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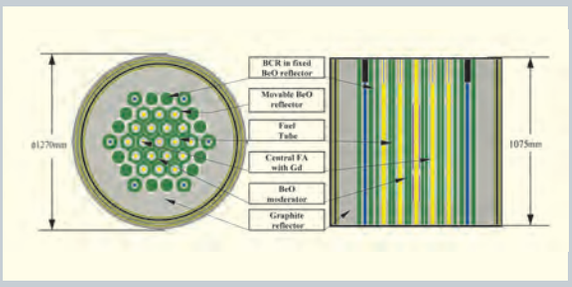

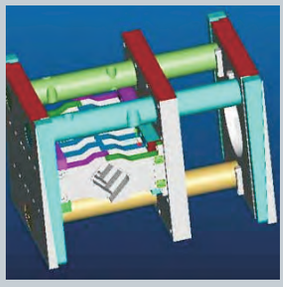

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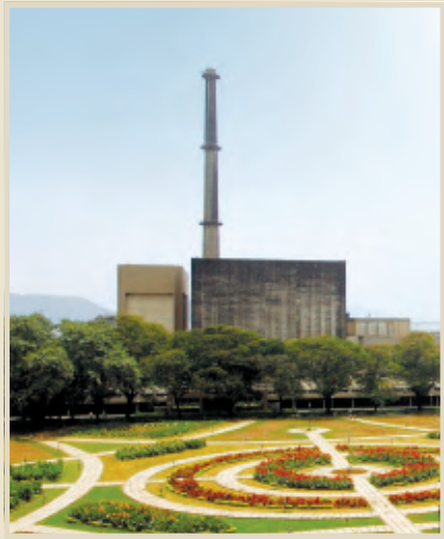
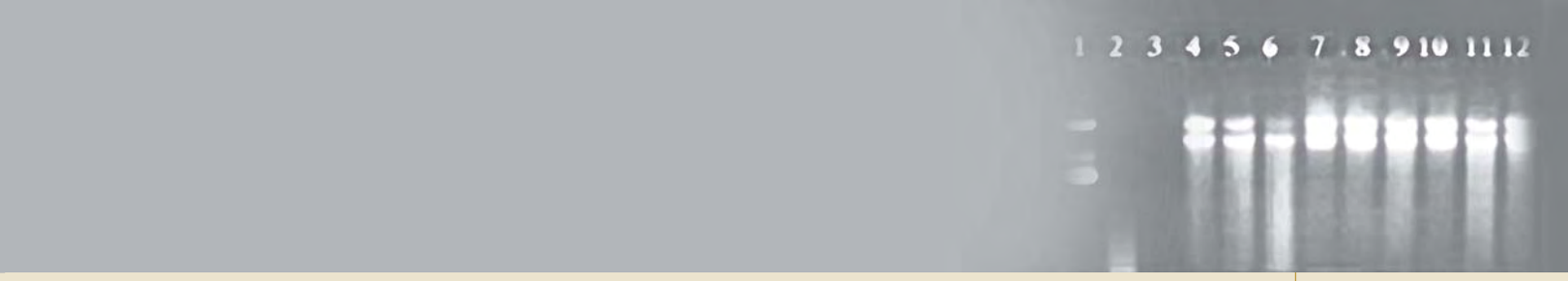


Celebrating Fifty Years of CIRUS and 25 years of DHRUVA at BARC

The CIRUS reactor, one of the high-flux research reactors at BARC, was commissioned on 10th July, 1960. It was built in collaboration with Canada, under the leadership of Dr. Homi Jehangir Bhabha. It was around CIRUS, that the nuclear programme of the country was initiated and has since steadily evolved over the years. All these years, CIRUS has proved very useful to Indian Scientists in basic research using the neutron, in the production of radioisotopes for use in Industry, Materials testing, Medicine and Biology and in training Engineers for energy production involving heavy water as moderator and natural uranium as fuel. Now after 50 years of successful operation, it has been decided to permanently shut down the reactor and subsequently decommission it. Again CIRUS will provide invaluable experience to Indian Scientists and Engineers in the decommissioning of a research reactor.

The Dhruva research reactor has been one of the most powerful research reactors in the world. It completed 25 years of successful operation, on 8th August, 2010. Project R-5 as it was called then, was mainly used for neutronic research. Its commissioning also facilitated the production of high specific gravity radioisotopes in large quantities especially for medical applications. Special materials irradiation, neutron scattering, testing and utilization of pneumatic carrier facility for trace element analysis have also been carried out extensively. After the decommissioning of CIRUS, Dhruva will become one of the most important research reactors for many years to come.



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From the Editor's Desk

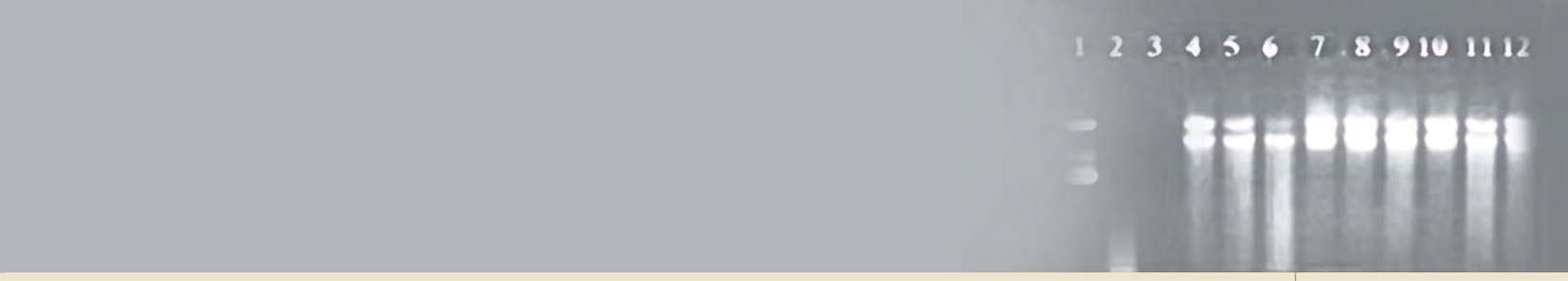
You will be having this issue in your hands in 2011. Let me wish you on my own behalf and also on behalf of all the committee members, a very happy and scientifically rewarding 2011.

This is the last issue of the BARC Newsletter for the year 2010. Obtaining the articles from diverse areas of our centre, editing and bringing out the seven issues in 2010 (including the Founder's Day Special Issue) was a challenge for us. Yes, there were few mistakes and there is large scope for further improvement. Further improvement is possible through close interactions between the editorial committee and the authors.

We have tried to cover most of the core areas of R&D in BARC and incorporate the suggestions received from our BARC fraternity. We wish to cover several other areas in the next year. I understand from the available statistics, that a large number of articles published in BARC Newsletter are downloaded and this trend is increasing.

All of this has been possible due to your support and cooperation. Please write to us and give your comments/suggestions as this will provide us scope for further improvement. We sincerely thank you all. We hope that you continue to do the same in the coming year and keep sending us your findings through the contributory articles.

Dr. K. Bhanumurthy
On behalf of the Editorial Committee



PM inaugurates new reprocessing plant at Tarapur

The Honourable Prime Minister Dr. Manmohan Singh dedicated the 100 Te annual capacity nuclear power reactor fuel reprocessing plant (PREFRE-2) at BARC, Tarapur, to the nation on 7th January, 2011.

On this occasion, Honourable Prime Minister of India, Dr. Manmohan Singh, visited the process cell area and fuel handling area of PREFRE-2 plant along with Mr. K. Sankaranarayanan, Honourable Governor, Maharashtra State, Mr. Prithviraj Chavan, Honourable Chief Minister, Maharashtra, Mr. Ajit Pawar, Honourable Deputy Chief Minister, Maharashtra, Dr. Srikumar Banerjee, Chairman, AEC, & Dr. R.K. Sinha, Director, BARC.

Mr. S. Basu, Chief Executive, Nuclear Recycle Board, Mr. R.D. Changrani, Chief Superintendent, TNRPO & Dr. Jose Pannakkal, Head, AFFF escorted the visiting dignitaries.

After the visit, a plaque was unveiled by the Honourable Prime minister Dr. Manmohan Singh to inaugurate the reprocessing plant, PREFRE-2.

Dr. S. Banerjee, Chairman, AEC welcomed the Prime Minister, dignitaries and the invitees.

Thereafter the Prime Minister Dr. Manmohan singh addressed the gathering of Scientists and Engineers. After the Prime Minister's address, Dr. R.K. Sinha, Director, BARC thanked the Prime Minister, the dignitaries and the invitees who attended the function.

PREFRE-2: The plant has been designed to process spent fuel from 220 MW PHWRs with an average burnup of 7000MWD/Te and cooling period of more than 3 years. PREFRE-2 aims to employ CHOP-LEACH head end treatment and solvent extraction process for the processing of dissolved spent fuel. The salient features of PREFRE-2 include engineered safety, redundancy in safety related equipment and components, defense in depth philosophy, fail safe logic, remote operation and maintenance. The plant has nominal processing capacity of 100 tonne heavy metal per annum. The plant has 5 process cells in a row and shares with PREFRE-1, certain facilities like, spent fuel pool, ADU conversion facility and utility services. The plant aims at reduced generation of nuclear waste. Low corrosion special material for process equipment and piping has been used. Quality assurance has been observed at all stages of design. procurement, fabrication and installation of plant systems. It is a 100 percent indigenous plant.

The Prime Minister, Dr. Manmohan Singh unveiling the plaque to inaugurate the Power Reactor Fuel Reprocessing Plant-2 at Tarapur, in Maharashtra on January 07, 2011. The Governor of Maharashtra, Mr. S. Sankaranarayanan, the Chief Minister of Maharashtra, Mr. Prithviraj Chavan and the National Security Advisor, Mr. Shivshankar Menon are also seen.

PM's address on the occasion of the inauguration at Tarapur

"I am delighted to be present at the historic occasion of the commissioning of the second Power Reactor Reprocessing Plant at Tarapur.

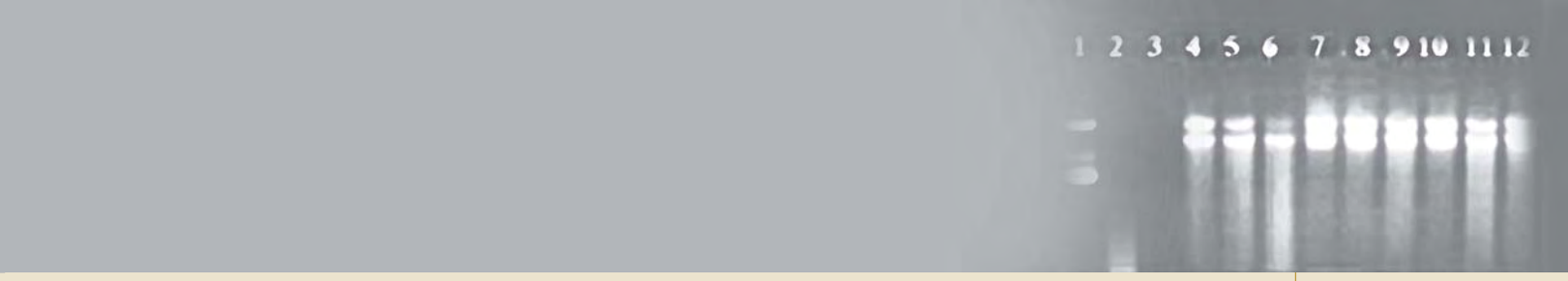
This is a significant milestone in our country's three-stage indigenous nuclear programme. I heartily congratulate the scientists and engineers who were involved in the design, construction and commissioning of this unique complex and state of the art facility. This is yet another instance that once we make up our mind, India can do anything.

We have come a long way since the first reprocessing of spent fuel in India in the year 1964 at Trombay. The recycling and optimal utilization of Uranium is essential to meet our current and future energy security needs. The vision of the founding fathers of our nuclear programme, Jawaharlal Nehru and Homi Bhabha, was to achieve the mastery of the complete fuel cycle, thus enabling India to use our vast and abundant thorium resources in advanced nuclear power reactors. The reprocessing of spent fuel is therefore the key to our three stage indigenous nuclear power programme. Reprocessing is essential in the transition to the second stage of fast breeder reactors which we have begun, and in the subsequent third stage using thorium in advanced reactors.

Honourable Prime Minister Dr. Manmohan Singh addressing the BARC fraternity

Reprocessing spent fuel will also ensure that we are better able to manage the wastes which are by-products of the nuclear fuel cycle.

Tarapur, itself is an outstanding example of nuclear energy's capacity to provide the clean, safe and economical energy that our nation requires for its development and growth. This site is home to the oldest boiling water reactors in the world. Here we have built our own reactors as well. And we have



subsequently added the entire range of facilities covering the entire fuel cycle from fuel fabrication to reprocessing and waste immobilization.

Taken together, the atomic energy programme of India represents a very important and significant step towards technological and energy self-reliance and security. That we have done so by the efforts of our own scientists and engineers is tribute to the vision of the founders of our atomic energy programme. Given the advanced status of our indigenous programme and the capabilities of our scientists and engineers we can now confidently utilize the new opportunities that have been created with the opening up of international cooperation in the field of nuclear energy.

As we move forward in the years to come to realize the potential of atomic energy to contribute to our nation's development, I would urge that we pay greater attention to capacity building, training and nurturing young and fresh talent which is in abundant supply in our country.

I once again congratulate all those who have played a role in this important landmark and who have contributed to the development of our capabilities in atomic energy. In their own way, each one of our scientists and engineers engaged in this very important national project are nation builders. I commend you all for your dedication and your hard work and your commitment to the goal of our national development. I wish you even greater success in your service to our nation. I thank each one of you on this historic occasion."

नव वर्ष के अवसर पर निदेशक, भापअ केंद्र का संदेश

नव वर्ष 2011 के अवसर पर मैं सबको अपनी हार्दिक शुभकामनाएं और बधाई देना चाहता हूँ। प्रत्येक नया वर्ष, नई आशाएँ और उमंगें, नए लक्ष्य और अब तक अनछुए रहे क्षेत्रों में आगे बढ़ने की चुनौतियाँ लेकर आता है। भापअ केंद्र, नाभिकीय ऊर्जा के रणनीतिक एवं गैर-रणनीतिक दोनों उद्देश्यों के लिए अनुप्रयोगों के क्षेत्र में उत्कृष्टता का केंद्र है और मैं आशा करता हूँ कि डॉ. होमी भाभा की विरासत में मिले उत्कृष्टता के इन उच्च मापदंडों को हम बनाए रखेंगे।

हमने अपने पीएचडब्ल्यूआर, एएचडब्ल्यूआर तथा सीएचटीआर कार्यक्रमों में तेजी से प्रगति की है। एफबीटीआर तथा पीएफबीआर के लिए ईंधनों के निर्माण के लिए चल रहे कार्य के अलावा तीव्र प्रजनक रिएक्टरों के लिए प्रगत धात्विक ईंधन विकसित करने के काम में अच्छी प्रगति हुई है। नई प्रिफ्री-2 से हमारी ईंधन पुनर्संसाधन क्षमता बढ़ी है और अतिरिक्त अपशिष्ट टैंक फार्म (एडब्ल्यूटीएफ) की कमीशनिंग के साथ ही साथ भुक्तशेष इंधन भंडारण सुविधा (एसएफएसएफ) पर किए जा रहे सघन कार्य ने हमारी अपशिष्ट प्रबंधन सुविधाओं को और अधिक मजबूत किया है।

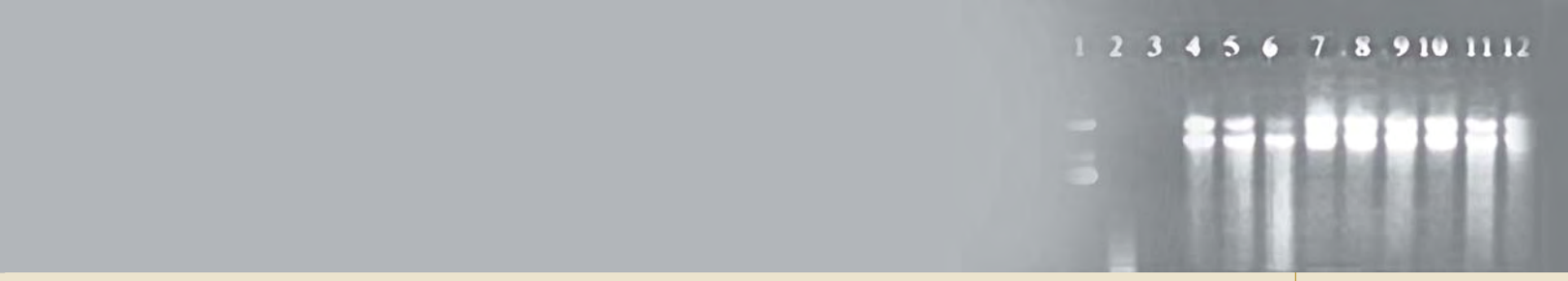
पिछले दिनों नई दिल्ली में हुई विकिरण की घटना में आपातकालीन अनुक्रिया केंद्रों (ईआरसीज़) की तैयारी की परख हुई और यह सफल साबित हुई। पर्यावरणीय विकिरण मॉनिटर के एक नए एकल मॉडल और साथ ही साथ बेंच पर लगाए जा सकने वाले तथा इधर-उधर लाए-ले जाए जा सकने वाले अविराम रेडॉन मॉनिटरों का भी विकास किया गया। रोबोटिकी के क्षेत्र में संहत लेप्रोस्कोप मॅनिपुलेटर (कोलाम) नामक एक नई युक्ति का विकास किया गया जो लेप्रोस्कोपी सर्जरी के दौरान सर्जनों के लिए मददगार होगी। इलेक्ट्रॉनिक तथा इंन्ट्रूमेंटेशन कार्यक्रम के अंतर्गत कॉम्पैक्ट, पोर्टेबल तथा हाथ में ले जाए सकने वाली टेलि रेडियोन्यूक्लाइड संसूचन प्रणालियों का विकास किया गया। पदार्थों और धात्विकी में अधिकांश अनुसंधान एवं विकास कार्य प्रगत रिएक्टर प्रणालियों के लिए ईंधनों एवं संरचनात्मक पदार्थों के विकास पर केंद्रित था।

भापअ केंद्र, नाभिकीय ऊर्जा के ऐसे अनुप्रयोगों में अग्रणी रहा है जो समाज के लिए लाभदायक हों जैसे कृषि, चिकित्सा एवं खाद्य प्रौद्योगिकी। वर्ष 2010 में प्रजनक बीजों की दो नई उत्परिवर्ती (म्यूटेंट) किस्में, एक मूंगफली और दूसरी अरहर की, खेती के लिए जारी की गईं। कैंसर के निदान के लिए आरएमसी में दो नए नैदानिक अभिकारकों का रेडियोरासायनिक मूल्यांकन तथा वाणिज्यिक उत्पादन किया गया। विभिन्न प्राकृतिक जैव-बहुलकों का प्रयोग करके जैव-अपक्षयी (बायोडिग्रेडेबल) तथा प्रतिरोगाणुक (एन्टीमायक्रोबियल) पैकेजिंग पदार्थों का निर्माण किया गया। देश के विभिन्न हिस्सों में पचास निसर्गऋण ठोस अपशिष्ट उपचार संयंत्र स्थापित किए गए।

मैं, आपके अनवरत सहयोग, समर्थन एवं सभी अनुप्रायोगिक क्षेत्रों में रचनात्मक विचार-विनिमय की आशा करता हूँ। हमारी वर्तमान उपलब्धियाँ, आगे के अनुसंधान, विकास और समाज के लाभ के लिए किए जाने वाले उपयोगी कार्यों के लिए पड़ाव मात्र हैं।

एक बार फिर, आपके लिए तथा आपके परिवारजनों के लिए नव वर्ष सुखद एवं समृद्धिशाली हो।

(आर.के. सिन्हा)



New Year Message from Director, BARC

"I would like to offer you my heartfelt good wishes for the new year 2011. Each new year brings new hopes and aspirations, new goals and targets and new challenges for forays into unexplored areas. BARC is the centre of excellence, both in strategic and nonstrategic applications of nuclear energy and I hope that we continue to maintain these high standards of excellence, a legacy from Dr. Homi Bhabha.

We have made rapid strides in our PHWR, AHWR and CHTR programmes. Apart from the ongoing work for the manufacture of fuels for FBTR and PFBR, the development of advanced metallic fuels for FBRs is well under way. The new PREFRE-2 has augmented our fuel reprocessing capabilities and the commissioning of the Additional Waste Tank Farm (AWTF) as well as extensive work on the Spent Fuel Storage Facility (SFSF) has further strengthened our waste management facilities.

The preparedness of the Emergency Response Centres (ERCs) was successfully put to test, during the recent radiological incident at New Delhi. A new stand-alone model of the environmental radiation monitor as well as bench-top and portable continuous radon monitors were also developed. In the area of robotics, a new device named Compact Laparoscope Manipulator (CoLaM) was developed, which would be of help to surgeons during laparoscopic surgeries. Under the Electronics and Instrumentation programme, compact, portable, hand-held Tele-Radionuclide Detection Systems were developed. Much of the R&D work on materials and metallurgy was concentrated on developing fuels and structural materials for advanced reactor systems.

BARC has been at the forefront of societal applications of nuclear energy such as in Agriculture, Medicine, and Food Technology. Two new mutant varieties of breeder seeds, one each of groundnut and pigeon pea were released for cultivation during 2010. Radiochemical evaluation and commercial production of two new diagnostic agents for cancer were carried out at RMC. Biodegradable and anti-microbial packaging material was prepared, using different natural bio-polymers. Fifty Nisargaruna solid waste treatment plants were established in various parts of the country.

I look forward to your continued support, cooperation and constructive interactions in all application areas. Our current achievements are but stepping stones to further research, development and deliverables for the benefit of society.

I once again wish you and your families a very happy and a prosperous New Year!"

(R. K. Sinha)

Innovative process flowsheet for the recovery of Uranium from Tummalapalle Ore

A.K Suri
Director, Materials Group, BARC, Mumbai

1. INTRODUCTION

Natural uranium (~99.3% U^{238} + ~ 0.7 % U^{235}) is the basic raw material for nuclear fuel in Pressurized Heavy Water Reactors (PHWR). The energy in the reactor is derived from the 'fission' of U^{235}, the only 'fissile' isotope in nature. These reactors also transmute the more abundant U^{238} to man–made fissile isotope Pu^{239}, which could be subjected to multiple recycling, as fuel, in fast reactor for efficient utilization of natural uranium resources and to ensure long term sustainability of nuclear energy. Thus the Indian nuclear power program has accorded a high priority to the use of all the three main fissionable materials, U^{235}, Pu^{239} and U^{233}, to meet the challenge of reaching energy independence through a well calibrated deployment of domestic uranium and thorium resources (Anil Kakodkar, 2008). Though the country has good resource base of thorium which is the precursor of U^{233}, the conventional uranium ore deposits are limited and lean in tenor. The indigenous supply of uranium to the power reactors of the country is met mainly from the uranium ore deposits located in East Singhbhum of Jharkhand milled at Jaduguda and Turamdih. The rising demand for nuclear power has naturally necessitated increased supplies of uranium. In view of this, the Department of Atomic Energy (DAE) has launched an aggressive exploration campaign for augmentation of indigenous uranium ore resources. Simultaneously research activity aimed at development of environmentally friendly technologies for the exploitation of various types of ore deposits has also been given renewed thrust.

Amongst the potential uranium ore deposits discovered by the Atomic Minerals Directorate for Exploration and Research (AMD), the exploration wing of DAE, out-side the Singhbhum Thrust Belt in Jharkhand, the Proterozoic Cuddapah Basin in southern India emerges as a major uranium province. Sustained exploration by AMD since 1986 had indicated a potential 160 km long belt of carbonate hosted stratabound uranium mineralization in impure dolostone of the Vempalle formation with the establishment of a low-grade but large tonnage uranium deposit in Tummalapalle - Gadankipalle area in Cuddapah district of Andhra Pradesh (Dhana Raju et al, 1993). Detailed exploration carried out over a stretch of about 9.5 km so far in Tummalapalle - Rachakuntapalle tract (Fig. 1) has established a resource of 29000 tonnes of U_3O_8 in about 61 million tonnes ore of 0.05% eU_3O_8 (Rai A.K. *et al.*, 2009). The complex nature of uranium mineralization in the ore *viz.* absence of discrete mineral phase, ultra-fine dissemination in various minerals, lean tenor and the need for deploying the alkaline leaching route for its extraction warranted exhaustive research investigations for making the process flowsheet techno-economically viable as well as eco-friendly. It may be noted that the existing uranium ore processing mills at Jaduguda and Turamdih in India

use conventional sulfuric acid leaching technology for the production of yellow cake or magnesium diuranate, hence the switch-over to alkaline leaching technology on commercial scale would be a first time venture.

The following discussion presents the salient features of the ore processing flowsheet for uranium recovery from the Tummalapalle ore which was the fore-runner for the commercial plant coming up at Tummalapalle in Andhra Pradesh with a slated capacity to treat 3000 tonnes of ore per day using state-of-art alkaline pressure leach process technology.

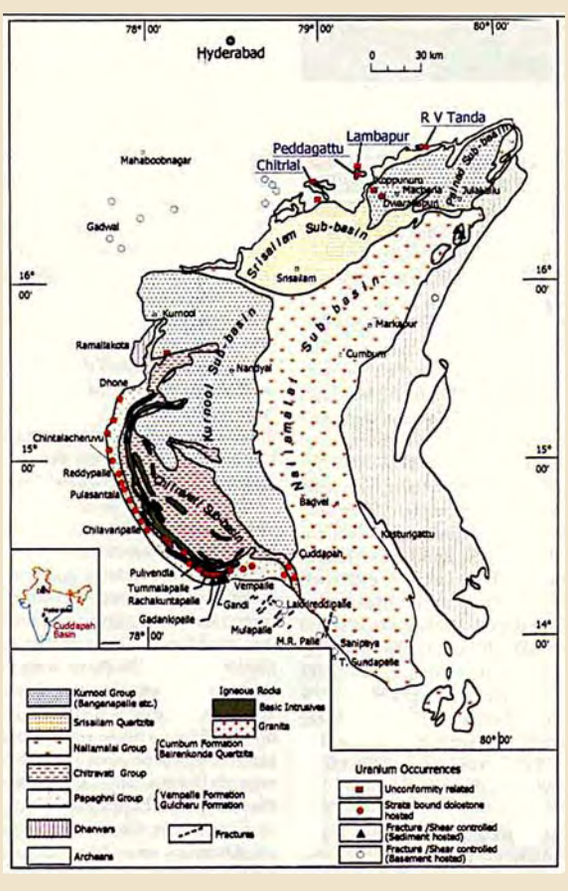


Fig. 1: Geological map of Kadapa basin showing uranium occurences

The research and development work on the Tummalapalle ore encompassed not only the bench-scale experimental studies in the laboratory but also setting-up of Technology Demonstration Pilot-plant for alkaline processing of uranium ores at M/s UCIL complex, Jaduguda, with combined efforts of Scientists and Engineers of BARC, NPCIL, AMD and UCIL (Suri A.K. 2008 and Suri A.K. *et al.*, 2009).

2. PROCESS DEVELOPMENT

Nature of host rock of valuable mineral/metal determines the process development strategy in any ore processing scheme. It is all the more critical in processing of uranium ores as the purity levels of final product in processing scheme – yellow cake, is very demanding. Achieving of good quality yellow cake product from low-grade uranium ores (U_3O_8 <0.2%) is quite challenging.

The different process options generally considered for the exploitation of low-grade ores are (i) pre-concentration of the valuable mineral by suitable physical separation technique followed by leaching of the pre-concentrate and (ii) direct "whole ore leaching" technique. Pre-concentration by physical separation methods would result in reducing the mass of the ore that goes for chemical attack subsequently. Thus the "pre-concentration - chemical leaching" route has got obvious technical, economical and environmental advantages. However, the absence of discrete uranium phase in physically recoverable size ranges in the Tummalapalle ore eliminates the application of physical beneficiation for direct pre-concentration of the uranium values. Nevertheless, the technique of "reverse physical beneficiation" for the separation of sulphide minerals as well as "thermal processing" methods like calcination-quenching-dissolution / desliming were attempted. The limited success met with all the pre-concentration methods prompted for

choosing direct "whole ore leaching" route for the recovery of uranium values from the Tummalapalle ore.

The generic flowsheet for chemical processing of uranium ores consists of different unit operations like, comminution, leaching, solid-liquid separation, liquor purification, precipitation of dissolved uranium and effluents processing. The type of leaching - acid or alkaline, depends upon the nature of the host rock. Wherever the host rock is acid consuming in nature, alkaline route is chartered upon. Since the host rock for uranium mineralization in Tummalapalle deposit is primarily dolostone type only alkaline leaching route is viable for the recovery of uranium values.

Amongst the various unit operations mentioned earlier for uranium ore processing, the leaching stage is of critical significance as higher the leachability attained higher would be the yield of the final product. Sub-optimal leachability of uranium would have high negative impact as more than 50% of the direct extraction cost is towards mining and comminution. Leaching of uranium values can be accomplished under normal or elevated pressure and temperature conditions. The choice depends upon the nature of mineralization of valuable mineral. Generally refractory mineral phases, either physical or chemical, require drastic leaching conditions which are possible only in an autoclave reactor. Similarly, solid-liquid separation of alkaline leach slurries is rather sluggish due to high viscosity of alkaline solutions. Optimum process conditions have to be developed diligently for increasing the rate of filtration with minimum dissolved solute loss in the leach residue. Though alkaline leaching with sodium carbonate - sodium bicarbonate reagent combination is relatively selective in comparison to sulfuric acid leaching, the process conditions are very aggressive and chemicals or lixiviants are very expensive underlining that their inventory too plays vital role in overall economy. Thus the focus of bench scale studies on Tummalapalle ore was centered on (i) atmospheric as well as autoclave leaching, (ii) filtration of leach slurry, (iii) determine the threshold uranium concentration required for direct precipitation of uranium from the leach liquor efficiently both quality-wise and quantity-wise, (iv) reagents recovery and (v) flowsheet synthesis cum locked-cycle testing.

2.1 Characterisation

The mineralogical composition of the exploratory mine ore sample used for the flowsheet development work (Table 1) indicate presence of 83.2% by weight of carbonate minerals. Siliceous minerals in the ore are quartz, feldspar and chlorite (13%). Collophane (4%) is the only phosphate bearing phase. Pyrite is the predominant sulphide ore mineral along with few grains of chalcopyrite and galena. The iron

Table 1: Mineralogical Composition of Tummalapalle Uranium Ore

Mineral	% Weight
Carbonates	83.2
Quartz + Feldspar	11.3
Collophane	4.3
Pyrite	0.47
Chalcopyrite	0.05
Galena	Traces
Magnetite	0.15
Ilmenite + Leucoxene	0.25
Iron Hydroxide (Goethite)	0.27
Pitchblende in intimate association with Pyrite	0.1
Total	100.0

bearing oxides are magnetite, ilmenite and goethite. Heavy media separation of various closely sized feed fractions using bromoform (BR) and methylene iodide (MI) liquids have indicated that about 91% of the uranium values are present in lighter fractions (specific gravity <3.2) (Fig. 2) as ultra-fine disseminations. The remaining 9% of uranium values reporting in methylene iodide heavies fraction are accounted towards discrete pitchblende, which is mostly associated with pyrite. Pitchblende occurring with pyrite is present as fine orbicular cluster separated by thin disconnected rims of pyrite or as garlands around pyrite.

The chemical assay of some important constituents in the ore indicates U_3O_8 content of 0.048% and the total sulfur as 0.6% (Table 2). The sulfur values are contributed by the sulfide minerals mainly pyrite.

The Bonds Work Index of the ore sample is 13.6 kWh/metric ton.

2.2 Process Chemistry

The alkaline leaching process for uranium is well known; it is in fact quite selective towards solubilization of uranium values and yield relatively pure leach liquor as compared to acid leaching. The essential chemical reactions in the alkaline leaching of uranium ores include oxidation of U^{IV} to U^{VI}:

$$UO_2 + \frac{1}{2}O_2 \rightarrow UO_3 \qquad [1]$$

and subsequent dissolution of U^{VI}:

$$UO_3 + 3Na_2CO_3 + H_2O \rightarrow Na_4UO_2(CO_3)_3 + 2NaOH \qquad [2]$$

The sodium hydroxide generated in reaction [2] could result in precipitation of dissolved uranium as per chemical equation [3] and this back precipitation during leaching is prevented by the buffering action of sodium bicarbonate as shown in equation [4].

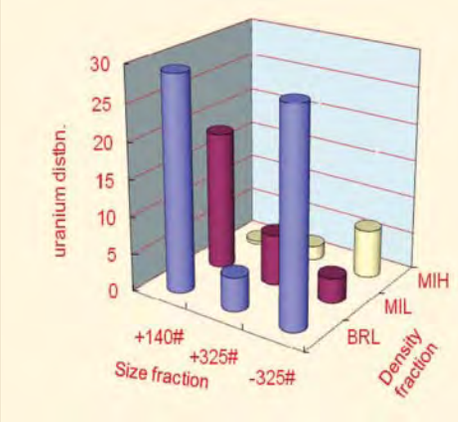


Fig. 2: Distribution of uranium as a function of size and density

$$2Na_4UO_2(CO_3)_3 + 6NaOH \rightarrow Na_2U_2O_7 + 6Na_2CO_3 + 3H_2O \qquad [3]$$

$$NaHCO_3 + NaOH \rightarrow Na_2CO_3CO_3 + H_2O \qquad [4]$$

Depending upon the reaction conditions other minerals present in the ore like sulphides, silica and alumina too undergo dissolution as given in [5], [6] and [7].

$$2FeS_2 + 7O_2 + 8Na_2CO_3 + 6H_2O \rightarrow 2Fe(OH)_2 + 4Na_2SO_4 + 8NaHCO_3 \qquad [5]$$

$$SiO_2 + 2Na_2CO_3 + H_2O \rightarrow Na_2SiO_3 + 2NaHCO_3 \qquad [6]$$

$$Al_2O_3.3H_2O + 2Na_2CO_3 \rightarrow 2NaAlO_2 + 2NaHCO_3 + 2H_2O \qquad [7]$$

Though sodium carbonate is consumed in different competitive reactions as illustrated in [5], [6] and [7], the consumption is maximum due to sulfide minerals which are more reactive at higher than boiling temperature of water in the presence of oxygen or oxidant. However, the sodium bicarbonate generated as a reaction product can be re-converted to sodium carbonate and re-used or recycled. Similarly sodium sulfate formed during the reaction of sulfides with sodium carbonate has to be taken-out of the process stream as excess concentration would hamper the leaching of

concentration would hamper the leaching of uranium. The dissolved uranium values are precipitated back using the chemical reaction given in [3] as sodium diuranate product (SDU).

2.3 Process Flowsheet

Extensive laboratory studies were carried out on alkaline leaching - both atmospheric and under elevated temperature and pressure, under various process variable settings, which include mesh-of-grind, oxidant, lixiviant dosage, contact time, temperature and pressure. As an illustration the leachability obtained with different oxidants are shown in Fig 3. Based upon the outcome of bench-scale studies, a tentative process flowsheet was developed with alkaline pressure leaching for solubilizing the uranium values from this ore using sodium carbonate as leachant, industrial oxygen as the oxidant at elevated temperature and pressure. The major issue was containing the loss of uranium and the price of uranium to a value comparable to the existing price structure. For this, the process flowsheet was engineered in such a manner that both the objectives could be achieved by alkaline processing scheme. The laboratory experiments were carried out to simulate the tentative scheme and on achieving a positive result a decision was taken up to set up a pilot-plant facility at the premises of Uranium Corporation of India Limited, Jaduguda and test the process on a pilot-scale. Batch type pilot facility was set up by middle of 2005 and on its successful demonstration it was decided to design and set up a continuous leach autoclave reactor to gain an operating experience as well as generate engineering data for setting up of a commercial plant.

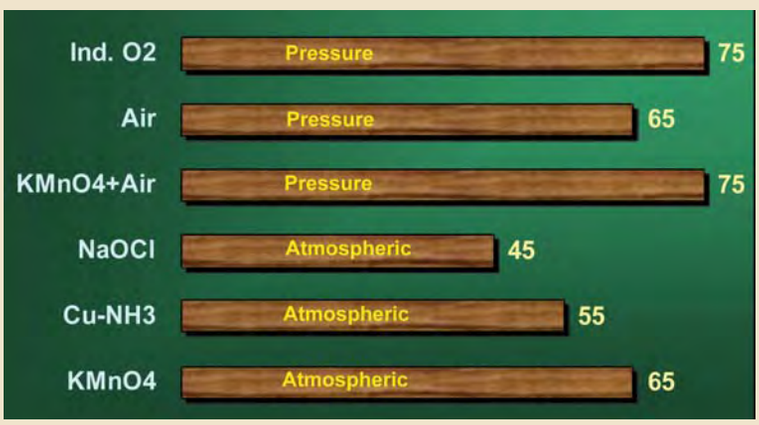


Fig. 3: Uranium leachability with various oxidants

A schematic process flowsheet developed for the recovery of uranium values from the Tummalapalle ore is given in Fig. 4.

Since the uranium content of the ore is very low, 0.05% U_3O_8, and a minimum concentration of leachant has to be retained for effective leaching of the ore, a leaching circuit with counter-current washing was found to be very effective in reducing the loss of uranium to the tailings. By re-circulating most of the leach liquor, with a small fraction as bleed, the concentration of uranium in the leach liquor could be raised to a level which is suitable for direct precipitation of uranium as sodium diuranate. The distribution of chemical species in the SDU cake of Tummalapalle is shown in Table. The leach liquor after precipitation of uranium contains large proportion of reagents with substantial concentration of sodium, carbonate, hydroxyl and sulfate ions. While sulfate is recovered as by-product by either freeze crystallization or evaporation. Rest of the solution is suitable as feed for the regeneration of lixiviants. Causticization of certain fraction of the solution followed by carbonation has been adopted to reuse almost all the reagents. In this process scheme the solution balance and the solution

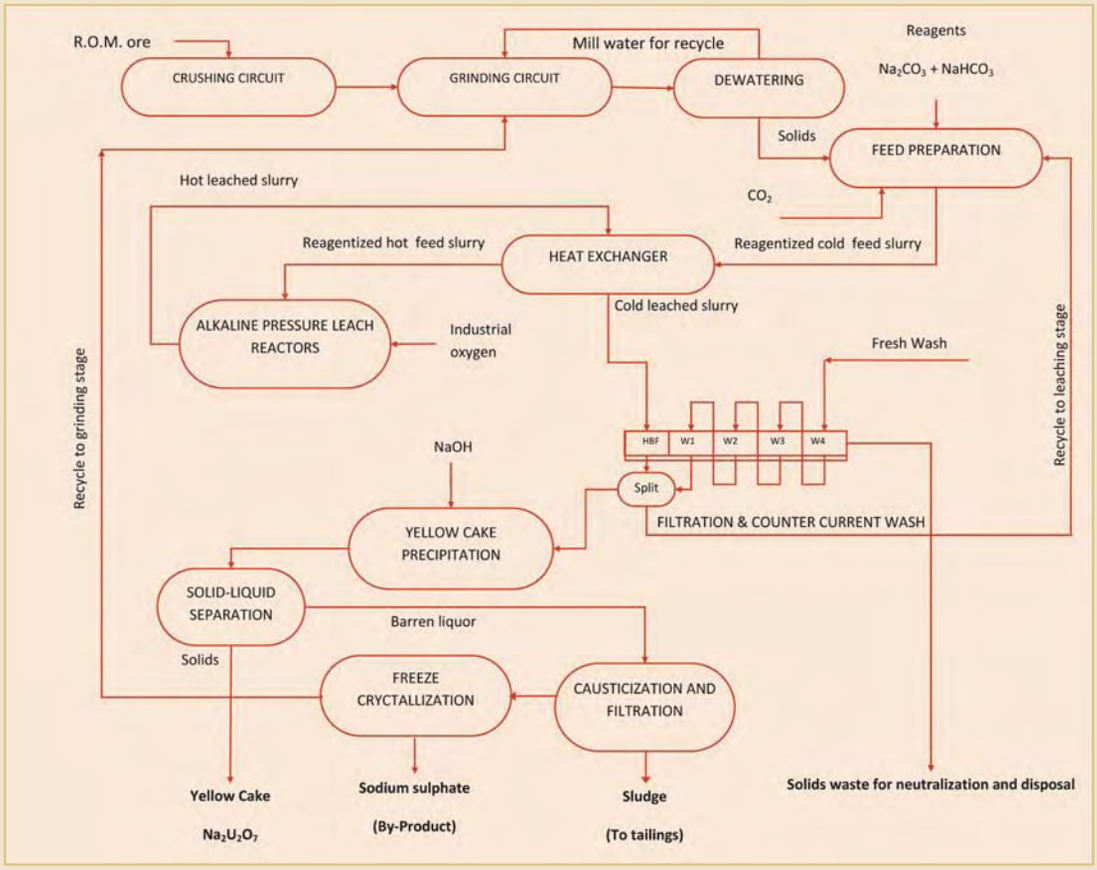


Fig. 4: Process flow sheet for processing Tummalapalle ore

chemistry control is extremely important to attain the twin objectives of reducing the uranium loss and obtaining uranium concentration suitable for direct precipitation. These have been accomplished both in the laboratory and in pilot-plant.

2.4 Interesting Features of the Process

The process flowsheet developed for the Tummalapalle ore could qualify for commercial exploitation mainly due to certain special attributes imbibed in the overall exploitation scheme, which include:

- Fewer number of processing stages as compared to conventional uranium ore processing flowsheet;
- Regeneration and recycle of cost-intensive reagents thereby reducing the fresh reagent inventory to bare minimum level inspite of the need to maintain very high solution concentration of leachants during leaching stage and, minimum fresh water inventory;
- Relatively pure yellow cake product with U_3O_8 assay of about 77 - 80% and with minimum impurities load for subsequent yellow cake processing stage.
- Stabilized tailings for safe disposal to environment and practically zero liquid waste generation.
- A technology which has relatively low equipment corrosion in comparison to conventional sulfuric acid leaching route.

- Production of sodium sulfate by-product with less than permissible levels of radioactivity.

Thus many challenges inherent in the ore characteristics were converted into opportunities such that a vast resource could be put to use for Country's nuclear power programme at a competitive cost.

3.0 CONCLUSIONS

A good understanding of the nature of mineralization of uranium values in the ore, uranium process chemistry and different unit operations, has led to the development of well integrated specially engineered alkaline leaching process flowsheet to treat the low-grade uranium deposit in the alkaline host rock. The objective of making a techno-economically viable process flowsheet could be realized primarily by reducing the number of stages of unit operations and conservation of leachants by regeneration and recycle. Effective recycle of process solution led to minimization of fresh water inventory as well as quantum of liquid effluent discharge. Inevitable chemical species *viz.* sodium sulphate and calcium carbonate, in the process were converted into useful by-products by carefully tailored sequence of chemical steps. The process technology developed is being translated for industrial adoption by UCIL and the mine and the mill are in advanced stages of completion.

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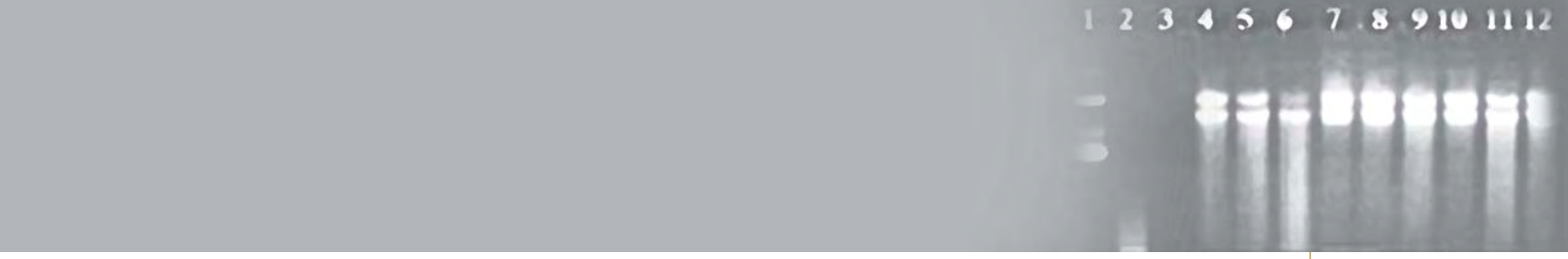

Simultaneous measurement of particle velocity and shock velocity for megabar laser driven shock studies

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Abstract

Studies of hydrodynamics of the laser driven targets are important for various applications. Determination of equation-of-state (EOS) of materials subjected to multi-Megabar pressure by laser ablation involves the simultaneous measurements of shock velocity and particle velocity. We have developed an accurate technique to achieve this. Multi-frame optical shadowgraphy technique coupled with an optical streak camera has been used to measure shock pressure with an accuracy of +/- 7%. Free surface velocity (particle velocity) of a laser driven target foil has been measured with multi-frame optical shadowgraph technique and shock velocity is measured with the optical streak camera. The shock pressure measured with the laser intensity up to 2.5 x 10^{14} W/cm^2 is about 25 Mbar in aluminum foils.

Introduction

The study of Equation of State (EOS) is of interest for several fields of Physics, in particular, to material science, inertial confinement fusion and astrophysics[1,2]. Lately, high power lasers are being increasingly used to generate extreme pressures and investigate the EOS of condensed matter at such high pressures[3]. Dynamic pressure of hundreds of Mbar can be generated by focusing high power lasers on various targets[4], which is not possible with other conventional means (gas guns, chemical explosives etc[5]), except with nuclear explosions.

Our group has been engaged in the generation and studies on laser driven shocks in various types of materials, using a high power, sub-nanosecond Nd:Glass laser[6,7]. This article presents measurements of laser driven shock pressures up to about 25 Megabar achieved in aluminum targets. Standard materials such as aluminum, copper and gold have been extensively used to test the various shock diagnostics and techniques in our laboratory. Experiments have also been done with complex targets with the aim of enhancement in pressure and restricting the growth of hydrodynamic instabilities. However, this report lays emphasis on the newly developed multi-frame optical shadowgraphy diagnostic technique, with high temporal and spatial resolution. The experimental results have been found to match with 1-D hydrodynamic code simulations.

RESEARCH ARTICLE

Direct measurement of the EOS data requires simultaneous measurement of shock velocity and particle velocity in the target material. In our laboratory, we have measured shock velocity using an optical streak camera with a 20 ps resolution. We have developed multi frame optical shadowgraphs with spatial and temporal resolution of 12 μm and 500ps respectively, to measure free surface velocity of target foils irradiated with an intense laser beam. The final accuracy in the measurement of shock pressure is to about 7%. In the next stage of experiments, it is planned to reduce the duration of the optical probe pulse from 500 ps to 1 ps and use streak camera of 2 ps temporal resolution. This is expected to improve the precision further. Beside EOS studies, there are several other applications of multi-frame shadowgraphy diagnostics. It can be used to study growth of hydrodynamic instabilities during the foil acceleration phase, which is the deciding factor in the efficient compression of fusion fuel pellet in ICF. This diagnostic could also be effectively utilized in the study of the concept of impact fusion using ultra high intensity lasers.

Shock production and determination of Equation of State of a material

When a pulsed high power laser interacts with matter, hot plasma is created which expands at a very high velocity in a direction opposite to the laser, into the vacuum. The outward expanding plasma exerts a high pressure in an inward direction, leading to the formation of an intense shock wave moving into the interior of the target and a change in material density as well as internal energy. Conservation of mass, momentum and internal energy inside the target, before and after the shock pulse can be expressed in the form of the Rankine - Hugoniot equations[8] given below.

$$\rho_0 u_s = \rho\left(u_s - u_p\right) \quad (1)$$

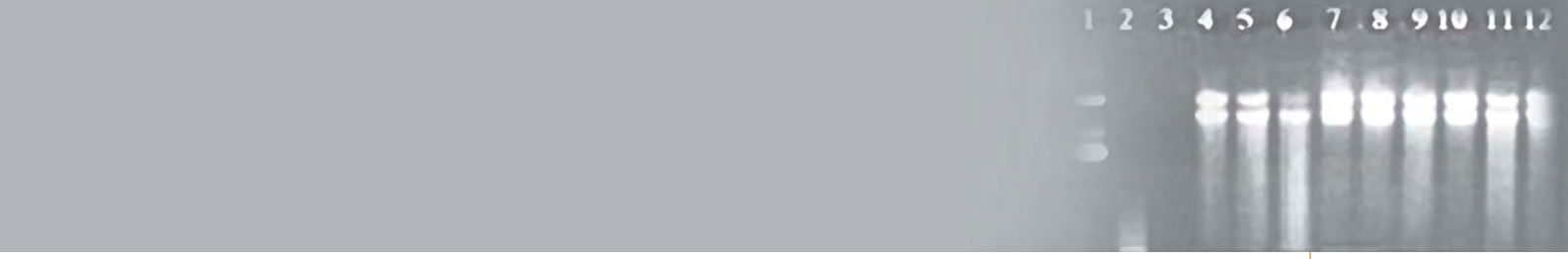
$$P - P_0 = \rho_0 u_s u_p \quad (2)$$

$$E - E_0 = u_p^2/2 \quad (3)$$

Here, u_p, ρ, p, u_s and E are respectively the fluid velocity, the mass density, the pressure, the shock velocity and the specific internal energy of the material (after shock passage). The subscript '0' indicates the values in the un-perturbed state of the material (i.e. before shock passage). The above three Rankine -Hugoniot relations relate five unknowns and hence one needs two more equations to close the system. EOS provides these two additional relations. On the other hand, experimental determination of EOS requires simultaneous measurement of two variables and most of the laser experiments carry out the simultaneous measurement of shock velocity and particle velocity. In our experiments, shock velocity was measured using an optical streak camera and the particle velocity (half of free surface velocity) in the laser irradiated target foil was determined using multi-frame optical shadowgraphy.

Measurement of shock velocity and free surface velocity in Aluminum

Laser driven shock studies reported in this article have been carried out using an indigenously developed 16 J/ 300-800 ps Nd:Glass laser system[9]. This pulsed-single shot laser system consists of a commercial laser oscillator with output energy of 100 mJ per pulse with a peak to background contrast of 10^5. A chain of amplifiers following the oscillator increases the laser pulse energy to 16J and focused laser intensity on the target is $> 10^{14}$ W/cm^2. The shock transit time is obtained by determining the time interval between the arrival of the main laser pulse on the target and the onset of the shock luminosity at the rear of the target. The instant of laser pulse arriving at the target is recorded in every shot by recording a time fiducial along with the shock luminosity. The schematic of the set up for the simultaneous measurement of the shock transit time (shock velocity) and free surface velocity of target foils is shown in figure 1a. Photograph of the laser system together with the diagnostic set up is shown in figure 1b.



Optical streak camera is accurately synchronized with the appearance of shock luminosity on the target foil rear side by triggering appropriately to control the timing of the streak sweep. The trigger pulse is generated using a fraction of the oscillator laser beam extracted by a beam splitter BS1. This is divided again into two beams. One of them is used to generate an electrical trigger pulse for the streak camera using a photodiode. The electrical trigger pulse is suitably delayed so as to be synchronized with the event being recorded, i.e, the glow of streak caused by shock luminosity. Other part of the split laser beam is focused into a KD*P (Potassium Dideuterium Phosphate) crystal to generate its second harmonic at 0.532 μm. This visible beam is made incident onto the streak camera slit through a fiber, to obtain the time reference signal (fiducial) on streak camera screen. The fiducial thus forms the time marker in all the laser shots and designates the time at which laser is incident on the target. The streak camera readout system transfers the image formed on the phosphor screen to PC with a frame grabber card for further analysis. The frame grabber card is also appropriately externally triggered and synchronized with the event to record the single shot image. Synchronization of the main beam with the fiducial has been done without a target in the path of the beam as shown in figure 2a. Subsequently, the target foil is introduced and shock velocity is measured by recording shock transit time (shock velocity) in the target of known thickness. The fiducial and the shock luminosity streak of the 10 μm aluminum, is shown in figure 2b and intensity plot of fiducial and shock luminosity is shown in figure 2c.

Two frame optical shadowgraphy is set up using a second harmonic backlighting probe beam. This probe is derived by extracting 1% of laser light from the main beam at the final stage by introducing beam splitter BS2. An appropriate delay has to be introduced in its path to record shadowgrams at desired delay times with respect to the main laser beam. This has been achieved with the help of an optical delay comprising of mirrors M6, M7 and a prism. Further, this beam is split into two parts with BS4, for the two shadowgram frames at two different delays. A polarizing beam splitter is used to recombine again, these two beams after a delay of 3.47 ns in one arm. These probe pulses, then pass through the KD*P crystal and are converted to second harmonic (532 nm) for the shadowgraphy. They are propagated along the same optical path and illuminate the target edge such that the target foil is aligned at the centre of the field of view. After this, the two pulses are split again into two beams with the help of polarizing beam splitter and recorded with the cameras CCD1 and CCD2. Thus, in the present set up, per laser shot, we can fix two delays between the two frames. For the subsequent laser shot, a constant delay can be introduced in both the arms by changing the delay in the main delay arm using the prism mounted on translation stage. In this set up, accuracy in delay setting between the two frames of the optical shadowgrams is 0.1 ns. Experiments have been performed wherein foil motion has been recorded in two laser shots of same energies. In the first set of shadowgrams recorded with one laser shot, delay in the two arms of the probe beam (PB) is fixed at 2.92 ns and 6.39 ns with respect to arrival of main beam on targets and in the second set of shadowgrams delay of probe beams are changed to 4.82 ns and 8.29 ns. All these delays are measured with the help of optical streak camera (20 ps temporal resolution) and verified with the vacuum bi-planar photodiodes (rise time 80 ps) as shown in figure 3a - f. The temporal resolution of the set up is 500ps as decided by probe pulse duration. The temporal laser pulse profile is shown in figure 4a. Typical shadowgrams recorded for 10 μm thick aluminium foil at laser intensity of 2.5×10^{14} W/cm^2 are shown in figure 4b-f for delays of 0 ns, 2.92 ns, 4.82 ns, 6.39 ns and 8.29 ns respectively. The temporal resolution can further be improved to about 300 ps with the existing laser system. In future, better temporal resolution ($<$1ps) is in plan by using femtosecond

pulses. Spatial resolution has been measured to be about 12 μm. The ultimate spatial resolution of the experimental set up is limited by the CCD camera resolution or pixel size which is 6.45 μm. The overall optical magnification from target plane on to the CCD camera plane is measured to be 3.457. The novelty of this shadowgraph experimental set up is that, it uses inexpensive CCD cameras to obtain a high temporal resolution in comparison to expensive CCD cameras. Since temporal resolution is limited by the exposure time or the probe pulse duration, it can be further improved even up to a few hundreds of femtoseconds.

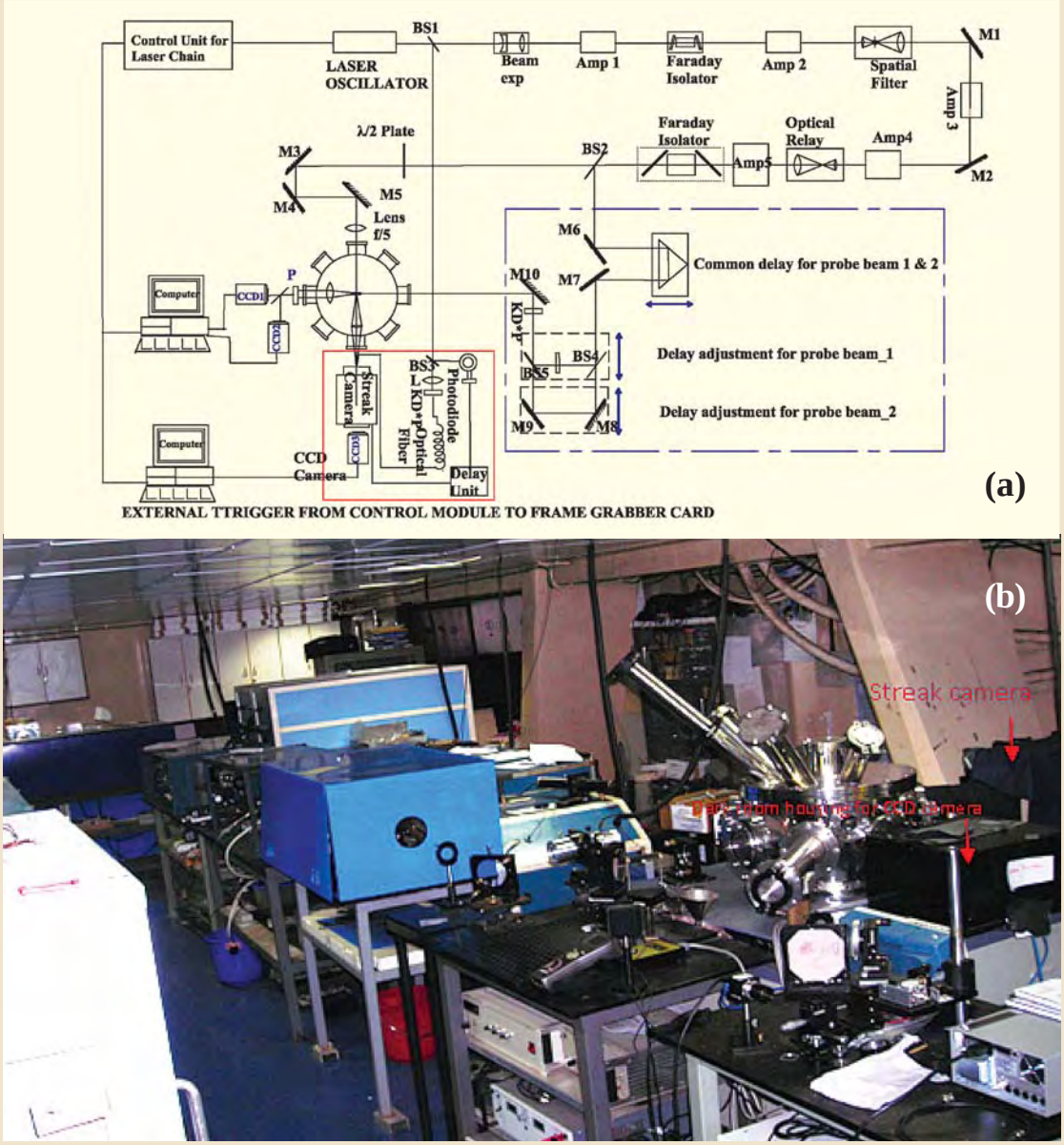


Fig.1: (a) Experimental set up for simultaneous measurement of shock velocity using optical streak camera and free surface velocity measurement using two frame optical shadowgraph.
(b) Photograph of the experimental set up along with the laser system

Fig. 2: Shock velocity measurement: (a) