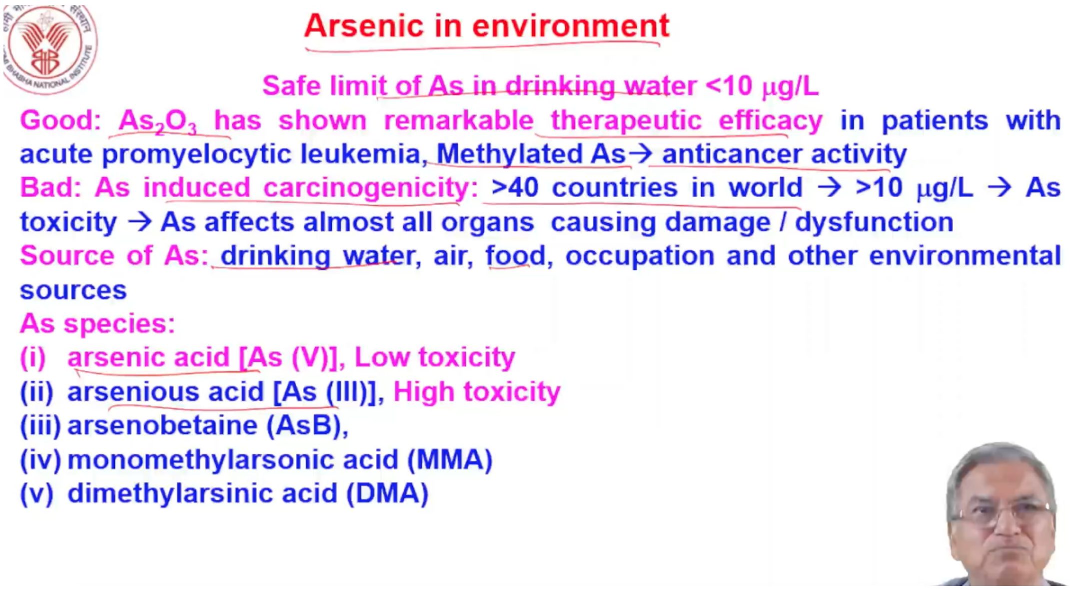
Then in food and nutrition, there are a lot of applications. And the people, who are doing the research in this area, will find NAA is very, popular. So there are many elements which at trace level play vital role in our biochemical system, in the genetic processes. There are many elements which are beneficial to our health. And those elements, if there is a deficiency of these elements, you get sick. If there is excess of these elements, then they become toxic. So there is an optimum level of concentration of these elements that are required for food and nutrition.

So the deficiency or excess of certain elements in our body leads to disorders and diseases. And therefore, we need to have a balanced diet, very controlled diet containing those elements. Certain elements are toxic, they are not needed by our body, like arsenic, mercury, chromium, and out of them certain elements like selenium, in fact, arsenic has got medicinal value. Some people used to recommend this mercury ladden bhasmas they have some medicinal value. But in terms of the nutritional elements, selenium and iodine are nutritional elements; they are required for the body.

For example, selenium, actually I will discuss more on the selenium NAA. Selenium, present as orgonosilenium is useful for the body. And the excess selenium can also lead to abnormalities in the humans and animals. So it is essential for the body at low concentration, but at high concentration it becomes toxic. So we will discuss the NAA of arsenic, selenium, and iodine.

In arsenic and selenium, there are limits prescribed by the WHO, World Health Organization, that any drinking water should not contain arsenic or selenium more than this concentration like 10 ppb. And then since these elements are useful for our body, we require them, there are recommended daily intake values. For example, for iodine we have 50 to 150 microgram per day. For selenium, people have been taking this kind of concentrations. And so these are the elements, you know, either they are in deficiency in our body, they can lead to problems.

If there is an excess, they become toxic. They can lead to even like thyroid disorders are due to iodine problem. So these all the three elements amenable to neutron activation analysis, As^{75} (n, γ) As^{76}, I^{127}(n, γ) I^{128}, Se^{76}(n, γ)Se^{77m}. So I'll give you some examples of activation analysis for these elements.



