Actinide Separation Demonstration Facility

Dhruva @ 100 MW

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BARC NEWSLETTER

Dr. R. Chidambaram (Interview)

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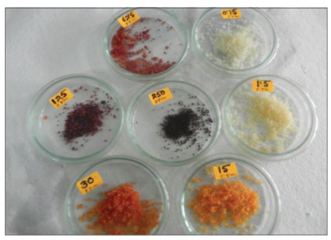
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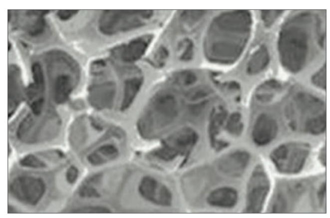
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Operation of Dhruva Reactor at Rated Power of 100 Mw on Sustained Basis

Dhruva is a research reactor, fuelled with metallic natural uranium. The reactor attained first criticality on August 8, 1985. The reactor caters to needs of broad spectrum multidisciplinary research and for production of various radioisotopes. Rated power of the reactor is 100 MW (thermal).

The reactor was generally operated at 50-60 MW power and at higher power levels for short durations. Operating power of the reactor was limited mainly by the radioactivity in the primary coolant system and fuel availability. Radioactivity in the primary coolant system is governed by instances of fuel failures.

Towards enhancing reactor utilisation, it was decided in June 2013 to operate the reactor close to its rated power. Various aspects related to operation of the reactor were reviewed, impediments identified and actions taken to achieve this objective. These include enhancement of operating margins through reassessment of safety, improvements in design of systems& components and change in operating practises. After implementation of these actions, the reactor is being operated at rated power on sustained basis since November 2014.

Introduction:

Dhruva is a research reactor with rated power of 100 MW (th). One of the main utilization of the reactor is for production of radioisotopes of high specific activity for application in medical, industrial and agricultural fields. The reactor also caters to needs of broad spectrum multidisciplinary research. The reactor uses Natural Uranium as fuel and heavy water as coolant, moderator & reflector. The maximum thermal neutron flux is 1.8×10^{14} n/cm^2/sec. The reactor vessel is made of stainless steel (SS-304L) and it is located in a water filled vault.

The primary cooling system of the reactor consists of three independent loops. Main coolant pumps operate to meet the core cooling requirement during normal operation. The reactor heat is transferred to the seawater through an intermediate process water cooling system. During reactor shutdown state, when main coolant pumps are not available, shut down cooling pumps (referred as auxiliary coolant pumps) pumps are operated to remove the core decay heat and for cooling of the reactor internal structures. Each auxiliary coolant pump is provided with two prime movers, one an electrical motor having uninterrupted AC (Class-II) power supply, and the other one a hydraulic turbine run by gravity flow of water from overhead tank. The core consists of fuel assemblies installed in 129 coolant channels made of Zircolly-2. A fuel assembly consists of aluminium clad 7-pin uranium fuel cluster along with other sub-assemblies.

Dhruva attained its first criticality on August 8, 1985. Since then, the reactor was operated at power levels of 50-60 MW, except for short durations it was operated at 100 MW. Power of reactor was limited mainly due to high coolant system activity because of high instances of fuel failures at higher powers and due to shortage in fuel supply. Operation of the reactor at limited power was resorted, so that production of radioisotopes could be sustained.

Towards enhancing reactor utilisation, it was decided in June 2013 to operate the reactor close to its rated power. To enable reactor operation close to the rated power on sustained basis, review of various aspects related to operation of reactor was carried out and remedial measures were implemented. These are described below along with plan of action in the future. These activities were carried out after due regulatory review and approval.

Enhancement of Operating Margins

One of the impediments in operation of the reactor at rated power was low operating margins in a few system parameters like cooling water temperature in core inlet plenum, channel power and shield cooling water temperature. These were reviewed and appropriate actions taken to overcome the difficulties:

Upward revision of trip setting on Core Inlet plenum high temperature

The trip on cooling water high temperature at Core Inlet plenum is set at 47°C. During summer months, the coolant inlet plenum temperature rises due to higher temperatures of sea water (~33°C) from normally observed temperature of 27°C, resulting in the coolant inlet temperature at inlet plenum approaching the trip value, thereby limiting the highest operating Reactor power. To overcome this limitation, it was necessary to raise trip set value; without affecting the safety of fuel. Coolant inlet temperature limit of 51°C was considered adequate for operating the reactor at rated power even with maximum observed sea water temperature of 33.5°C till date. Safety analysis carried out considering worst case scenario indicated that all the critical temperatures of the fuel assembly would be within acceptable limits, even for maximum rated fuel assembly. Necessary clearance were obtained for this.

Upward revision of allowable channel power output

During reactor operation at rated power, power output of a few of the central pile position fuel channel was exceeding the limiting channel output power, thus limiting the operating power of the reactor. Limit on the channel output power is set based on fuel assembly temperatures, especially during transients.

As adequate margin between channel low flow trip setting and the actual flow through the fuel channels was available, low flow trip setting was revised closer to the actual coolant flow. With the change in trip setting, the limit on channel output power could be enhanced by about 4%, resulting in more operating margins for the reactor.

Safety analysis carried out for the revised power output along with higher inlet plenum temperature confirmed availability of adequate safety margins for the fuel during normal operation and during transients.

Upward revision of limit on Shield cooling water outlet temperature:

Shield cooling water outlet temperature was a limiting parameter for operation of the reactor at full power as it was exceeding the limit set of 48°C , especially during some operational transients. Based on detailed analysis of stress intensities and deformations arising due to thermo mechanical loads, which showed that temperature limit could be raised to 55°C without any safety concern, the temperature limit was revised to 55°C.

Improvements in Design of Systems& Components

Enhancement in performance of Heavy water purification system :

Heavy water purification system, consisting of filters and ion exchange beds is used for purification of the system by removing radioactive impurities like fission products, corrosion products from the system. As the radioactivity in the primary cooling system was a limiting factor for operation of the reactor at high power, a thorough review of performance of the purification system was carried out. Based on it, additional ion exchange bed was incorporated in the system. Ion exchange resin in the beds was replaced with resin of superior quality and mechanism to monitor performance of the system was augmented. With these measures, the system activity could be reduced to its lowest level since commissioning of the reactor.

Installation of adjuster rod:

An adjuster rod was installed in the core to provide facility for production of coblat samples of high specific activity, without causing appreciable change in the xenon override time. This also helped in increasing the stablilized opearting moderator level in the reactor vessel, resulting in reduced linear heat rating of the fuel; thereby reducing the thermal stresses in the fuel.

Modification of Failed Fuel Detection (FFD) system:

Early identification of any failed fuel and its removal from core is essential to reduce the primary coolant system activity. Failed Fuel Detection system is provided to locate the clad failed fuel assembly in the core. To enhance performance of FFD system, the detector configuration was modified so as to obtain better discrimination between signal and background noise. This modification in system has resulted in better performance of the FFD system.

Modification of sea water strainers:

Continuous operation of the reactor is hampered by carryover of materials like marine litter and other materials in seawater to the heat exchangers, which choke the heat exchangers' seawater inlet strainers and results in shutting down of the reactor for cleaning the strainers. Modification of the strainers to increase the filtration surface area was taken up so that frequency of its cleaning is reduced.

Change in Operating Practises:

Limiting Linear Power rate during power changes:

As thermal shock to the fuel was identified to be a contributing factor in instances of fuel failures, control on the rate of change of power while varying reactor power was introduced. The operating practice was modified to limit linear power rate and setting of the alarm on 'Linear Power Rate High' was changed from 1MW/s to 0.12 MW/s. All the power changes are carried out on manual mode to the extent possible, keeping the limit on linear power rate. Modification of the reactor regulating system to limit the linear power rate during auto mode is envisaged.

Enhanced quality assurance during fuel fabrication:

Measures have been implemented to ensure quality of fuel during fuel fabrication and the quality assurance checks have been made more stringent. Some of the measures include procurement of nuclear grade aluminium (with very less hydrogen and inclusion content), fabrication of the fuel in humidity controlled environment, storage of machined uranium rods in quenching oil to prevent oxidation before processing, blowing of hot air between uranium rod and clad tube prior to canning operation to avoid condensation etc.

Availability of Fuel

Reactor power was earlier curtailed to conserve fuel, due to its shortage. Presently the supply position of fuel has improved; eliminating the constraint.

Future Actions

As porosity due to dissolved hydrogen in aluminium could be a cause of failure of aluminium clad of fuel, a few fuel assemblies have been fabricated with aluminium clad having stringent specifications for hydrogen. Performance of these fuel assemblies will be monitored.

Operating practise of lowering the reactor power by 10% during reactor load changes like isotope assembly changes is being reviewed as it has bearing on thermal shocks imparted to the fuel elements.

Modification in the design of fuel assemblies is envisaged. Loading the core with fuel assemblies of modified design will cause flattening of neutron flux in the core and it will result in reducuction in thermal stress on the fuel elements. The modification will also enhance reactivity of the core and thus help in improved utilization of the reactor. Two fuel assemblies with the modified design have successfully undergone irradiation on trial basis.

Conclusion

Dhruva was operated at the power level of 80 MW by October 2014, with a high level of safety and availability. The power was raised to rated power of 100 MW by November 2014 and it is operating at this power level. During year 2014, the reactor logged availability factor of about 76% and highest ever capacity factor of 53% till then. During the year 2015, availability factor of about 77% and capacity factor of about 62 % were achieved. With measures already implemented and with the measures planned, it is expected that reactor can be operated at rated power on sustained basis, which will go a long way in fulfillment of national demand for radioisotopes.

Actinide Separation Demonstration Facility:

A step towards making nuclear energy safer

Smitha Manohar

Using uranium in nuclear power plants and recycling the spent fuel can give a dependable supply of fuel. This reduces the waste to be disposed off and keeps valuable resource in circulation providing energy to meet growing demands. But during this entire process of producing energy and recycling the spent fuel, a special class of waste termed High Level radioactive waste does get generated albeit at very low volumes compared to the fossil counterpart. Experts in the field of nuclear technology know that nuclear power, with its small volumes of high-level waste, has distinct advantages compared to the large volumes of toxic waste produced by coal fired plants.

The concern about the high level waste is due to the presence of very small amounts of long-lived minor actinides (<0.1% in spent fuel). The time frame for consideration ranges from 10^4 to 10^5 years. To meet the waste management objectives of HLW management, these wastes are isolated using multiple barriers so as to prevent the migration of radionuclides into our environment. High-level liquid wastes are immobilized in vitreous matrices, which form the primary barrier. These along with its packaging and other engineered barriers are to be emplaced in geological disposal facilities thereby preventing any release of radionuclides into our environment over extended periods of time.

Though vitrification of High level liquid waste is well recognized and adopted industrially in India, attempts are being aimed at either reduction or elimination or of radioactive inventories from these wastes. This is termed as partitioning & transmutation strategy and has both environmental and resource advantage. Significant reduction in the potential radiotoxicity of the waste can be achieved through improved recovery and recycling of plutonium and separation of minor actinides (Np, Am, Cm) followed by their transmutation.

Setting up of an engineering scale test facility for actinide partitioning of high level liquid waste was perceived as a first technological milestone towards adoption of the actinide

The individual locations for storing vitrified HLW at SSSF, Tarapur

The Solid Storage Surveillance Facility, houses the Actinide Separation Demonstration Facility at Tarapur

partitioning process on an industrial scale. Thus, the Actinde Separation Demonstration Facility (ASDF) has been set up and hot commissioned at BARC, Tarapur. In the Indian context, partitioned minor actinides could be routed into the fast breeder reactor systems scheduled for commissioning in the near time frame.

'Separating the alpha content from a waste stream has always been a waste managers dream....since by doing so one can render the major bulk of the waste alpha free and hence.....easily manageable. The tiny amount of the separated alpha could be transmuted into short lived radionuclides or contained better and kept safely" says Shri S. Basu, Chairman AEC.

The President of India, Inaugurates ASDF on 15th November 2013

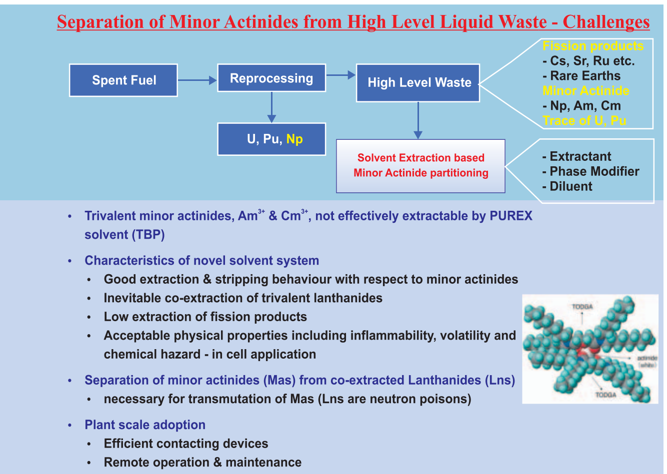
"But this dream turned real on 28th October 2013 when ASDF demonstrated alpha separation from HLW to an extent of >99.9% at a rated throughput of 35 L/Hr". "Repeated performance of this demonstration has now fuelled our imagination and we are looking at various options to manage our wastes in a better and safer manner" he added.

The results of this facility are being directly used for design of such facilities coming up in the near time frame. In the Indian context, partitioning technology is being perceived as a pretreatment step that could result in considerable reduction in waste volumes for final disposal. Besides, this strategy favors separation of useful fission products like Cs-137 and Sr-90 leading to societal benefits on one hand and further simplifying repository designs on the other. "As a direct spin-off we have already inducted the partitioning technology into our Trombay plant for addressing legacy high level waste with very beneficial outcomes in terms of waste volume reduction" said Dr. C.P. Kaushik, Chief Superintendent, Waste Immobilisation Plant, Trombay.

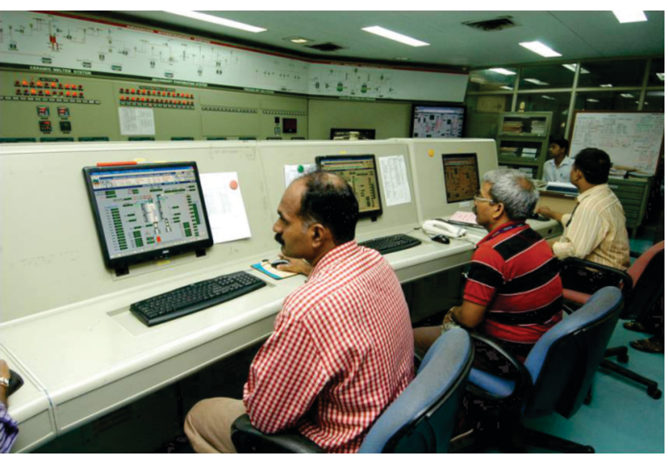
"The technological breakthrough in solvent development catalyzed the partitioning programme in India. The special challenge that the team had to face was to develop solvent systems to address extraction of trivalent Am-241, since TBP is not capable of it" says Shri.P.K.Wattal, former Director, Nuclear Recycle Group. "It was a huge elimination process, since we wanted the solvent systems to be deployed on plant scale.....but our perseverance paid off...the fittest solvent systems were identified and synthesized indegenously. We are proud to say that this technology is completely indigenous" he continued

"Then came the phase of rigorous testing these solvents on engineering scale using simulated solutions. This phase lasted

The radiological cell housing ASDF



The mixer-settlers with passive mixing devices located inside the radiological cell



a few years since we did not want any surprises when these solvents would see actual high level waste. Besides, keeping in mind the remote operation of such facility, a considerable amount of remote instrumentation & controls were built into the plant, to ensure that they serve as the "eyes & ears" of the plant. These were all studied and perfected in inactive engineering facilities before being implemented on the actual plant." He added.

"Selection of suitable contactors for such a unique facility was also addressed by this team. This was done keeping in mind the relatively large no of equilibrium stages required to bring down the concentrations to near zero values and at the same time recognizing that the cell height is limited. The in- house developed mixer-settlers with passive mixing devices were rigourously tested before a selection was made. The selected combined air lift based mixer-settler was then evaluated from every possible angle and was modified to suit high level waste conditions. The existing designs were modified to result in >90% stage efficiency with optimum air rates. All the hard work did pay off ultimately…and the design of the facility has been validated during the hot commissioning runs." He concluded.

The ASDF facility comprises of three distinct solvent extraction cycles, facilitating the use of three different solvents to typically address separation of residual U & Pu from concentrated HLW, separation of bulk minor actinides along with rare earths & separation of trivalent actinides from lanthanides. The challenging aspect of separation of trivalent lanthanides from chemically similar trivalent actinides were addressed in ASDF by deploying a modified TALSPEAK process taking into account critical considerations with respect to pH adjustment on plant scale. In line with matching vitrification throughputs, the cycles have been designed for an average throughput of 30 l/hr of high level waste and have been provided with flexibility to try out various options for optimizing the overall partitioning process.

"Although, the plant has been designed in line with any of our radiochemical facilities, what is special is that the ASDF has tried to tie up the entire waste stream emanating from this facility. Hence it has a spent solvent management facility integrated to it to take care of the spent solvents. Commissioning of such a unique facility was addressed by the selection of appropriate markers which were expected to reveal the extent of separation that ASDF would yield. The final separation with actual HLW was perfectly in line with these marker results" says Smitha Manohar, who is the process engineer in charge of developing and deploying the partitioning process. "The very enthusiastic young team that has made this project happen, will ensure that this technology will be nurtured in the days to come" said Dr. Anil Kakodkar, Member, AEC and former Chairman DAE.

Being the first of its kind, the ASDF project was required to be thoroughly reviewed with regard to safety & regulatory aspects, before clearances could be giving to take up trials with active wastes. A specially formulated committee looked at all the safety aspects of this facility and after rigorous review lasting a few years, the apex safety body of BARC, the BARC Safety Council accorded its approval for undertaking the active commissioning of ASDF in a stagewise manner. Accordingly, the facility undertook stage wise active commissioning trials with increasing

The remotely operated sampling system of ASDF

levels of activity and was hot commissioned using actual HLLW. Stable operating conditions could be maintained for runs lasting about 48 hrs – 115 hrs at an average throughput of 35 l/hr of high level liquid waste. Separation efficiencies for the first and second cycle was observed to be 99.5% & 99.85% respectively with regard to uranium for first cycle and and alpha activity for the second cycle. In line with inactive commissioning results, Neodymium was observed as the main impurity associated with the alpha product emanating from the third cycle during active operations with a separation efficiency of 97% with regard to alpha activity. " The hot commissioning experiences of ASDF have been great….we have been able to carry out all the operations in strict adherence to stipulated safety limits and we are all very excited with the outcome" says Umesh Dani, who has been responsible for the commissioning operations, "Fine tuning of operating parameters are presently in progress for obtaining better separation efficiencies…we are aiming at better separation efficiencies in the third step….only then can we produce vitrified waste <100 nCi/gm" he adds.

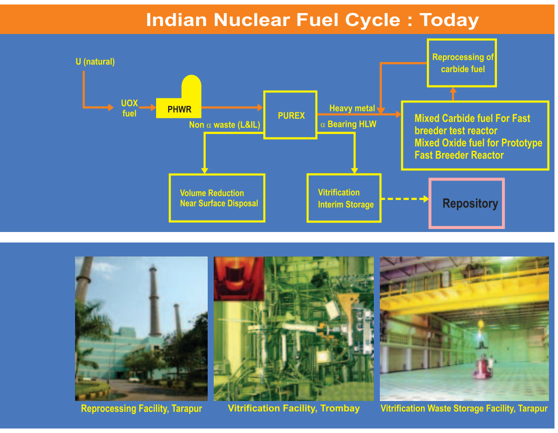
Markers and Flow rates of the three cycles of ASDF

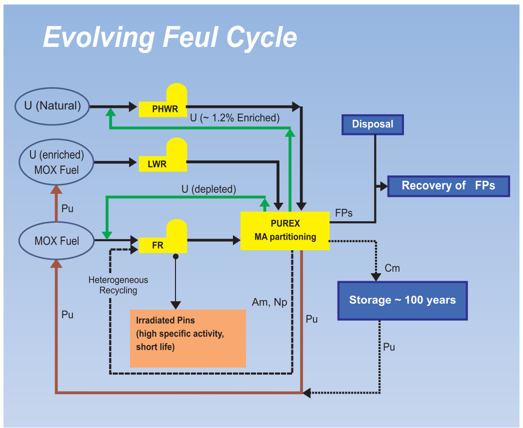
Cycle	Markers	Flow rates (L/hr) A/O/S (A: Aqueous; O: Organic: S: Strip)
Cycle 1	Nitric acid, Uranium	40/14/16
Cycle 2	Rare earths (La,Ce,Nd,Sm)	40/20/20
Cycle 3	Ndas a marker for Am-241 in TALSPEAK environment La, Ce etc are markers for lanthanides	42/28/17

Inactive & Active commissioning of ASDF
Mass Transfer Performance based on concentrations of markers

	HLW (Feed)		U Lean HLW (Ist cycle)		MA Lean HLW (IIndCycle)		MA + RE Product (IInd cycle)		Actinide product (IIIrd Cycle)		RE Rafinate (IIIrdCycle)	
	I	A	I	A	I	A	I	A	I	A	I	A
U mg/L	3260	4900	14.7	15.8	ND	ND	25.3	14	ND	ND	19.1	10
Ce mg/L	332	218	320	226	0.22	0.35	700	368	8.95	0.8	1250	585
La mg/L	157	114	153	123	ND	0.31	332	191	ND	0.64	597	310
Nd mg/L	194	308	190	356	ND	ND	390	473	69.3	62	552	612
Sm mg/L	35.4	86.5	31.1	76	ND	ND	64.1	109	18.9	22	73.6	125

HLW : High Level Waste; MA: minor actinide ; RE: rare earth; I-Inactive Simulated Trial & A-Active HLW Trial





"This milestone is helping us evolve our nuclear fuel cycle….considering that our prototype fast breeder reactor is coming up for commissioning in a near time frame….and that our thorium utilization programme is picking up pace…we do forsee exciting possibilities in the Indian Fuel Cycle and that means we have a lot of work to do" concludes Shri K.N. Vyas, Director, BARC

Interview with Dr.R.Chidambaram PSA to Govt. of India

Several questions were proposed by the members of the BARC Newsletter Editorial committee. An edited version of the conversation of Dr S M Sharma (SMS), Chairman of the editorial committee with Dr. R. Chidambaram (RC), Principal Scientific Advisor to the Government of India.

SMS: You are an internationally acclaimed condensed matter physicist. In your view, what is the role of condensed matter physics in the programmes of BARC and DAE.

RC: Condensed matter physics or materials physics is at the foundation of practically every technology. This is apart from the fascination which condensed matter physics has, purely from a scientific point of view. You take computers or communication devices or nuclear structural materials, nuclear fuel materials and several kinds of alloys used in strategic programmes. We had zircalloy to start with as structural material in PHWRs, then we changed to zirc-niobium because of the hydriding problem. Or biological materials – in recent times, many of the people working in soft condensed matter physics have gone over into biological physics. On the strategic side, we must know the equation of state of materials and the way shock waves propagate through them. Today one can use first principles methods for calculating the energy of materials. In fact, we can now determine the equation of state very precisely from theory for most materials. Phase transitions are also very interesting and important. For example, the complex phases and phase transitions in Plutonium and its alloys. There is tremendous capability in the Solid State Physics and the High Pressure Physics Divisions of BARC and also the Materials Science Group. So I would say that condensed matter physics has got a very widespread reach in the programmes of BARC and DAE. I don't distinguish between those who are working in condensed matter physics or materials science.

SMS: BARC & DAE are perceived to be mission-oriented research and development organisations. What is the relevance of basic research in these organisations. Historically what has been the contribution of basic research to the various mission oriented programmes?

RC: Generally speaking, if you want to be a knowledge economy, you must build an advanced technology superstructure. That requires high-quality applied research, technology development, and R&D-led innovation, backed by high-quality manufacturing skills. This applies generally and certainly applies to nuclear technology. However, to sustain that advanced technology superstructure, the foundation is provided by basic research. If you don't have people who understand the fundamentals of the subject, whatever the subject, including nuclear technology, one day the superstructure will collapse. That is why any advanced technology organisation has to have a back-up of top class basic research scientists, as is there in the Department of Atomic energy. It so happens that in the case of India, DAE is the only one capable of building large research facilities like superconducting cyclotrons or research reactors or synchrotron radiation sources, which are used by basic researchers from all over the country. You must have a component of that user community here also for effective usage of such large scale facilities. Historically several BARC scientists have been involved in the building and utilization of research reactors and synchrotron beam-lines, etc.

SMS: DAE under its ambit has several aided institutions which are engaged in basic research. While parts of these institutions take part in the large DAE programmes such as INO (India-based Neutrino Observatory), by and large their programmes are curiosity driven. Some people feel that excellence in basic research has the potential to enhance the "soft power quotient" of the country. Do you suggest that they engage themselves in the mainstream programs of DAE?

RC: Of course this should be done to the extent possible. But I think the central thing is excellence. When you look at what Dr. Homi Bhabha did when he was building up the Tata Institute of Fundamental Research, he had recruited people like Govind Swarup and Obaid Siddiqui. Once he had them, he built centres of excellence in radio-astronomy and molecular biology around them. As long as a group of scientists are doing internationally competitive research, it doesn't matter where they are located or where the support comes from. It so happens that the support comes from DAE. You cannot expect a complete overlap of the activities of basic research scientists with the applied programmes of the department. When I was Director, BARC, I had the motto 'Relevance or Excellence, preferably both'.

If you take TIFR's participation in the Large Hadron Collider programme, in the CMS detector, or the ALICE detector by VECC, they are looking for some fundamental answers to questions like existence of the Higg's Boson. The CMS detector was the first to detect the signature of the Higg's Boson and TIFR had contributed to its development. Similar things are going on in the nuclear establishments around the world. Also, the aided institutions coming under the DAE umbrella gives them a great advantage. You mentioned about INO and we are going to build the third Advanced LIGO detector, for locating precisely the source of gravitational waves (whose discovery a couple of months back was sensational). The science will be the major interest, of course, with the involvement also of other non-DAE institutions like IUCAA or Raman Research Institute. But the building of that LIGO detector will have to be done by DAE institutions like RRCAT and IPR. Incidentally, IPR is also a DAE-aided institution which is of very direct relevance to the fusion energy programme. They are building the superconducting TOKAMAK and partnering in the ITER (International Thermo-nuclear Experimental Reactor) project. That's an international collaborative technology project. Sooner or later, fusion energy will become practical when energy resources begin to run out. So we have to look at aided institutions in a broad perspective.

SMS: There is a perennial issue of which is more important, basic or the applied sciences. Can the latter excel without the former? Where should India focus?

RC: India is too large a country to ignore either. We should focus clearly on both. As I mentioned, for a knowledge-driven economy, we need excellence in basic research and we need excellence in applied research, and then right upto manufacturing. You can also have what I have called 'directed basic research'. This is an additionality to, and not a substitute for, self-directed basic research, which is very important. Directed basic research focuses on basic research directed to the interests of industry or of the society in the long term. The needed knowledge would be available when the demand comes. You take our own DAE. The three main fissile isotopes are Uranium 235, Plutonium 239 and Uranium 233. But you need to have knowledge of the properties and the phase diagrams of all the actinides. Without that knowledge you may not be able to even interpret completely what is going on inside a reactor. Very clearly, only people who have a broader perspective and the desire for knowledge will be able to help. Just applied research may not be able to interpret all the situations which may occur. Take 'nuclear data' as another example. You can say, "look, I have built the reactor. What more knowledge about nuclear data do I need?" But if there is an unusual occurrence, even when it is not anything serious, you want to explain that. Then you need people who have knowledge about nuclear data with a much broader perspective.

SMS: In R&D, developed countries are perceived to be significantly ahead of developing countries like India, say by 30-40 years. How can India leapfrog to be competitive?

I don't think that statement, that we are 30-40 years behind the developed countries, is really true. I don't go with that kind of statements. You and I know that when we go to international conferences in our field of interest, we are on par with the scientists from the developed countries. There may be some areas where we may be behind, particularly in several technology-related areas. Manufacturing of micro-processor chips and memory chips, for example. But if you take nuclear reactors, we are leaders in Fast Breeder Reactors, we are leaders in Pressured Heavy Water Reactors. And even in technology related to basic research, we supplied 1800 super conducting corrector magnets to the Large Hadron Collider in CERN Geneva, and that is high tech equipment and they have put it there because this was the best equipment which they selected after international competitive bidding. Or you take our Space Department. The Polar Satellite Launch Vehicle is made in India, by our own Indian industry and it is a very very robust vehicle and they also launch commercial satellites from other countries. To date they have launched

57 commercial satellites from 19 countries using the PSLV. The Department of Space, like DAE, is a global leader. Similar examples can be found in many areas of defence research, like the missile programme.

You see, if you take a developed country like United States there is a thermodynamic equilibrium between the knowledge in the academic system and the knowledge which has been transferred to industry or generated within the industry. The two are very close to each other; of course, the knowledge in the academic system is always ahead. That's why industry is constantly waiting for new knowledge to come out of academic system.

Basic researchers in India want to be in thermodynamic equilibrium with the basic researchers in the developed countries. Then only can they publish in leading high-citation journals of the world and raise their so-called h-index. This is a natural desire, particularly for young scientists.

Knowledge in the Indian industry system, examined sector-wise, covers a broad spectrum. Nuclear and space are more or less on par with global leaders. So are several areas of defence research and of knowledge chemicals. Other sectors like the electronics hardware sector need to move up.

If industrially you are too far down compared to the global standards in any sector, then there is an automatic disconnect between the academic system and the industry system in that sector. The industry is happy to take technology through technology transfer. But then nobody is going to give them tomorrow's technology.

But as India goes up, and India is going up – there is no question about it, as its products become more and more globally competitive, industry-academia interactions will increase, research funding from industry will also increase. Now 80% or something like that of the money for R&D comes from the government, whereas, in the developed countries, there is substantial research funding from industry into the academic system. One major thing we are looking at from my office is as to how to enhance academia-industry interactions.

There is also the Make-in-India initiative of the Government which, in my opinion has three components:

1. Make in India using indigenous technology for the Indian market,
2. Make in India leveraging international cooperation for the Indian market, and
3. Both the above for the global market.

That is why we are also discussing in my Office how to nucleate and nurture 'high-tech manufacturing start-ups'. The knowledge is there or can be created in the academic system. In the US, as you mentioned, there is a greater tendency for people working in the academic system to go over and start high- tech industries. The more academically qualified they are, the more research oriented they are, the more advanced is the manufacturing start-up that they can nucleate. In fact, we are going to discuss that in our office, what are the things we should do in order to encourage high-tech manufacturing start-ups. Most of the start-ups in India so far are in the services and in the commerce sectors. The government is very much interested in encouraging startups in the manufacturing also – of course, there will be support for the manufacturing sector as a whole but also there will be encouragement for start-ups in this sector.

The thing is that, if industry can make money using yesterday's technology, why would it bother about tomorrow's technology. That is the basic question. But things are changing rapidly in India. People here want the latest technology products. Indigenous products must satisfy that demand. To do that, India must also strengthen the attitude to become the first introducer of new technologies.

Many people are happy with proven technologies. Proven technologies, as I often say, unless of course these technologies are being continuously subjected to evolutionary improvements, (proven technologies) are often a synonym for obsolete technologies. This doesn't apply to the Indian nuclear sector, it doesn't apply to the space sector, or the missile sector and parts of the knowledge chemicals sector. India is as advanced as any developed country in these areas. As more and more Indian industries push up their technologies to globally competitive or even higher levels, that is the time we will have the thermodynamic equilibrium we need in India between the knowledge in the academic system and the knowledge in the industrial system.

SMS: DAE had established HBNI (Homi Bhabha National Institute). It has provided the opportunity for young recruits to pursue advanced courses such as M Tech and PhD. Department of space has set up IIEST and attracting bright youngsters into undergraduate programs (4 or 5 years) in space technologies with a promise of guaranteed job. These are quite contrasting approaches to human resource development. What are the best practices these departments can learn from each other in human *resource development. Can we adopt some methodology to attract even brighter persons in DAE?*

RC: BARC Training Schools have withstood the test of time. In the BARC model, we want everybody to have liberal and general science or engineering education up to a point, Bachelor of Engineering or higher or Master of Science. When you want to super-specialise, say in the field of atomic energy and related fuel cycle areas, it is very economical to select and then train. If you train a large number of people and select a few of them, the danger is that whenever you go for a job they will say "you are over qualified in some other area. Why are you coming to this area?" and the trainees would find difficulty in finding jobs. Ministry of Earth Sciences was looking for atmospheric scientists to work on the climate change issue, but where are enough atmospheric scientists? I suggested to them the BARC Training School model. Now, in the Indian Institute of Tropical Meteorology, Pune, they have an identical programme which follows exactly the same model as BARC Training School.

There is romance in space. Chandrayan, the Mars Orbiter Mission and all that. Young people are very much attracted and so they thought we will do it from after the 10+2 stage. Department of Space has also got a variety of scientific disciplines. Payloads can be very scientific and payloads also come from different scientific organisations. Of course, there is also a variety of engineering disciplines from propellants to control systems and guidance systems.

I think the time has come for increased horizontal entry into BARC in higher grades. People with the kind of qualifications we need, both in science and in engineering, are available now, in India and abroad. They will come with new ideas, around which new programmes can be nucleated.

SMS: In the western world researchers themselves can become entrepreneurs. Do you think Indian science would gain by adopting similar ways to speed up the conversion of research into products? Any suggestions about how should this be built into our systems.

RC: This is related to start-ups by the people who are scientifically qualified. It is happening in some of the IITs and IISc. IISc has got a Society for Innovation and Design (SID). There is a society in IIT, Bombay called Society for Innovation and Entrepreneurship. There is a University - driven research park in IIT, Madras. All these are attempts to help people who are young and who want to initiate start-ups, apart from enhancing academia-industry interactions.

SMS: You know in developed countries, if a person is a professor, develops something in the lab and then decides to market. The organisation permits him/her so that he/she can attend to his/her job and can also do the other part. These probably may be under some appropriate mechanisms.

RC: Some of these things are being thought of here also. A programme in this context has been implemented by the Department of Bio-Technology. For example, in the US, SBIR (Small Business Innovation Research) programme selects, say 100 professors from all over the US and gives them US$ 100,000 each. The professor is given enough time to develop a product in a technology park or an area proximate to the university while he continues to be a professor. He can use the US$ 100,000 for buying equipment, for paying staff, but can't pay himself. After a certain period of time they review the progress and select 10 out of these 100, and give them a million dollar grant each in order to further develop the product. As the Chairman of TIFAC (Technology Information, Forecasting and Assessment Council), I had organised a meeting many years back between TIFAC, SBIR people and others who were familiar with the programme.

This programme can lead to start-ups. I am personally interested, as I said before, in high-tech manufacturing start-ups. Everybody is watching India. MIT had a global start up workshop in Hyderabad from 21-23 March. They go around the world holding it in different countries. I was a member of their Advisory Board. I said I will focus only on high tech manufacturing startups. Independent of that, we had called together people from IITs, IISc, the mission oriented agencies, DBT, Department of commerce, etc. for a brain-storming session in this context under the chairmanship of Dr. Ashok Jhunjhunwala of IIT Madras. In the high tech manufacturing area, we want to utilize the new incentives that the government has provided in the Startup India Action Plan. Are they enough for high-tech startups? Definition of high-tech is difficult. What was high tech yesterday is no longer high tech today. But what I am thinking of is, high-tech which is based on current R&D. If you take building of large high tech systems, reactors or launch vehicles and so on, that of course only large industries can do. But sub-systems, OEMs which go into large systems, those can be done by start-ups. You know small companies tend to be more innovative than established companies because they have no baggage to carry, they don't have established assembly lines.

SMS: As the PSA to Government of India, you have been supporting various programmes about rural development. How can we have more vibrant linkages with the society in general and rural areas in particular? This question is obviously from entire intelligentsia, DAE included.

RC: One of my definitions of a developed India is when the quality of life in rural India becomes comparable to that in the non-urban areas of already developed countries. Other criteria are the per capita electricity consumption and female literacy. We started a programme in our office called Rural Technology Action Group RuTAG. RuTAG is centered in seven IITs. It is based on the premise that active scientists are not the best people for grassroots interventions in rural areas.

Their *karma* is different! If you and I go there, who will do this work which is equally important. In RuTAG, we work with voluntary organisations led by scientists, who for their own personal, emotional, whatever reasons have decided to settle in rural India, or organizations which have a substantial scientific content. They know where the demand for new technology is. Since they are scientists they are easy to communicate with and they tell us and then we find out a solution. Essentially it is routed through IITs. Many of the innovations may look simple but actually these have a lot of impact on the rural life. You see *muri* (puffed rice) is made in rural areas of West Bengal. In a recent initiative, IIT, Kharagpur redesigned their furnace so that no heat is wasted and heating is very uniform. Productivity has gone up and the quality is much better. You may think it is a small thing but suppose their earning doubles as it happened in this case, it makes a lot of difference to their quality of life.

Sometimes you take up such work directly. For instance, we work with a voluntary organisation called HESCO in Dehradun. Its Chairman Dr. Anil Joshi has visited BARC for a lecture. One day some years back we had organised a meeting on water security with MS Swaminathan Foundation in Chennai. Dr. Anil Joshi said there that, in the rainy season, water runs away downhill very fast. So they make what they call *khalls* on top of the hill. These are for water harvesting; water seeps through broken rock and reaches aquifers where the villages are located. He said: "my problem is – when I build the khall, I do not know where the water will go. Will it go to aquifers where the villages are located or will it run away to useless places? In the latter case all the effort is a waste." I got Dr. Gursharan Singh and Shivanna from Isotope Hydrology Group of BARC to look into the problem. They took water samples at various places, looked at their isotopic composition: Oxygen 18/Oxygen 16 ratio, heavy hydrogen content, amount of radioactive tritium. Using this information, they established the water connectivity and said water is trying to flow this way, you put sub-surface dykes at these points, water will flow the way you want. When this was done, the average recharge of the aquifers in the 17 or so villages in this Gaucher area went up by three times. Some acquifers which had dried up started giving water. The villagers in that area call it BARC water!

Some Harvard Business School academics have coined the word '*knowledge brokering*'. They say that most new innovations are old innovations in a new environment. They give the example of the steam engine. Everybody thinks Robert Fulton discovered the steam engine. But actually steam engines were used in mines for 75 years before that. But he took that innovation out and put it in a new environment after looking at the market value.

I went to Pune for a conference on Robotics which Manjeet Singh from BARC had organised. I visited the facilities of the "R&D Engineers, Pune", which is a DRDO lab. They make foldable bridges for movement of troops - both foot bridges as well as big bridges. They make them very light using special material so that the soldier can carry a foot bridge as a back pack. Just then Uttarakhand floods had occurred, roads had been cut. I told Guruprasad, Director, R&D Engineers "why can't you make it for Uttarakhand?" He said "no problem" and made it. I said "don't make it very costly. Make it out of normal steel". The first footbridge they made in HESCO Gaon. There are natural ravines in that area, in addition to the roads which were cut by the floods in those days. There are also small ravines and during rainy season they get flooded. Women carry the load and go up and down. This is a terrible job for them and they can trip because you can't see what is under the water. Now they put up a small 10-15 meter bridge. That has been a big boon to the people there. Dr. Anil Joshi told me that some organization has funded 4 more bridges which have all been commissioned in the flood-affected areas of Uttarkashi. This is an example of *knowledge brokering* of a successful DRDO technology.

Under another project in the RuTAG programme, IIT Bombay and NITIE are redesigning the *palki* to make it lighter and to take care of the occupational health problem caused by the high stress on the bearers who carry the *palki*. This activity is going on very well.

SMS: When you talk of high tech manufacturing, I know two examples of helium plants which have been built in BARC and RRCAT both with different technologies. They are very successful plants but probably if somebody has to set up a manufacturing plant he has to be the researcher himself. There is a barrier in our system for the reseacher to jump into a start up.

RC: He has to take a career break. In case, the start-up fails, he should have an opening to come back to the old job. In any startup, you always have to take a bit of risk. You must have a mental make up for that. Everybody cannot become an entrepreneur. Some people find an intellectual challenge in converting an idea into a product. This is what the whole idea of Start-up India is all about. When Start-up India and Make-in-India are put together, you have manufacturing start-ups.

Should the possibility of a start-up be considered with extra-mural research support from the mission oriented agencies for high tech systems like reactors, launch vehicles, missiles, etc.? In case a scientist is interested, can you hold his hand for a while? So the questions are "what are the difficulties faced by high tech startups? What more needs to be done?" These are issues we are beginning to address.

SMS: The growth of science and technology in any country is inter-linked with industrial growth. Do we have a synergistic growth of science & technology and industry in India? What should we do to improve upon that?

RC: It has to be done sector by sector. You have this chain - Research, Development, Delivery. More than 10 years back, Kenan Sahin, wrote in his article entitled "Innovation Backlog" published in MIT Technology Review, that academic institutions are good in Research, poor in development, and by and large zero in delivery. Industry is good in delivery, poor in development and by and large zero in research. He was talking about the US. So in their system, and more so in ours, both academic institutions and industries are weak in development. So we have to create the necessary academia-industry interfaces in order to enhance academia - industry interactions. Mission oriented agencies like DAE have done it in a different way. You design a sub-system here in BARC for a nuclear reactor. A company is employed to do the development work on cost plus basis. That is one way of getting the industry on board in high-tech areas.

Then there is the GoCo (government-owned and company-operated) manufacturing model which has been used for strategic systems. This way the company has no control over it, and the government department does not have to worry about manpower and technical resources. Broadly speaking, the selection of strategy in this context has to be done sector by sector.

Some ten years back, our Office started a Core advisory group for Automotive Research (CAR). Any sector, which is beginning to boom (that is why we chose the automotive sector), would like to interact with academia. Any sector not doing well does not have enough cash to support any R&D. CAR programme was very successful. It had members from scientific organisations as well as from industry. This is for what I call pre-competitive applied research which has to be distinguished from proprietary applied research. Proprietary applied research is not the business of the government. It is to be done by the concerned company. But from pre-competitive applied research, it can telescope into proprietary applied research. After the automotive sector, our Office did similar programmes for the machine tool sector and for the electronics hardware sector. It has to be done sector by sector but there is an absolute need to enhance academia-industry interactions and this is beginning to happen now.

The industry is also setting up in-house R&D centres. I inaugurated the Aditya Birla R&D Centre some years back in Taloja, which would focus on the research problems of the Birla Group of companies.

SMS: Though research expenditure in India is below 1% of GDP, it is a large sum of money, close to 1 lakh crore. There is a general perception that the outcomes are not commensurate with this investment, in spite of some bright spots. What is your perspective on this.

RC: We are trying continuously to increase R&D expenditure from 1% to 2% of GDP. Prime Ministers have been trying to do that but when you say 2%, half should come from industry and industry will invest when the results coming out of the research suits their own manufacturing or their industrial programme. In fact, for the amount of money we spend, the output is quite high, particularly if you look at the research output from mission oriented agencies.

The young people who come from a middle class or poor background, their focus is to improve the quality of life of their families. That is why you find sometimes young people who win, say, a gold medal in the International Physics Olympiad, joining IIT to become an electrical engineer. They feel their career is assured. If they are really interested in an electrical engineering career, their physics research talent would be valuable. They should not, however, be doing it because of parental pressure or peer behaviour.

But in spite of that, there are excellent people with very high talent who take up research careers. They should be provided rewarding careers. In our office we have a programme for identifying and nurturing gifted children. Giftedness in science and technology can be identified, though with difficulty, from a very young age. Among them are those who are 'profoundly gifted', to which I have added 'profoundly & selectively gifted'. Today a new Srinivasa Ramanujan cannot pass any entrance exam! Our Office has supported projects in the University of Delhi and NIAS, Bangalore and they have devised criteria to identify giftedness. One in 10,000 is perhaps profoundly gifted among the children, it is necessary to identify and nurture them and put them all into career in research and development. I am not talking about sports and music. There the giftedness is immediately obvious. Giftedness in science and mathematics is much more difficult to identify. How to nurture gifted children coming from disadvantaged sections of the society and rural areas is also an issue. There are, I am sure, as many gifted children there as in urban areas per capita.

SMS: Despite a large number of research institutions of excellence, high impact journal publications and international awards are rather low. We have very few international patents. Rarely an Indian product is successful in the international market. Can you suggest as to how we can enhance the visibility of our research internationally?

RC: We have to wait a little bit for international awards to come. Long back, I had defined a term called velocity of R&D. This is a relative velocity, compared to the velocity in the already-developed countries. When this velocity catches up with those in the developed countries, awards will automatically come. It is like India having enough ability to participate in every Olympic event. And then if you get an occasional Olympic gold medal, you feel very happy. What kinds of R&D are important for India - basic research whose metrics are research publications, citations, h - index. What is the metric for industry oriented R & D - patents, innovations. They can be easily quantified. When you send up the Chandrayan or you commission a reactor or do the Pokhran tests, everybody knows it is a big achievement. What is the metric for that - neither papers nor patents? But it is important for India. Lastly what is the metric for success in the application of science and technology for rural development? Certainly not papers. But it is very important for India.

Once we become a developed country in the fullest sense of the term, everything will be in equilibrium and all these awards will come to India. There is no question. When much of what mission-oriented agencies, national labs or universities do for instrumentation development for their research is beginning to be done by the industry, scientists are released for doing more focussed research work. I think we will have to wait a little for that.

SMS: IT and financial sector are attracting much of young talent. Generally a career in science necessitates more intense involvement, though financially it is less lucrative. Yet it is not easy to find good research positions. How do you think this issue should be handled.

RC: There is a kind of dichotomy here - a number of people looking for good research positions and the large number of vacant faculty positions. Sometimes the faculty position is at a place where good research is not yet being done. One of the suggestions I have is that talented young people with Ph.D. or equivalent could have a dual kind of position. Let them go and teach in an institution which may not be a well known research institution, but allow them access to a proximate institution of their choice to pursue research, wherever the institution is - in a university system, or in a national lab. That will be good for both. That is one solution.

There is also a problem of dissemination of information to our young people abroad. On one of my recent visits to Japan, some young researchers were saying that they do not know where to apply for positions. My visit was for a meeting organized by the JSPS Indian Alumni Association. So I said why not get your alumni in India to collect all the information which is being put out on faculty or scientist positions by the MHRD, DST, DBT, universities and other organizations and put that in your website. I understand they are doing that now. And for the brightest, the budget allocation should also be done so that you don't wait for a university to have the funds. *INSPIRE* programme of the DST is helping in that. So things are happening in India. That is what I always say, nobody knows India fully. All of us talk with our limited knowledge. Many people are trying to do innovative things.

SMS: Related question to this is also about horizontal movement. Suppose a person has done extremely well in a particular field and now feels may be he could be better if he gets located in university environment. Or a person from University side says that I think I am more ideally suited for a government organisation or Mission oriented organisation. Such transfers are not easy.

RC: This is one of the issues we discussed in the last meeting of the Scientific Advisory Committee to the Cabinet (SAC-C). We are going to prepare a report on that. The fact that the service conditions are different makes mobility more difficult. In India people don't want to be mobile like in the US, for a number of reasons, for example the state languages are different. Suppose a child is in school and it is learning Marathi here, take the child to Bangalore, he or she needs to learn Kannada there. So there are special situations here, which are not there in the U.S. – our situation is more like Europe. But these are problems that can be solved. One method which is helping is electronic connectivity.

You can also accelerate research collaboration through electronic connectivity. The Indian National Knowledge Network (NKN), a project being implemented by the National Informatics Centre (NIC), is a very high speed optical fibre network and we can overlay it with Grids which allow people to collaborate in specific areas without moving out of their own laboratories. Say, for brain research, all those who are working in Alzheimer's or dementia, to the extent they want to share their MRI images, can do so through the 'NKN Brain Grid'. These are part of what we call NKN 'model projects', which we started for academics to know the power of NKN. The National Brain Research Centre and AIIMS are collaborating on epilepsy. This is what I call a 'suo-motu model project'. If there are experts in both places, the MEG information, for example, is shared and they take a joint decision on what should be done. Similarly there is an NKN Grid for Climate Science. Once you have a high speed network, data-bases can be in one place, computers can be in another place and NKN makes it appear as if they are next door.

We have recently taken up a model project in 'Big Data Science'. Big data is used in astrophysics and biology. Each one of them has best practices for data mining and accessing. Why can't they share their best practices? So a great deal of need for physical mobility can be replaced by electronic connectivity. With respect to the other question you asked, if somebody in a national lab thinks he is a good teacher, why should he not go and teach in a university. For that to happen, service conditions must be made a little more homogenous or harmonious among institutions.

SMS: Science has great potential to contribute to the growth in India. Indian Scientists excel abroad. Back home, they do not seem to perform as well. Can you share your insights?

RC: Frankly, I don't accept any such simple statement. The advantage in a developed society is that everybody can be fitted into a particular position and can begin to contribute immediately. Here you have to do your own instrument development, though things are getting much better now. The research and innovation ecosystem has to develop further. That is where the challenge is. As a USA person (blue-collar, not an academic) told his Indian counterpart many years back, "Our forefathers built this country and brought it to this level. You find it easy to fit in here. If you are so smart, do it in your own country."

Our challenge should be to bring India to a status of a developed country and a knowledge economy. Of course, there are going to be difficulties. Everything doesn't come on a platter. You must also remember that there is a large percentage of population that don't even have the basic facilities we take for granted. Think of them rather than think of what is missing over here. People can do well here after they come back. But if they stay too long abroad, they have more difficulty in fitting back here. If they come in a couple of years after their Ph.D., it is not a problem. So many young IIT Professors, not so much in mission-oriented institutions, are those who have returned from abroad. In India you do get other things which you can't get abroad. You are culturally more at ease here. If Bhabha could build the DAE from scratch after coming back to India, nobody should tell me it's difficult to do things here.

SMS: I wanted to add that of late it has been seen that those who have gone for post-doc in some of the disciplines, their number of publications, when they are abroad, is less than when they are here. This is because BARC is a big organisation with a lot of facilities in different areas. And if one wants to make use of all that, obviously his productivity will be much more than what he can achieve in a small university abroad.

RC: You are right; if you give them the right environment, they flourish. We do need an excellent research and innovation ecosystem in the country, which requires talented young students, which requires high quality faculty or top senior scientists, it requires funds, then it requires an excellent infrastructure including an e-infrastructure and of course world class research facilities. If you have all that, then you find people come. Actually starting from an initiative from our office, two Centres of Excellence in nano-electronics in IISc, Bangalore and IIT, Bombay were established. These are world class facilities funded by DIETY. Very good scientists from top class laboratories, Stanford, Cornell and IMEC Belgium have come and joined them. We must set up more such world class facilities. This is one of the criteria for an excellent ecosystem. The young people who have joined these Centres have contacts abroad when they come back and this connectivity is also valuable.

THANK YOU.

Sequestration Enhanced Coloration of Laden Polyamidehydroxamate for Effluent Characterization

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Specific complexation between an extractant and different metal ions provides the potential in extraction and selective removal of the contaminant/toxic metal ions from the effluents of chemical industry, nuclear industry, mining industry, hydrometallurgical processes etc. Though may not be visually detectable, industrial effluents mostly contain metal ions e.g. Al, Co, Fe, Mn, Mo, V, Hg, Pb, Cd, As, U, Pu etc. in excess of the disposable limits stipulated by environmental regulations. Detection of these metal ions is possible by sophisticated instruments such as ICP-AES, EDXRF etc. For fast and spot detection of these metal contaminants, a resin matrix viz., Polyamidehydroxamate (PAH) has been designed and developed in-house **DD, BARC** which develops color especially with transition metals; helps in visual observation, approximate indication (qualification) and detection of these elements (quantification). Effluents with unknown compositions can be treated with this resin to identify prima facie these metal ions.

Key words: - Effluent characterization, complexation, coloration, PAH sorbent, EDXRF

Introduction

Effluents from industries like chemical pharmaceutical, textile, tannery, paint, nuclear, semiconductor production etc. if disposed-off untreated may get mixed with natural streams of water, thus contaminating the water which could pose serious health issues.

Some metal ions in relatively low concentrations, usually less than a few mg/l (trace elements), may be present in conventional irrigation waters and are not generally included in routine analysis of regular irrigation water. But attentions need be paid when using sewage effluents, particularly if contamination with industrial wastewater discharges is suspected. These may include Aluminium(Al), Cobalt(Co), Iron(Fe), Manganese(Mn), Molybdenum(Mo), Selenium(Se), Tin(Sn), Titanium(Ti), and Vanadium(V). Heavy metals like Arsenic(As), Cadmium(Cd), Chromium(Cr), Copper(Cu), Lead(Pb), Mercury(Hg) and Zinc(Zn) are a special group of trace elements which have been shown to create definite health hazards especially when taken up by plants. Metals especially transition metals, if present in the effluents make the effluent heavily colored, may contain high concentrations of salts and demand a treatment. A variety of water treatment techniques are available, e.g., electro-oxidation, biological treatment, photochemical processing, ion-exchange, membrane separation etc.

For an effluent with unknown characteristics, it is essential to identify and qualify the presence of metal ions and also to have a prima-facie idea about the concentration of metal ions. Conventional methods such as color change, flame burning, precipitation, gravimetry, colorimetry, conductometric titration etc. and sophisticated instrumental technique like AAS, UV-VISible spectra, fluorescence spectra, ICP-AES, EDXRF, EXAFS etc enable detection and quantification of those various metal ions. But practically, it is difficult to analyze all the elements of periodic table with one or two instruments and to access all the instruments mentioned above every time poses restriction of instant urgent analysis. Although nature and category of industry make it easier to identify the presence of these metal ions but after mixing with natural receiving streams, it becomes unmanageable to sort the elements.

In Desalination Division, we have developed [1-6] resin-PAH, determined its properties, processes e.g., 1) Visual detection of elements by developed color with PAH, 2) Pre-concentration in the matrix-PAH to detect by instrument such as EDXRF instantly, 3) Value recovery of the metals [7-12] and 4) regeneration and reusability of the matrix-PAH. The approach and the methodology will serve to characterize known as well as unknown effluents almost instantly- similar to spot detection.

Experimentation Methodology and Observations

Polyamidehydroxamic acid (PAH) sorbent preparation

Preparation of sorbent [1] consists of two steps, preparation of polyacrylamide (PAAm) from monomer acrylamide (AAm) and conversion of PAAm to polyacrylhydroxamic acid (PAH). Cross-linked polyacrylamides are prepared by polymerizing an aqueous solution of acrylamide and N,N'methylene-bis-acrylamide in a fixed mole ratio (required degree of cross-linking) with a fixed number of initiator at 60°C. After achieving room temperature, acetone is poured in the gel mass of polyacrylamide for phase inversion. After about 24 h, the gel is crumpled and washed with distilled water. For conversion to PAH, a solution of hydroxyl amine hydrochloride and sodium hydroxide are added to cross-linked polyacrylamide and the reaction is continued at 70°C. The resultant polymeric sorbent is cooled to room temperature, filtered and washed with distilled water thoroughly. The sorbent is dried in an oven for 5 hours. PAH sorbent is peach colored irregular solid beads. Dried sorbent beads are crushed to 16 ASTM mesh size before use. A schematic flow sheet of the methodology of preparation of PAH sorbent is shown in Fig.1.

Coloration characterization of the loaded matrix for spot identification

Characterization [12-14] due to different coloration of the loaded matrix has been depicted in the Chart in Fig. 2. From the figure it is clear that almost all transition metals, for which d-d transition is possible, indicated color due to which it is easy to detect the metal ions present in the effluents.

A. Indication of approximate concentration by color intensity with pure metal solution

Metal ion loaded PAH develops distinct color and coloration intensity varies with metal ion concentration which can be well exploited for the determination and a calibration for spot identification of the specific ion present in effluents. In Fig.3 iron loaded samples of different concentrations have been shown which establishes the gradual change in color and intensity with gradual increase of the iron concentration.

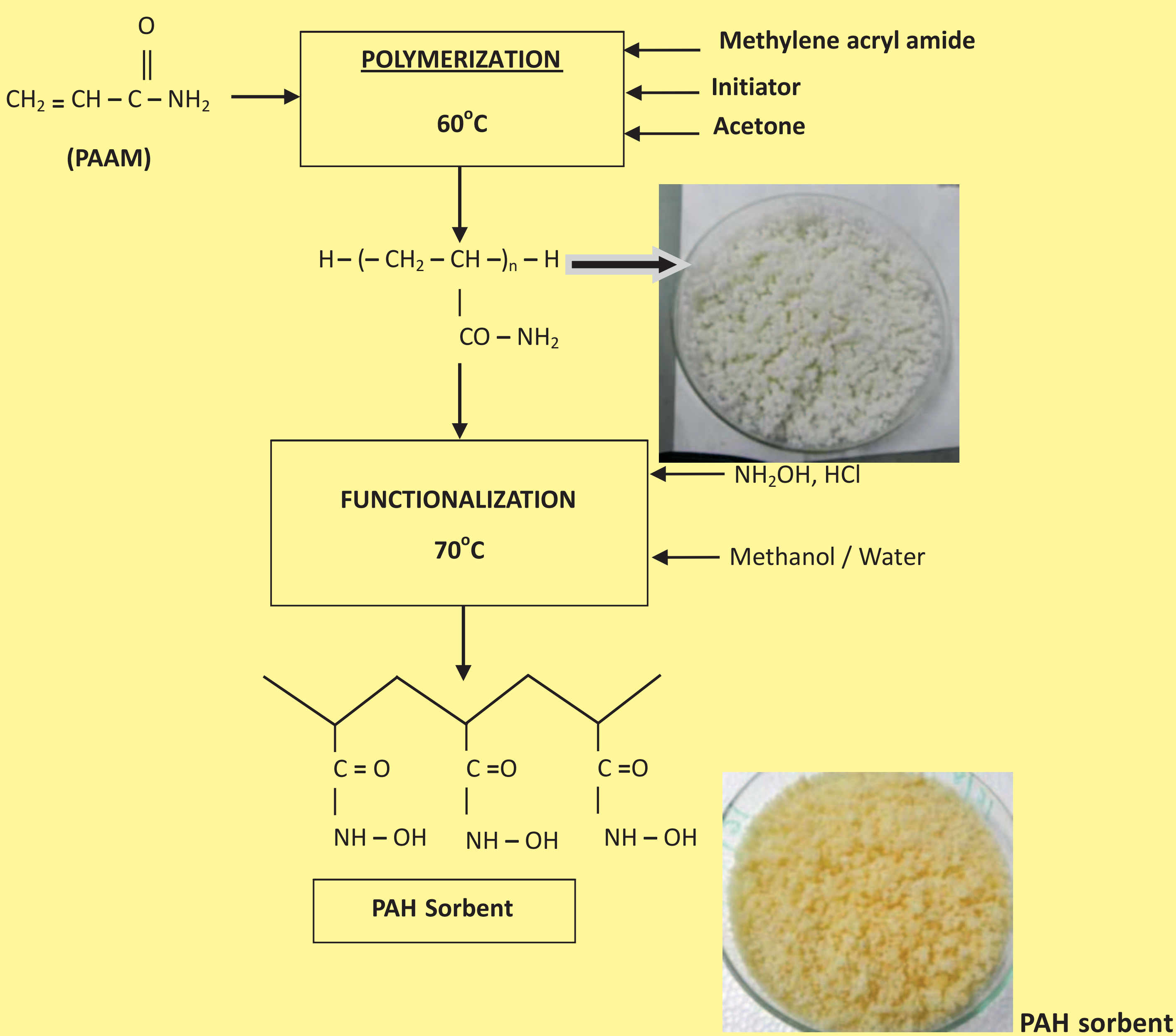
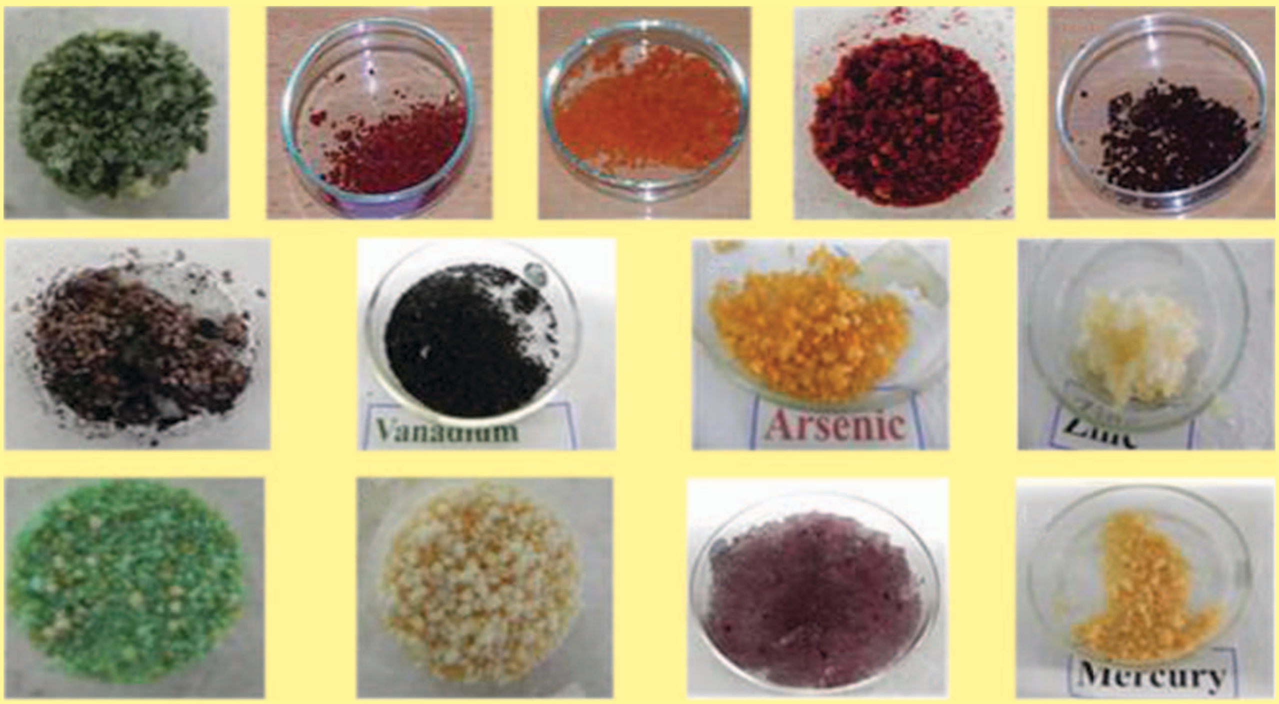


Fig.1: A schematic diagram of the preparation methodology of PAH sorbent

S. Nos.	Metal ions	Colors	Color bank
1.	Fe(III)	Maroon	
2.	Co(II)	Reddish pink	
3.	Ni(II)	Parrot green	
4.	Cu(II)	Deep green	
5.	Zn(II)	colorless	
6.	U(VI)	Orange	
7.	Mn(VII)	Violet	
8.	V(V)	Olive green	
9.	Pb(II)	colorless	
10.	Al(III)	colorless	
11.	Mo(VI)	Yellow	
12.	Hg(II)	colorless	
13.	Cd(II)	colorless	
14.	As(V)	Reddish orange	



Metal sequestered complex of (A) PAH-Cr(VI) (B) PAH-Fe(II) (C) PAH-UO_2^{+2}(VI), (D) PAH-Fe(III) red mud with UO_2^{+2}(VI), (E) PAH-Fe(II) with Fe(II) of ammonium ferrous sulphate, (F) PAH-Fe(II) with UO_2^{+2}(VI) and Cr(VI) (simulated solution) and others (vanadium-G, Arsenic-H, copper-I, Zinc-J, nickel-K, cadmium-:, manganese (M) and mercury (N))

Fig. 2: The characteristic color bank /changes with PAH-loaded metal ions

B. Application of Coloration phenomenon with composite effluent solution

Composite effluent solutions from industrial plants may contain a mixture of elements namely Fe, Cu, Cr [7], Ni, Zn, Mg, Ca, Na etc. Coloration of this effluent on PAH depends on

i. The type of metal ions as well as on

ii. Their concentration.

A visually clear and transparent "nuclear plant washed effluent" with unknown composition when treated with PAH resin exhibited green coloration (Fig. 4). It has two advantages. Firstly, specific coloration narrows down the spectrum of possible elements in the effluent and hence facilitates easy identification. As shown in Fig. 2, Cu, Cr, Ni show green coloration when sorbed on PAH resin. Hence, green coloration, narrowed down detection of number of elemental spectrum in the effluent. Then, only by using EDXRF, instant identification of the elements is possible. Secondly, during sorption, lean concentration of effluent solution concentrates in PAH resin. Hence, Pre-concentration of metal ions in PAH resin reduces the arduous task of quantification through sophisticated instruments and only

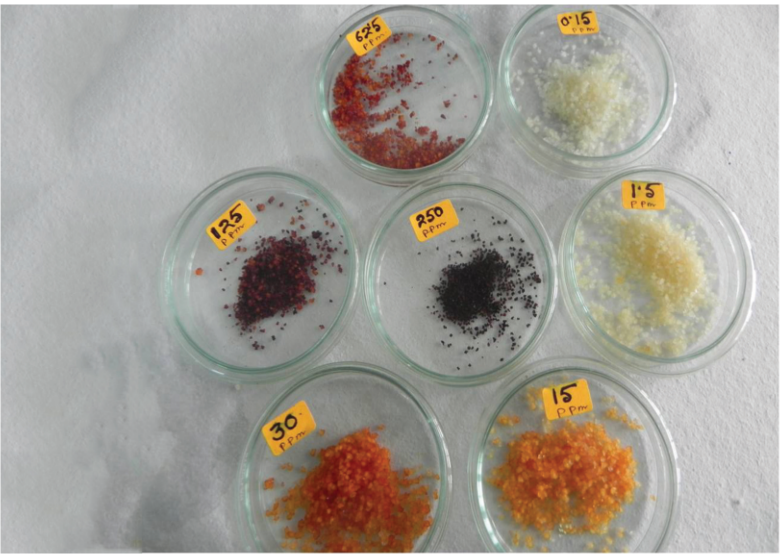


Fig. 3: Intensity Change of different iron salt solution contacted with PAH

EDXRF alone qualifies both i.e., identification as well as quantification.

"The detailed account of the study has been given in the next text under the category of "**Unknown effluent characterization - A case study**" and explaining through Fig. 4 using composite effluent solution.

Pre-concentration of solution before analysis through EDXRF/ICP-AES

Pre-concentration assists in concentrating dilute solutions of metal ions to concentrated one. PAH matrix has a concentration factor of more than 1000, due to which laden PAH sorbent helps in utilization of EDXRF instrument which instantly indicates all the metal ions present in the effluents and quantifies as well. Even the unknown effluents can well be characterized with the help of PAH and EDXRF for quantification which is attributable to the property of pre-concentration.

Unknown effluent characterization - A case study with qualification (spot detection) and quantification (through instrumental analysis)

Treatment of an unknown plant effluent has been shown in Fig. 4. The effluent is a nuclear plant wash and presence of some radioactive elements hinders the effluents to be disposed-off. Diagnosis and analysis of all the elements of interest in the effluent are not possible as a single instrument may not detect all the elements and the ranges of detection limits are also below the EDXRF detection limit.

Treatment with the in-house PHA resin yielded a high degree of pre-concentration of PHA matrix with the loaded elements which assisted the analysis as the pre-concentration helped in the detection range of EDXRF. Thus, an instant analysis of solid laden concentrated (100-1000 times) PAH matrix is able to overcome the hindrance of level of EDXRF and detection of elements present in the effluent are possible as Ca, U, and Cu. After achieving EDXRF identification of the metal ions, the effluent is re-confirmed for Ca, Cu and U using ICP-AES.

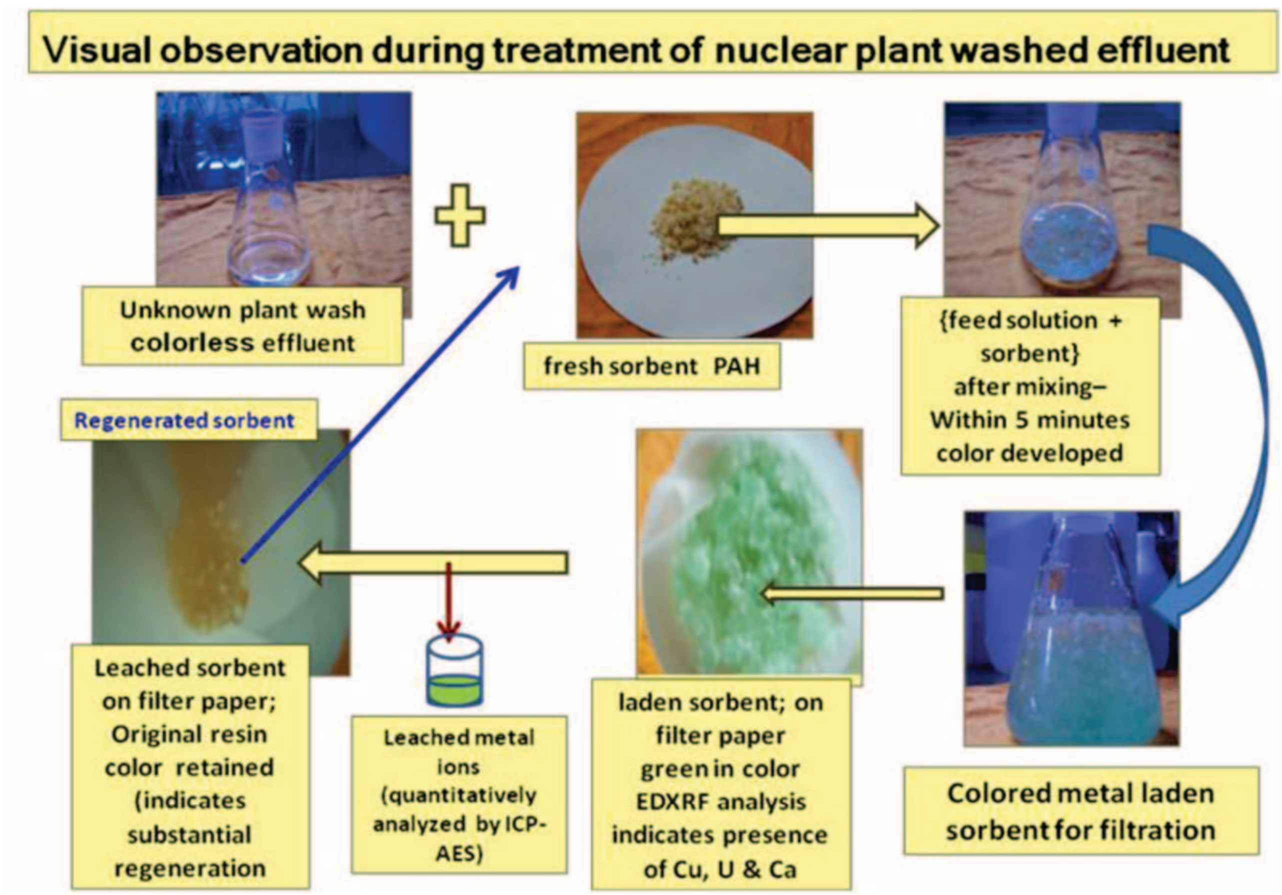


Fig.4: A schematic methodology for the treatment of unknown effluents

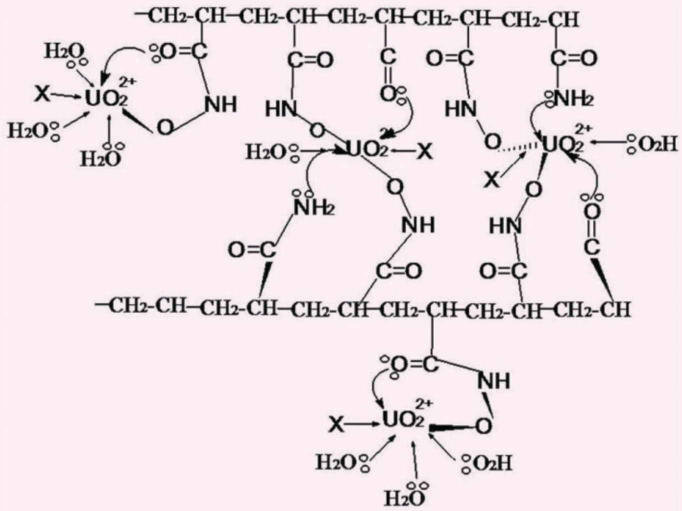


Fig. 5: Sequestration/Chelation of uranyl ions with PAH resin

Metal sequestration-and elution

Uranium sequesters with the functional groups such as hydroxamates, form covalent bonds and amide groups helps in forming coordinate bonds. Fig. 5 indicates the chelation/sequestration scheme of uranyl ions with PAH. Metal loaded sorbent can be treated with mineral acid such as HCl, H_2SO_4, HNO_3 effectively. Depending on the nature of effluent and types of metal ions present more than 80% metals, especially uranium can be recovered. Concentration of eluent can be varied and fractional elution is possible. For example, in "the unknown case study" (section 4), Ca and Cu can be eluted with pH 1.0 HCl solution and for uranium 1N HCl will suffice. Excess acid can be washed with de-ionized water and regenerated PAH can be reused for effluent treatment.

The distribution ratio (K_d) of various metal ions and the effect of pH on K_d

Distribution-coefficient (K_d) is the ratio of concentrations of a compound in a mixture of two immiscible phases at equilibrium. Hence, Distribution-coefficient (K_d) is a measure of the difference in solubility or distribution of the compound between two phases namely solid (PAH resin) and liquid (composite solution). Composite effluent solutions may contain various metal ions specifically alkaline earth metals such as Ca, Mg; transition metals such as Fe, Cu, Cr, Mo, Mn, Ni, Co, Zn, lanthanides and toxic metals such as Hg, As, Pb, Cd which is well sorbed by the PAH resin along with uranium.

Distribution ratio of uranium study has been studied considering two different types of composite nuclear effluents:

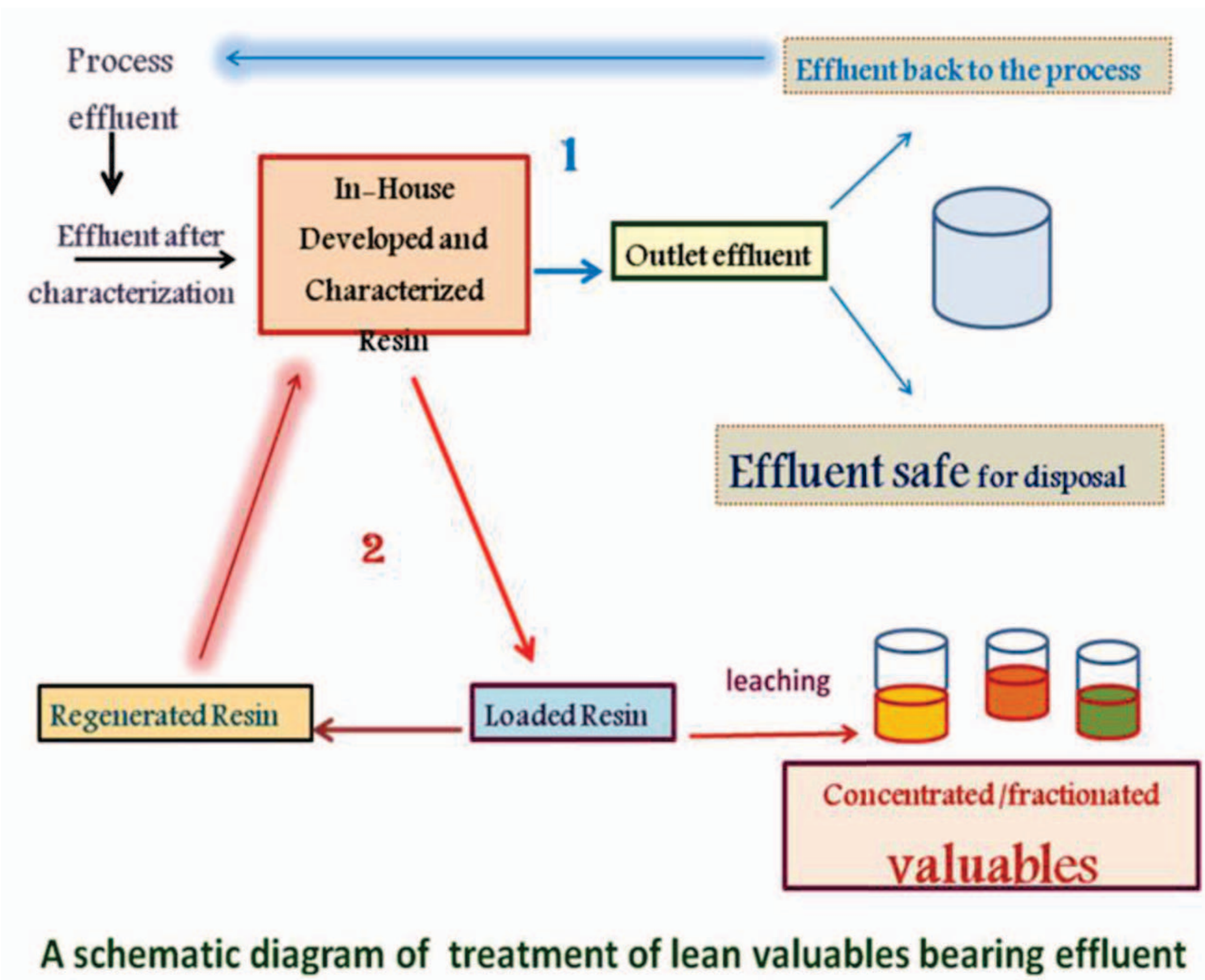


Fig. 6: Closed loop operation methodology for recovery of valuables from waste effluent

1. Disposed MDU Effluent generated [4, 10-12] from UED, BARC and

2. Effluent treatment plant (ETP) generated outlet of UCIL, Jadugudah.

In the first case of effluent from UED BARC, has significant amount of alkaline earth metals such as magnesium (0.5% concentration) with 10 ppm of uranium, indicating K_d of 1250 for uranium over magnesium and in later case of UCIL effluent, manganese (60,000 ppb) with 300 ppb of uranium ion indicates K_d of uranium [6] is 1410 w.r.t. manganese.

PAH sorbent is highly efficient at neutral pH range although its working range is from 6 to 8.5. At pH 4 metal ions starts desorption indicates low distribution of metal ions within the matrix.

Closed loop operation methodology for recovery of valuables from waste effluent

A feasible operation methodology is proposed to identify and characterize unknown effluents. Fig. 6 is a schematic diagram in a stepwise manner which consists of two loops.

I. Treatment of waste effluent using in-house resin/sorption process (column operation)

II. Generation of two components -

i. Outlet effluent- which is safe for disposal, and
ii. Metal ion laden sorbent matrix.

III. Coloration of the loaded matrix as per the characteristics of the elements in the effluent

IV. This pre-concentrated metal ion loaded sorbent is analysed with EDXRF as PAH has concentration factor 100-1000 times compared to mother liquor.

V. Elution of the laden sorbent recovers the metal ions.

VI. Separation of metal ion is also possible through fractionation by elution.

VII. During elution sorbent is regenerated and can be reused.

Conclusion

The resin has been synthesized and developed in Desalination Division and deployed mainly for waste composite effluent solution treatment related to nuclear industries. Metal ions e.g. Co, Fe, Mn, Mo, V, Gd[9], Hg, Pb, Cd, As, U and even Pu[8] etc. exert ~~a~~ specific colors when loaded on PAH matrix. It almost instantly (5 minutes) helps to understand the type and intensity of metal ions. This is reanalyzed and confirmed with EDXRF studies.

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Immiscible and Emulsified Oil/Water Separator Designed by an Easy Gamma Radiation Assisted One-step Synthesis

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In the last few years oil spillage has become one of the most serious environmental and ecological issues [1, 2.] So there is an urgent need of development of material for collection and separation of organic pollutant from water surfaces. There are problems in time consumption, cost, environmental and eco-system friendliness with the presently used techniques. The most effective and convenient way to clean and recollect oil from oil spillage is the use of sorbents.[3.]Highly selective absorption can be realized on a sponge by construction of befitted surface (chemical and physical) modification.[4]

In this study, we report the first instance of fabrication of polymeric light weight economic sponge based superhydrophobic and superoleophilic highly efficient oil/water separator by facile one pot radiation assisted grafting of acrylate, which is environmental friendly, inexpensive and highly scalable process. We demonstrate here the capability of developed material to separate oil-water from layered (immiscible) as well as emulsified (with and without surfactant) oil/water mixtures.

The quantity of grafting is measured gravimetrically. We have prepared four compositions and four different yields (18wt%, 25wt%, 29wt% and 34wt% grafting) are obtained. For 25wt%, 29wt% and 34wt% grafting, contact angles (CA) of water do not differ much (CA around 153^{o}) and for 18wt% grafting the contact angle of water is around 140^{o}. That's why we have chosen here 25wt% grafted sponge for further studies and discussions.

A water CA of 153°±2° and oil CA of less than 1^{o} obtained in this case, are showing both superhydrophobic and superoleophilic properties of grafted sponge (Fig. 1A,B)[5]. Pure sponge shows moderate hydrophobicity and oleophilicity with a water contact angle of 95° ± 2° and oil contact angle 70 ± 3^{o} respectively (Fig. 1E, F) confirming the nonselectivity towards oil/water. On the grafted sponge, the water drops appear almost like complete spheres but the oil drop is absorbed by the surface instantaneously (Fig. 1C, D). Optical images of water drop and oil drop on unmodified sponge support the observations from CA measurements (Fig. 1E-H).

SEM images (Fig. 2C-F) indicate the formation of rough surface consisting of micron, submicron and nano size hemisphere or bumps (ups and downs), which are constructed by grafting of acrylate molecule on the sponge surface. SEM images of pure sponge show smooth surface of sponge (Fig. 2A-B). The decrease of surface energy and physical (rough topography) modification of the surface is responsible for super selectivity.

To test oil uptake capacities of modified sponge, we have taken seven different kinds of oils. The oil uptake capacities of modified sponge from immiscible (layered) oil/water mixtures are tested. Due to it's porous structure, the absorption capacity is found to be from 30 to 60 times of absorbent's weight (g/g) depending on the oil.

In Fig. 3 (i-v), images of oil removal from layered oil/water mixture by modified sponge and it's collection are represented.

To investigate the emulsified oil/water separation efficiency of our modified sponge, a series of surfactant free and surfactant stabilized oil/water emulsions with a droplet size ranges from micron to nano range, are prepared. Modified sponges are immersed into the emulsions. It is noticed that droplets of surfactant free and surfactant stabilized emulsions are demulsified and oils are absorbed by the sponge leaving waters behind in 10 min and 35-40 min respectively (Fig. 4A-C and 4D-E). This is unprecedented in literature that submicron and nanoscale emulsions are also separated with micron size emulsions. Submicron and nano size emulsions are reportedly difficult to separate by membranes.

In order to recover the absorbed oil and reuse sponge, oil loaded sponge is squeezed and the sponge is reused for next absorption-collection cycle. After using the sponge for 100 cycles the sponge is found to show almost no change in mechanical properties and contact angle We have already grafted 153mmx153mmx2mm sheet, which can be extended up to couple of feet.

In conclusion, for the first time, we are able to fabricate a sponge based superhydrophobic and superoleophilic absorbent material for oil/water separation from layered oil/water mixture as well as emulsified oil/water mixture with wide range of droplets (surfactant free and surfactant stabilized), by a rapid, clean, scalable and economic route, gamma assisted low surface energy molecule grafting. The material is mechanically flexible, extensively reusable and economic. Thus, our material is promising for numerous applications, such as oil spill cleaning from water, purification of crude oil, fuel and emulsified waste water produced in industry and daily life.

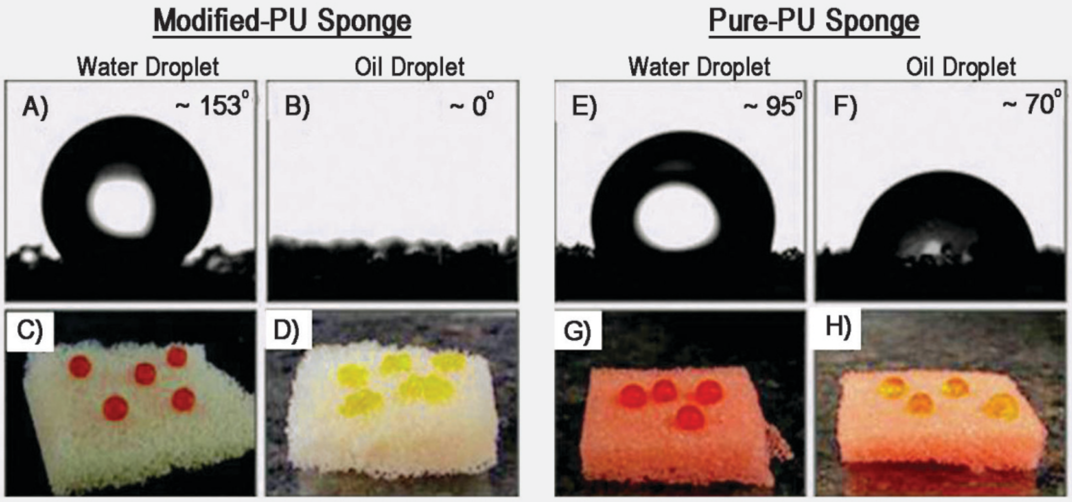

Fig.1: A-H) Images of contact angles (A-B, E-F) and beading (C-D, G-H) of liquid water (A,C,E,G) and oil (B,D,F,H) droplets on both the pure-PU sponge (E-H) and DMA-grafted PU Sponge (A-D).

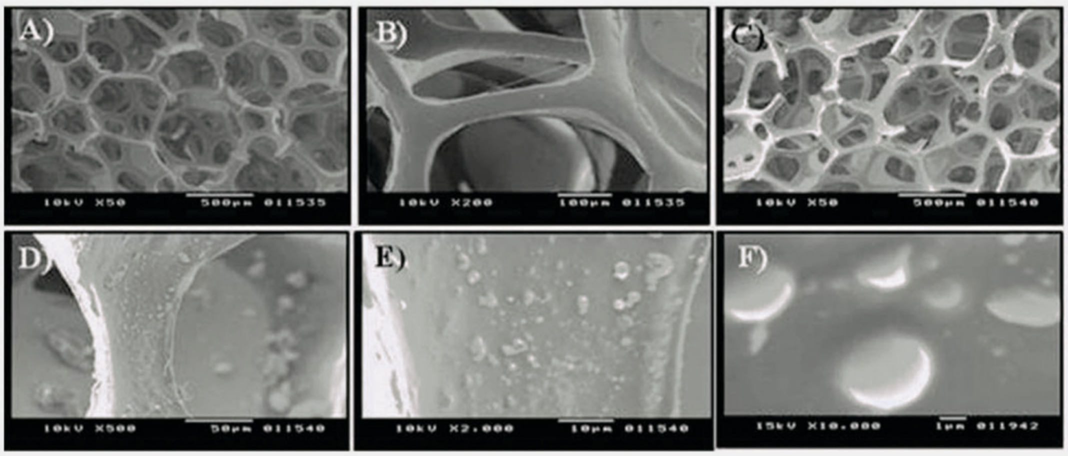

Fig. 2: SEM images: A-B) unmodified sponge with different magnifications. C-F) modified sponge with different magnifications showing rough surface consisting of micron, submicron and nano size hemisphere or bumps (ups and downs).

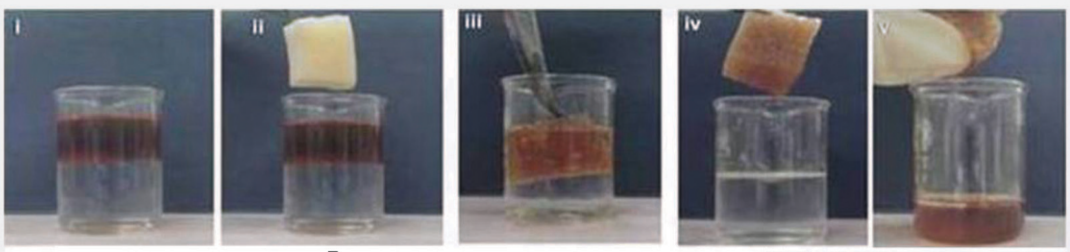

Fig.3: Diagrammatic representation of successive steps (i-v) of separating oil/water mixture and recollection of oil from it.

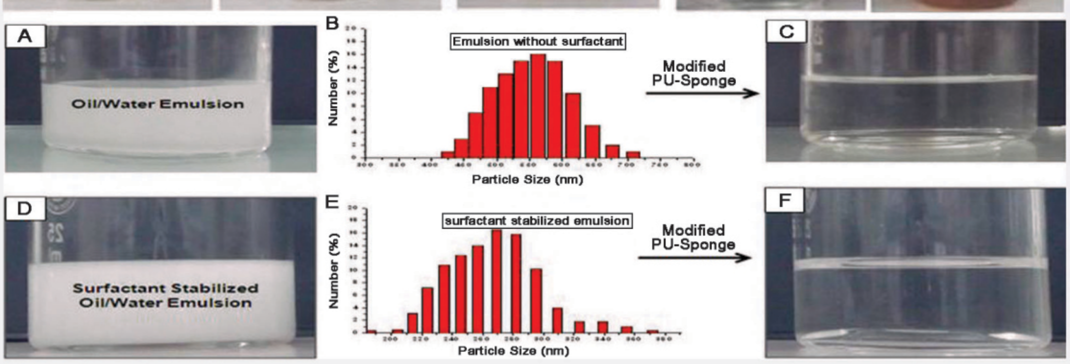

Fig.4: A-C) Photographs of emulsions without surfactant: before and after separation. D-F) with surfactant: before and after separation.

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Development of Laser Assisted Fuel Bundle Dismantling and Single Pin Chopping System for 19-Pin PHWR Thoria Fuel Bundles

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Dissolution of spent fuel is one of the essential head-end processes of reprocessing. Mechanical de-cladding of Zircaloy-clad fuel bundle is a pre-requisite for dissolution. Development of a hot cell worthy system for dismantling of 19-pin PHWR irradiated Thoria fuel bundle and subsequent chopping of dismantled pins in single pin chopper was necessary to have better dissolution of Thoria with minimum hull losses. Laser-based fuel dismantling technique also makes it amenable to segregate the pins for different streams of reprocessing with different fuel materials. In a step toward this direction; design, development & hot cell commissioning of the Laser-assisted fuel bundle dismantling and single pin chopping system were completed at Trombay. The system performed satisfactorily for operations with eight irradiated PHWR Thoria fuel bundles. The head-end process involves various steps such as fuel charging, fuel receipt & positioning, fuel bundle dismantling, pin feeding to chopper, chopping and dissolution in HNO_3. Customized equipment such as miniature power arm, CNC-based positioning system for Laser cutting nozzle, trolley for segregation of pins and the hydraulic shearing machine to chop the fuel pins were developed. The system was designed for remote operation and remote maintenance requirements of hot cell. The material of construction was chosen to meet the structural & functional requirements as well as high acidic & radiation environment. This article describes the design details and remote handling features of the system and also the experience gained during cold and hot commissioning.

Keywords: thoria reprocessing, chopping, de-cladding, CNC-based laser cutting

Introduction

Utilization of Thorium is long term objective of the Indian Nuclear Power Programme to provide energy security on sustainable basis. A Power Reactor Thoria Reprocessing Facility (PRTRF) is set up at Trombay for extraction of U^{233} from Thoria fuel bundles irradiated at 220 MWe PHWRs. The PRTRF facility is retrofitted inside two concrete shielded cells at Trombay. The chopping and dissolution equipment are housed in cell-1 and solvent extraction & purification equipment are housed located in cell-2. The PRTRF facility is successfully hot commissioned to embark on 3rd stage Indian Nuclear Power Program. Chemical dissolution of zircaloy-cladded irradiated Thoria fuel bundles in HNO_3 is an essential step for reprocessing. Development of "Laser Assisted Fuel Bundle Dismantling and Single Pin Chopping System" was necessary for PRTRF to house the system within a smaller cell, to gain experience in laser dismantling of multi-pin bundles on industrial scale, to enhance dissolution of Thoria in HNO_3 due to better cut quality achieved with single pin chopping and also to reduce hull losses achieved with single pin chopping (due to expected 500ppm U^{232} contamination with U^{233}). Laser based fuel dismantling technique also makes it amenable to segregate pins for different streams of reprocessing with different fuel materials.

In the past, laser dismantling & shear systems were developed to gain experience in laser dismantling of PHWR bundles. Analyses of cutting forces encountered during single pin chopping, cut quality, behavior of cut pieces, generation of Zr fine and life of cutting tool were carried out during this study[1]. Laser cutting operations for dismantling highly radioactive fuel sub-assemblies of FBTR and fuel bundles of PHWR were successfully carried out in hot cell at IGCAR, Kalpakkam and BARC, Trombay, respectively, using fiber coupled industrial Nd-YAG lasers [2]-[3]. Feedbacks received from these operations provided basis for modification of the system to suit the layout of PRTRF hot cells.

The process of mechanical de-cladding involves various steps such as fuel charging, automated remote positioning of fuel bundle, laser-assisted dismantling of the bundle into pins, remote feeding of the pins into the chopper using manipulator and chopping of fuel pin into small cut pieces for exposing the fuel for chemical dissolution. *Laser Assisted Fuel Bundle Dismantling and Single Pin Chopping System* was developed for mechanical de-cladding of 19 pin PHWR Thoria fuel bundles. This system is an automated system and designed to operate in highly radioactive hot cell. It comprises customized equipment such as *4 Axis Miniature Power Arm* for fuel bundle handling & positioning system, *3 Axis CNC Machine-*

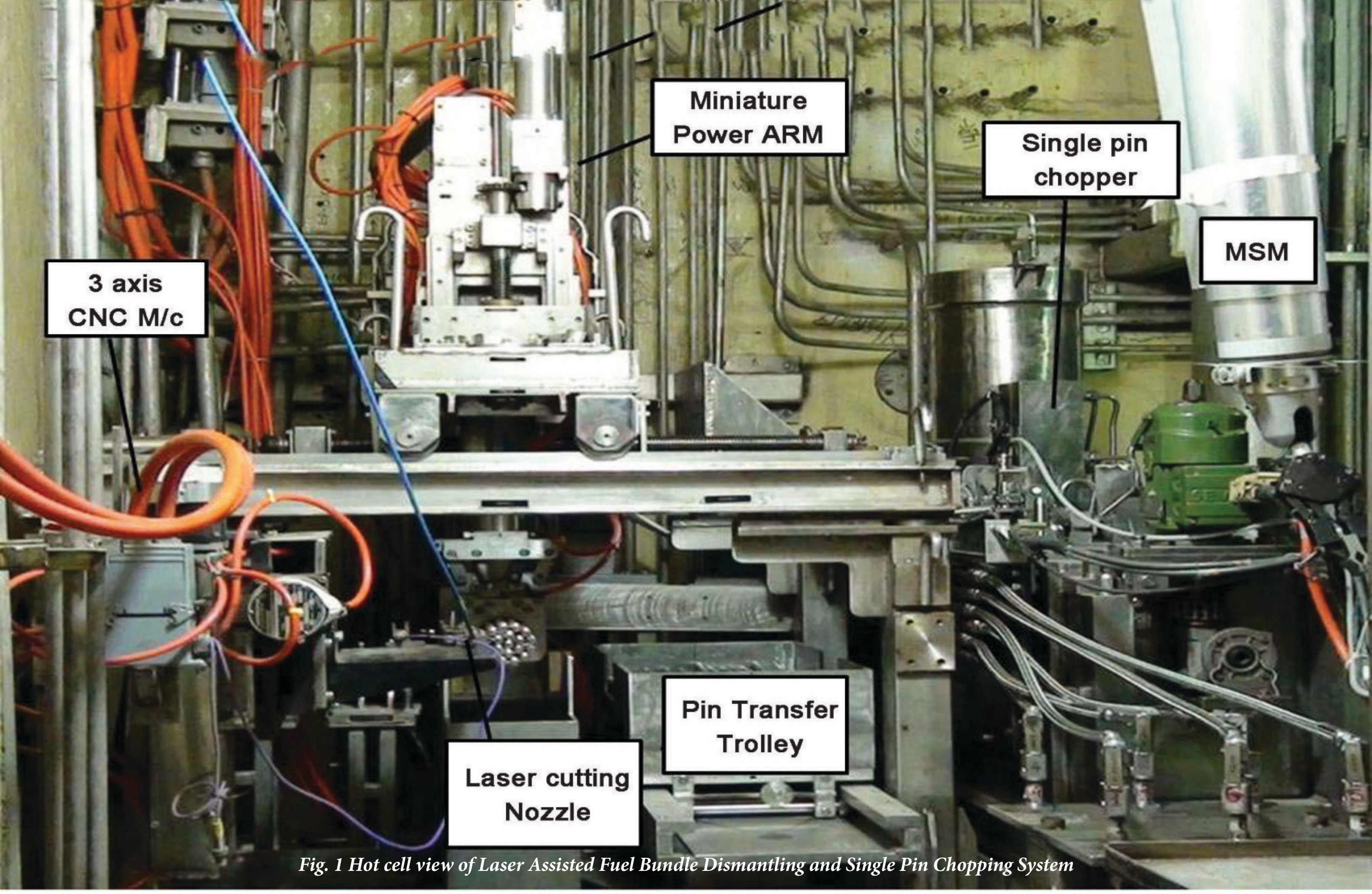

Fig. 1 Hot cell view of Laser Assisted Fuel Bundle Dismantling and Single Pin Chopping System

based bundle orientation detection system for laser dismantling, *Transfer Trolley* for segregation of pins and the *Single Pin Chopping Machine* for mechanical de-cladding of Zr clad fuel pin. The system was designed for easy remote operation and maintenance. The system can be remotely removed from cell at component/sub-assembly/assembly level in case of maintenance. Manual over-ride is provided to all the drives of the system for emergency operations. The materials of construction for the components of system were chosen to meet the structural & functional requirements and also to withstand system under highly acidic environment & high gamma radiation. The hot cell view of the system is shown in the Fig. 1.

Steps of Head-End Operations for PRTRF

Various steps of Head-End Operations for PRTRF are indicated in Fig. 2. For charging operation, fuel bundles are loaded into the charging cask and transferred to PRTRF. The charging cask is first mated with shielded transfer port door with the help of charging trolley and fuel bundles are pushed inside the chopper-dissolver cell on matching fuel receiving liner. A gripper of *4 Axis Miniature Power Arm* grips one bundle from fuel liner and positions the end-plate ends towards *3 Axis CNC Machine* for programmed laser cutting of end plates and dismantling of bundle into individual pins. The 200 Watt flash lamp pumped fiber coupled Nd-YAG laser (developed by RRCAT, Indore) is used for end plate cutting. The fuel bundle is then brought towards dismantling station where gripper is opened and all pins are singled inside *Transfer Trolley Tray*. Using MSM fuel pin is fed to *Single Pin Chopper*, which progressively pushes the fuel pin into the shear module. The gripper first grips the fuel pin and pin is chopped using a punch. Each pin is chopped into 11 cut pieces of 46 mm length. The chopped cut pieces fall into the dissolver through an inclined chute via pneumatic isolation door by gravity for subsequent dissolution. The dissolved solution is clarified using vacuum filtration and sent for solvent extraction. The hulls are retained in the perforated basket and transferred later into hull canister.

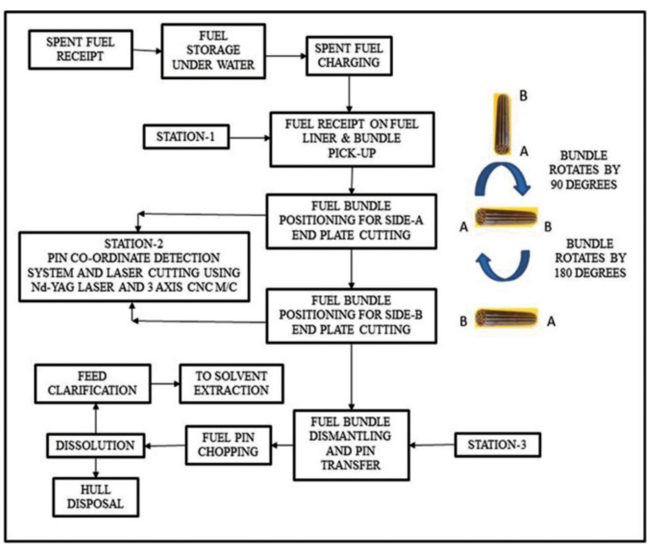

Fig. 2 Flow chart of Head-End Operations for PRTRF

System Description

The *Laser Assisted Fuel Bundle Dismantling and Single Pin Chopping System* consists of the following sub-systems:

Miniature Power Arm and Transfer Trolley

4 Axis Miniature Power Arm was developed for remote pick up of fuel bundle from fuel receiving liner, rotation of bundle by 0°, 90° and 180° for alignment with laser nozzle & liner, vertical & horizontal movement of bundle for positioning at various stations, un-gripping of bundle for releasing the pins in to the *Transfer Trolley Tray*. The motions to all the axes are provided by DC motors. The system also houses chip collection hopper with disposable cups to contain aerosol and end plate cut pieces generated during laser cutting operation. Complete system can be operated in auto as well as manual mode through a PLC-based *Control Panel* with safety interlocks.

Laser Assisted Fuel Bundle Dismantling System

The system consists of *3 Axis CNC Machine*, control panel for CNC operations, laser beam module, high voltage power supply, compressed air system and chiller. The system is designed to dismantle 19 -pin fuel bundle into individual pins using laser cutting of end plates. A 200 Watt flash pumped Nd-YAG laser is used for this purpose. The laser beam is delivered to cutting nozzle by fiber optic cable for hot cell application. Radiation resistant fiber and special quartz lenses are used in cutting nozzle in view of high gamma radiation. Fig. 3 shows Graphical User Interface (GUI) of the *CNC Machine*. The GUI of CNC has been provided with buttons for circular, grid and single pin cutting path options.

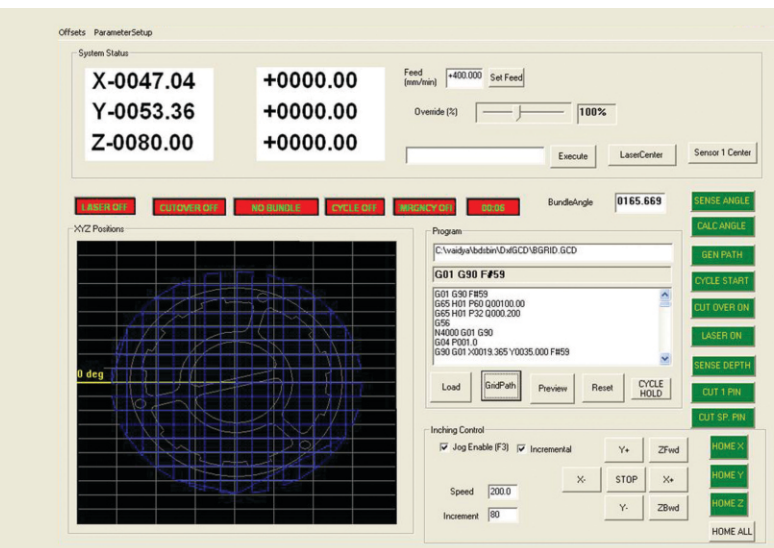

Fig. 3 GUI of CNC Machine

Single Fuel Pin Chopper System

It is a first of its kind system designed & developed for hot cell application. The *Single Fuel Pin Chopper* system (SFPC) is designed to chop fuel pin of 15.4mm OD x 495mm length into small cut pieces of 46mm length (10 nos. of cuts & 11 Nos. of cut pieces). The SFPC is an automated system developed on progressive feed-grip-chop concept (i.e. one cut at a time).

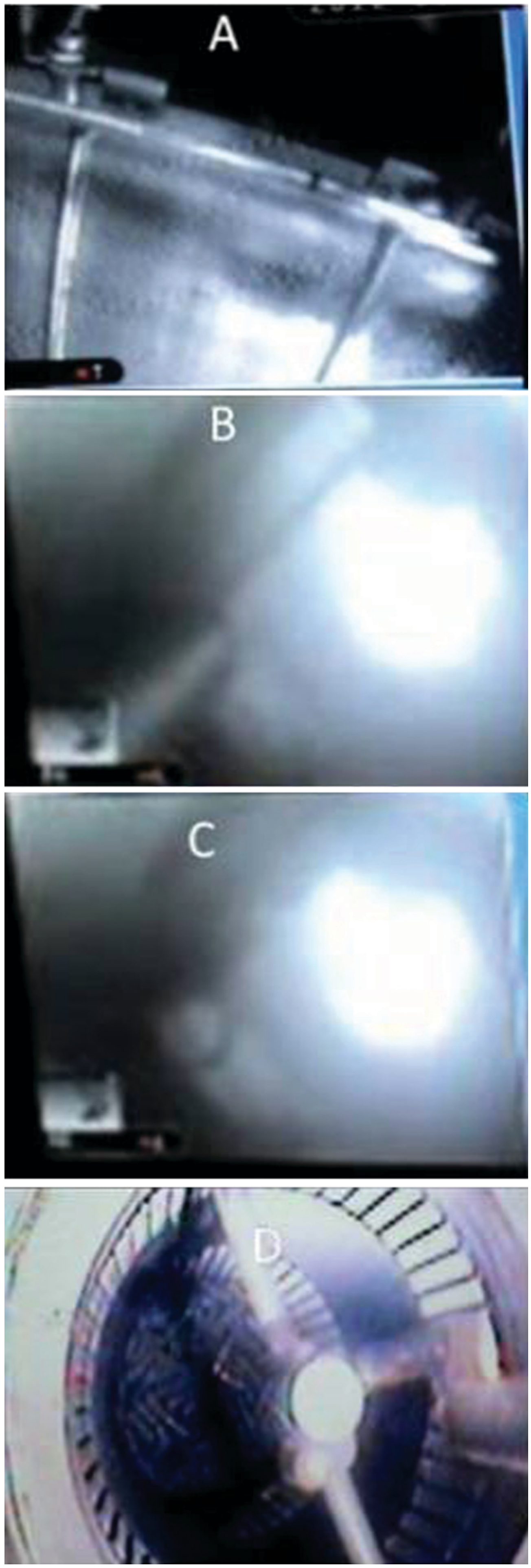

Fig. 4 Sequence of fuel pin chopping operation
A: Pin pushing , B: Pin gripping,
C: Pin chopping D: Cut piece transfer to the dissolver

The chopped cut pieces fall under gravity into the dissolver via an isolation door. Chopping and gripping forces are generated by hydraulic cylinders. The hydraulic power pack is located outside the cell. The hydraulic connections to cylinder are provided using fixed tubes as well as flexible metallic hoses. The MSM & hot cell qualified hydraulic couplings are used for maintenance of hydraulic cylinder. Chopper works on PLC-based control panel with safety interlocks. Radiation resistant magnetic switches, peek insulated electrical connectors and electrical cables are used. Chopping machine is designed to provide maximum 5.5 Te chopping and 10 Te gripping forces at 210 bar hydraulic pressure. Suitable grades of SS materials are used for manufacturing of chopper. Graphitized bushes, guides and nut are used for oil free service of chopper. Radiation resistant PU/VITON seals are used in hydraulic cylinder. Sintered HSS M3-2 cutting tool material is used for punch, die and gripper. Fig.4 shows sequence of fuel pin chopping operation.

4. Special Features

Following special features are provided in the system for remote operation and maintenance:

- Remote operation of laser with fibre optics beam delivery system (Fig.5 and Fig. 6)
- Modular system design to allow easy removal of defective parts
- Use of radiation resistant modified electrical connectors for remote operations (Fig.7)
- Use of remotely removable coupling for motors and impact head for manual overrides for critical motions (Fig. 8)
- Use of magnetic switches and hermitically sealed micro switches
- Use of MSM qualified hydraulic/pneumatic couplings for remote removability (Fig.9)
- Use of radiation resistant cables and seals to sustain the radioactive environment
- Use of graphitized bushes/nuts etc.

Manufacturing, Testing and Installation Requirements

Manufacturing of such system calls for precision machining of parts, precise assembly and dimensional quality control because of operational and remote handling requirements. All the systems have been rigorously put on testing with weight simulated & Zr clad bundles. Alignment of all the system with each other is must for functional requirement. All the systems are kept on dowels for easy alignment during maintenance.

Commissioning and Operation

The system was initially cold commissioned with dummy fuel bundles and subsequently hot commissioned with irradiated Thoria fuel bundles. The system performed satisfactorily during hot commissioning and subsequent plant operations. The performance of systems during active operations are discussed below:

Fig. 5: Arrangement for remote insertion of laser nozzle inside the hot cell

Fig. 6: Specially designed clamps for laser head and proximity sensors

Fig. 7: Modified electrical connector for remote operations

Fig. 8: Remotely removable motor couplings and impact head for manual override

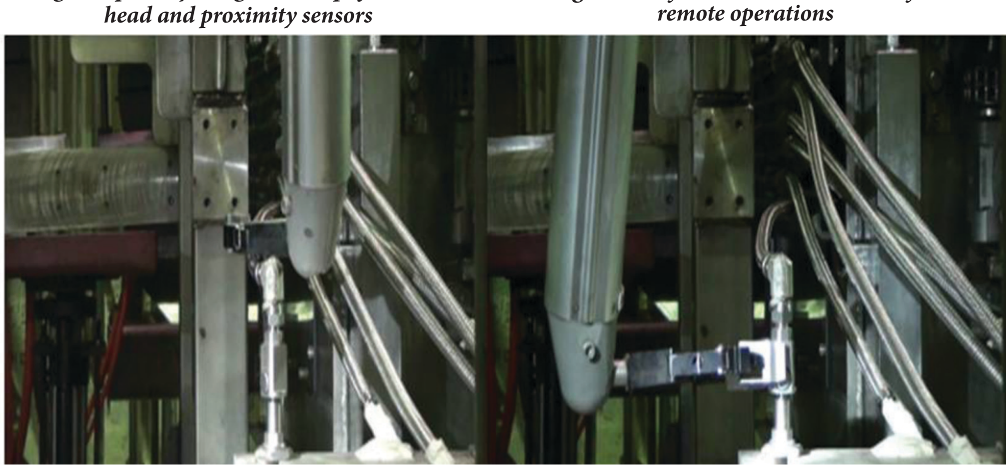

Fig. 9: Hydraulic connectors for decoupling and coupling operations using MSM

Table I: Laser cutting parameters for Zr clad bundle

I=Current	200 Amps	R=Frequency	20Hz	W=Pulse width	4 ms
F=Feed Rate	60 mm/min	Cutting clearance	3mm	Assist dry air pressure	10 bar

Bundle Handling and Positioning System

Alignment of charging cask liner with bundle receiving liner is very important to have smooth transfer of fuel bundles during charging operation. Graphitized guides are provided at laser cutting location to take care of roll axis backlash of bundle gripper and for accurate positioning of fuel bundle with respect to laser cutting nozzle.

End Plate Cutting Using Laser Beam

Several trials were carried out for laser dismantling of Zr clad, cement filled bundles to gain the experience in laser cutting. Table I gives the laser cutting parameters used during active operations with irradiated Thoria bundles. A cutting gap of 3 to 4 mm was maintained between laser nozzle and end plate using proximity sensors. The inductive proximity sensor worked well in hot cell without any radiation damage. During hot cell active operations, the bundles were laser dismantled using 5 mm grid path cutting. Grid cutting method facilitates smooth operation of CNC without hunting for centering of bundle. Fig. 10 shows laser cutting operation of irradiated Thoria bundles inside hot cell.

Dismantled Pin Transfer and Pin Feeding into the Chopper

The dismantled pins are released into the transfer trolley and subsequently single fuel pin is fed to chopper using MSM. The conventional jaws of MSM were modified for safe handling of slender pin. Fig.11 shows loading of fuel pin from tray to chopper using MSM.

Single Pin Chopping

The performance of the chopper was evaluated initially using testing with simulated pins made from different clad and filler materials. During testing, various parameters like cutting forces, performance of hydraulic cylinders and cutting tool life were monitored to generate base line data. Life of sintered HSS

Table II: Cutting forces observed with different clad and filler materials

Sr. No.	Clad material	Filler material	Cutting force (kgf)	Gripping force (kgf)	Commissioning stage
1	SS304L	Alumina cement	2300	5500	Cold
2	SS304L	White cement	2500	5500	Cold
3	SS304L	Steatite	4000	5500	Cold
4	Zircaloy	Cement + sand	2200	5500	Cold
5	Zircaloy	Irradiated thoria	2800	5500	Hot

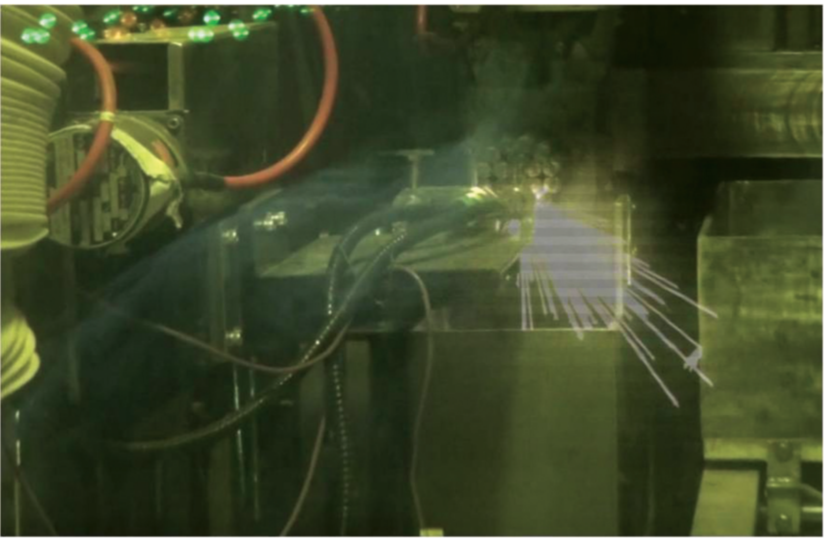

Fig. 10: Laser dismantling of irradiated Thoria bundle inside hot cell

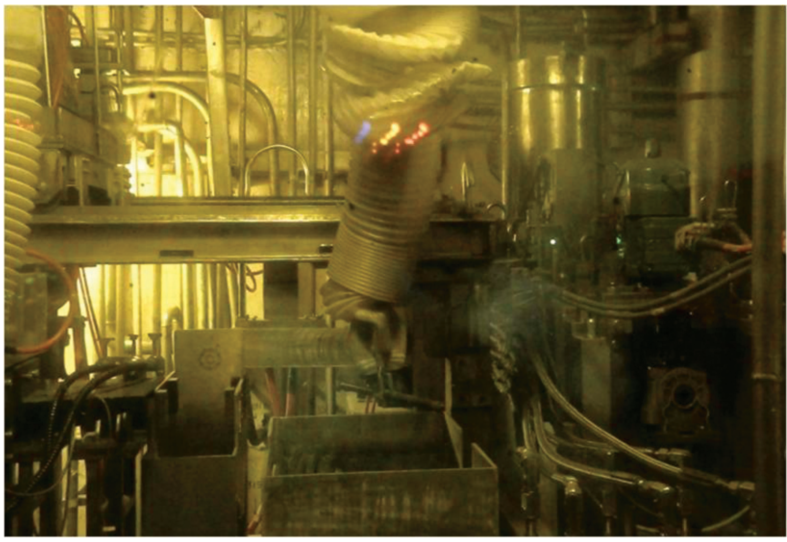

Fig.11: Loading of fuel pin into the chopper using MSM

M3-Gr-2 tool material found to be better than HCHC - D2. Single pin chopping method offered several advantages such as clean cut (without crimping), minimal generation of Zr fines and reduced cutting forces. Table II shows the cutting forces observed with different clad and filler materials.

Conclusions

A Laser Assisted Fuel Bundle Dismantling and Single Pin Chopping System was developed for 19-Pin PHWR Thoria Fuel Bundles. The system was installed and hot commissioned in the Power Reactor Thoria Reprocessing Facility, Trombay. The operation of laser dismantling of Thoria fuel bundles is very effective without any portion of the end plate projecting outside the diameter of a pin. This ensures smooth feeding and transfer of fuel pin into the chopper. Laser cutting also avoids opening up of the pins from the welds as no pressure is exerted on the pins. The method of grid path laser cutting of end plate is easier to operate. Complete dissolution of Thoria in HNO_3 occurs during dissolution due to crumple-free cuts. Generation of Zr fines is negligible due to single pin chopping. Successful active operation of the system has given useful experience in handling and operation of irradiated Thoria bundles from PHWRs and this has set a milestone in our reprocessing history.

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Abbreviations

PRTRF: Power Rector Thoria Reprocessing Facility

GUI: Graphic User Interface

CNC: Computer Numerical Control

RSW: Radiation Shielding Window

MSM: Master Slave Manipulator

RRCAT: Raja Ramanna Centre for Advanced Technology, Indore

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Dr. Sreenivas Tumuluri, Scientific Officer 'H' & Head, Mineral Processing Division, Bhabha Atomic Research Centre, Hyderabad, has made major contributions in the field of mineral beneficiation of strategic minerals. Dr. Sreenivas has developed techno-economic and environmentally viable processing flow sheets for the recovery of various strategic and energy critical minerals from low-grade primary resources and industrial waste. His approach of comprehensive extraction of mined material led to successful application of sustainability in resource utilisation as well as making exploitation of low-grade complex ores of strategic minerals economical. He has characterised and developed an industrially acceptable mineral processing flow sheet for the recovery of value added metals like Heavy Rare Earths Elements (HREE) from waste and from fly ash generated at lignite and coal based thermal power plants. In recognition of his significant contribution in the field of Mineral Beneficiation, the National Geoscience Award-2014 is conferred on Dr. Sreenivas Tumuluri. He shares the award with Dr. Swati Mohanty.

- The paper "Magnetic nanoparticles in combination with gamma radiation induce G2-M arrest and mitotic catastrophe mediated cell death in mouse fibrosarcoma cell line" by Smt. Neena Girish Shetake presented in the International Conference on Radiation Research: Impact on Human Health and Environment (ICRR-HHE 2016), held in BARC, Mumbai during February, 11-13, 2016 won the Best Oral Presentation Award.

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