Arsenic in environment

Safe limit of As in drinking water <10 μg/L

Good: As_2O_3 has shown remarkable therapeutic efficacy in patients with acute promyelocytic leukemia, Methylated As → anticancer activity

Bad: As induced carcinogenicity: >40 countries in world → >10 μg/L → As toxicity → As affects almost all organs causing damage / dysfunction

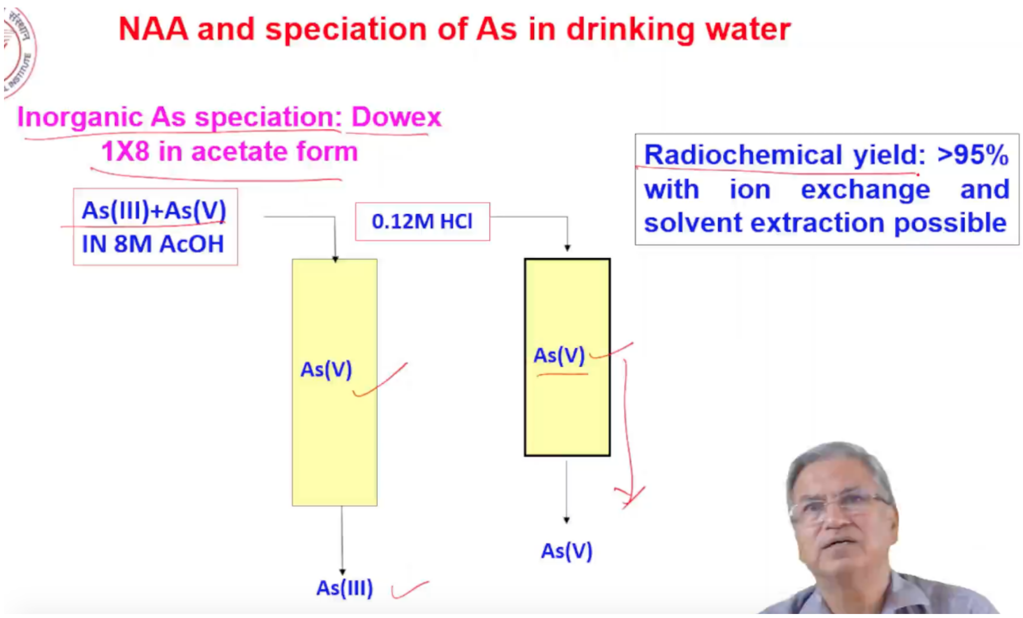
Source of As: drinking water, air, food, occupation and other environmental sources

As species:

(i) arsenic acid [As (V)], Low toxicity
(ii) arsenious acid [As (III)], High toxicity
(iii) arsenobetaine (AsB),
(iv) monomethylarsonic acid (MMA)
(v) dimethylarsinic acid (DMA)

So arsenic in environment, there are safe limits for drinking water, less than 10 microgram per liter ppb. So it has the good and the bad part of it. Arsenic in trivalent state has shown remarkable benefits. Arseneous oxide is found to have therapeutic efficacy in patients who are suffering from promyelocytic leukemia and methylated arsenic, organic arsenic has been known to have anti-cancer activity. The bad part of it is that arsenic can induce carcinogenicity in the human beings. And there are many areas in the world including some part in our country, more than 40 countries in the world have drinking water concentrations, more than 10 micrograms per liter. That leads to arsenic toxicity. So, high concentration of arsenic affects organs causing to dysfunction of so many organs, damaging the organs and so on.

Arsenic can become airborne because it has a tendency to bind with the organic molecules present in drinking water and food. So many people are susceptible to arsenic poisoning. As species arsenic is present, if it is arsenic acid, arsenic is pentavalent state, it is less toxic than Arsenic acid which is in the trivalent. So trivalent arsenic is absorbed by the body and it can lead to high toxicity. Organic Arsenides, they are considered to be less toxic and so some of them in fact have some medicine for therapeutic application they are being utilized.



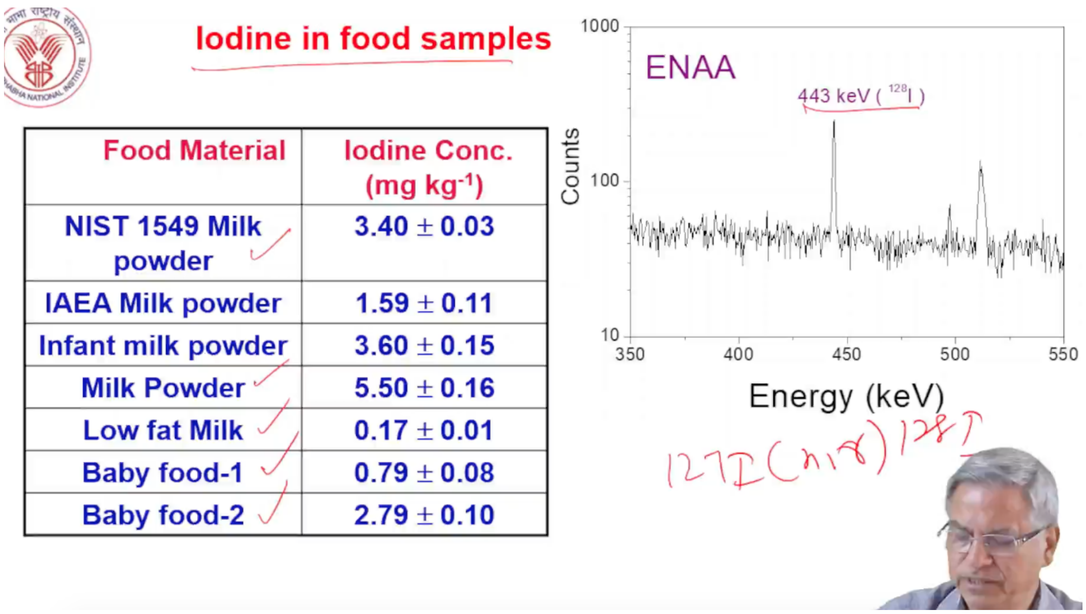
NAA and speciation of As in drinking water

Inorganic As speciation: Dowex 1X8 in acetate form

Radiochemical yield: >95% with ion exchange and solvent extraction possible

As I was telling that the oxidation state of arsenic is important, the trivalent Arseneous acid is more toxic than pentavalent acid. So people are doing the speciation that means you separate the elements depending upon their oxidation state and for inorganic Arsenic one can use anion exchanger, Dowex 1X8 in acidic form. So one of the columns will retain Arsenic(V) and elute Arsenic(III) and then the retained Arsenic(V) can be eluted separately. So lot of people who do research in food and nutrition, they need to also separate Arsenic in different oxidation state.

So this is one of the studies by our colleagues at the BARC. They found that you can separate more than 95% of arsenic with a good radiochemical yield using ion exchange and solvent extraction. So neutron activation analysis in combination with speciation becomes a very important tool to study toxicity associated with different oxidation states.



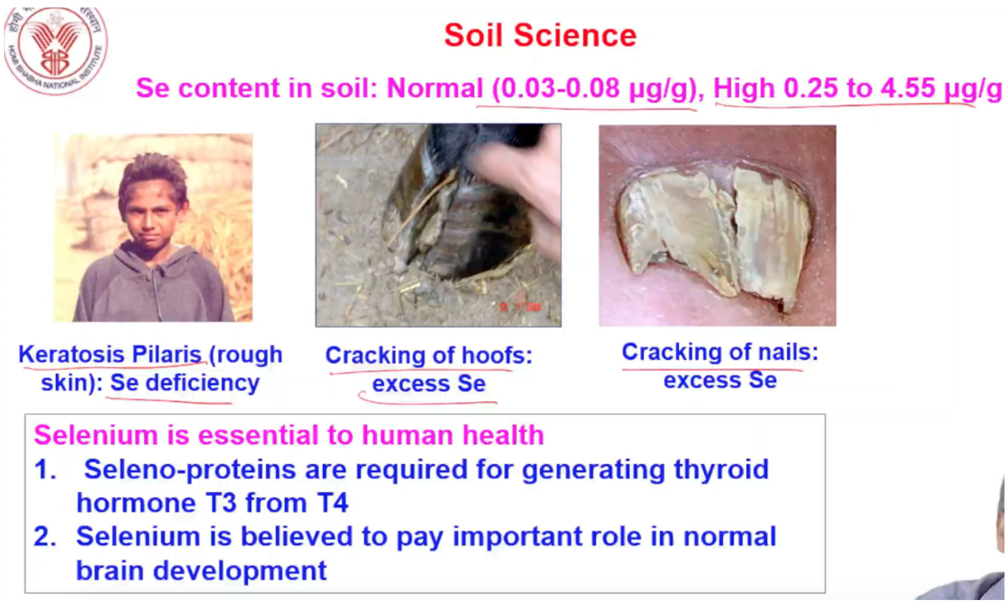
Iodine in food samples

Food Material	Iodine Conc. (mg kg^{-1})
NIST 1549 Milk powder ✓	3.40 ± 0.03
IAEA Milk powder	1.59 ± 0.11
Infant milk powder	3.60 ± 0.15
Milk Powder ✓	5.50 ± 0.16
Low fat Milk ✓	0.17 ± 0.01
Baby food-1 ✓	0.79 ± 0.08
Baby food-2 ✓	2.79 ± 0.10

$^{127}I(n,\gamma)^{128}I$

Iodine is another important element which is required for the body. Our body like thyroid hormones contain iodine. Like there are three thyroid hormones T3, T4 and TSH and what is the source of iodine it is important to know the content of iodine in different food samples.

So we have milk powders. So this group did actually the neutron ativation analysis of different milk powders, baby foods, different baby foods, low fat milk powder and so on and found out the concentration of iodine in milligram per kg. And the gamma ray spectrum of $I^{127}(n, \gamma)\ I^{128}$. You can see that 443 keV gamma ray highly selective. So you do not have any doubt. There is no interference in that peak. So this is the kind of study people do to find out iodine in different food samples. So you can just irradiate the powder without doing any chemistry. You can seal it in a container, aluminum foil, irradiate and count for gamma activity and find out the iodine content.



Soil Science

Se content in soil: Normal (0.03-0.08 μg/g), High 0.25 to 4.55 μg/g

Keratosis Pilaris (rough skin): Se deficiency

Cracking of hoofs: excess Se

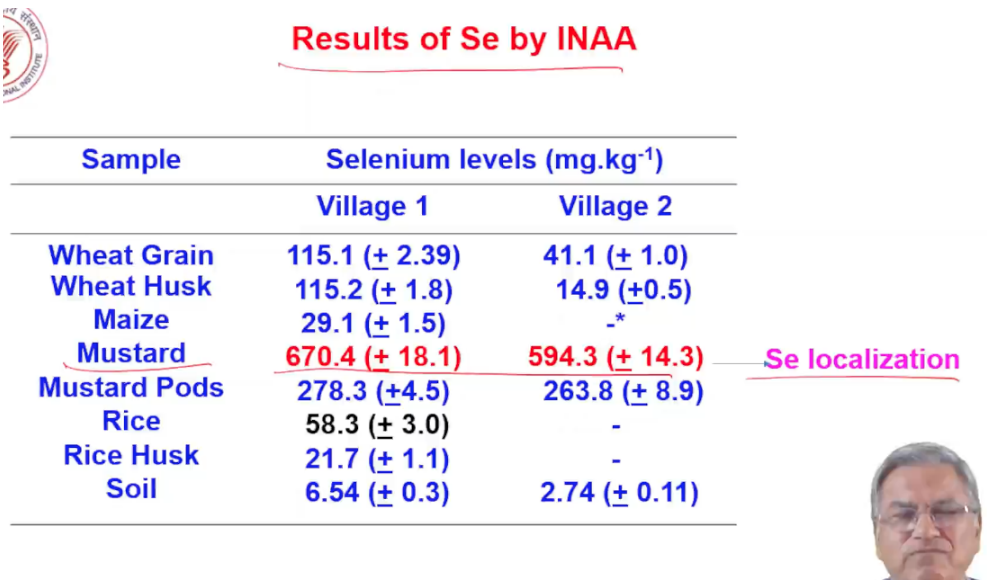
Cracking of nails: excess Se

Selenium is essential to human health

1. Seleno-proteins are required for generating thyroid hormone T3 from T4
2. Selenium is believed to pay important role in normal brain development

Selenium is another important element which has got both the aspects, good and the bad. Low selenium content, there can be selenium deficiency. Selenium is required for our body. Selenium deficiency can lead to diseases. For example, there is a skin disease called keratosis pilaris. It leads to cracking of the skin. The skin becomes very rough because of the selenium deficiency. Excess of selenium in our body leads to, along with animals, cracking of their hoofs and cracking of the nails can take place if we have excess of selenium. So what is the normal range of selenium.? So selenium can be picked up by different plants and when we consume those plants, our body will accumulate selenium. So in soil, selenium content is an important priority. If there is a selenium rich soil, then the people living in that area, people eating the vegetation in that area are prone to getting selenium problems.

So normal concentration is 0.03 to 0.08 microgram per gram ppm and selenium concentration can go to very high. In fact, very, very high concentrations are also seen in the world. So while selenium in excess concentration is toxic and low concentration is also not desirable, and low concentration, the deficiency of selenium can lead to diseases, there are the good part of selenium because it is essential to health. Selenoproteins are required for generating thyroid hormone T3 from T4. So to convert T4 to T3 requires selenoproteins and selenium is believed to play an important role in the brain development.So you will find that it is again this story where an element is good for health, at the same time when there is a deficiency or an excess, then it can lead to diseases.

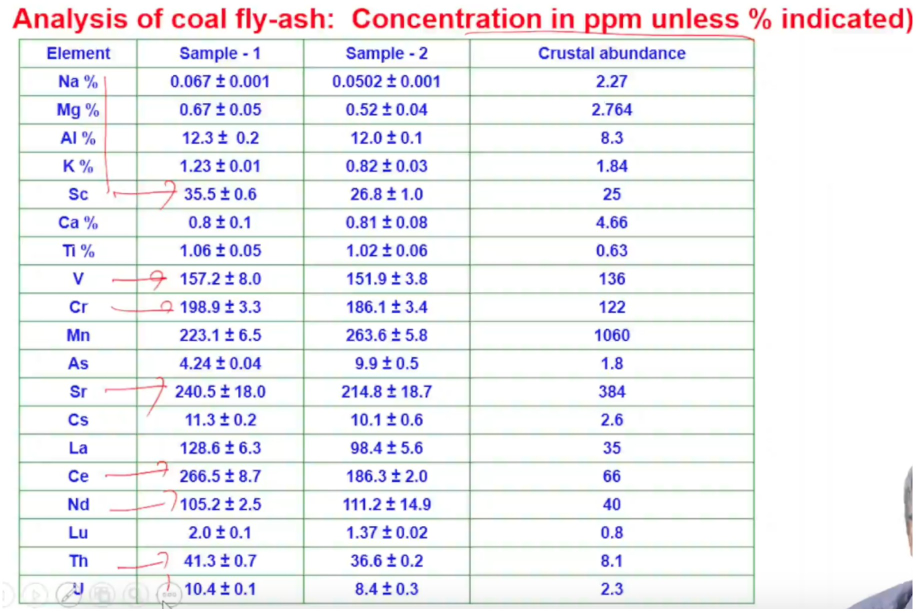


Results of Se by INAA

Sample	Selenium levels (mg.kg^{-1})	
	Village 1	Village 2
Wheat Grain	115.1 (± 2.39)	41.1 (± 1.0)
Wheat Husk	115.2 (± 1.8)	14.9 (±0.5)
Maize	29.1 (± 1.5)	-*
Mustard	670.4 (± 18.1)	594.3 (± 14.3)
Mustard Pods	278.3 (±4.5)	263.8 (± 8.9)
Rice	58.3 (± 3.0)	-
Rice Husk	21.7 (± 1.1)	-
Soil	6.54 (± 0.3)	2.74 (± 0.11)

Se localization

So these are the results of selenium determination by neutron activation analysis. And you can see mustard, particular mustard from that particular area was found to contain very high concentration of selenium. So people who are consuming that mustard might be getting excess of Se, and this also shows that selenium can be localized. Particularly, you know, the mustard contains some sulfur compounds. And wherever there is sulfur, sulfur and selenium are homologs of each other. So selenium will go along with sulfur. So any plant containing sulfur will enrich the selenium. And therefore, it is important to study the concentration of selenium in different plants so that one can understand whether there is a selenium related diseases in the population.



Analysis of coal fly-ash: Concentration in ppm unless % indicated)

Element	Sample - 1	Sample - 2	Crustal abundance
Na %	0.067 ± 0.001	0.0502 ± 0.001	2.27
Mg %	0.67 ± 0.05	0.52 ± 0.04	2.764
Al %	12.3 ± 0.2	12.0 ± 0.1	8.3
K %	1.23 ± 0.01	0.82 ± 0.03	1.84
Sc	35.5 ± 0.6	26.8 ± 1.0	25
Ca %	0.8 ± 0.1	0.81 ± 0.08	4.66
Ti %	1.06 ± 0.05	1.02 ± 0.06	0.63
V	157.2 ± 8.0	151.9 ± 3.8	136
Cr	198.9 ± 3.3	186.1 ± 3.4	122
Mn	223.1 ± 6.5	263.6 ± 5.8	1060
As	4.24 ± 0.04	9.9 ± 0.5	1.8
Sr	240.5 ± 18.0	214.8 ± 18.7	384
Cs	11.3 ± 0.2	10.1 ± 0.6	2.6
La	128.6 ± 6.3	98.4 ± 5.6	35
Ce	266.5 ± 8.7	186.3 ± 2.0	66
Nd	105.2 ± 2.5	111.2 ± 14.9	40
Lu	2.0 ± 0.1	1.37 ± 0.02	0.8
Th	41.3 ± 0.7	36.6 ± 0.2	8.1
U	10.4 ± 0.1	8.4 ± 0.3	2.3

So lastly, there is another area of study that is coal fly ash. There are thermal power stations emitting a lot of flue gases and these flue gases cause pollution in the area around the thermal power plant you will find a lot of dust settled everywhere and there are the people who are exposed to this, and they get diseases. So it is important to convince ourselves that people living in that area are safe. So that dust, the coals fly ash was analyzed in our laboratory for the concentration of the metal ions. So you can see sodium, magnesium, aluminum, potassium, and scandium.

So whatever shown as percentage, rest are in ppm. And you can see here different samples, the concentrations of the different elements, say hundreds of ppm, strontium, cerium, nyodinium, thorium and uranium. So this coal fly ash can be used as a rich source of certain elements, whereas at the same time high concentration of certain elements can lead to diseases in the area. And so in the environmental clearances of some plants, you know, this is the data utilized or seeing that the plant is working properly.

So that's all I have to convey. There are many, many more applications of NAA, but in the short span of time, one can always go and look at the literature and see what are the kinds of different applications in different area. So I'll stop here and the next lecture I will take the ion beam analysis, another nuclear analytical technique. Thank you very much. Thank you.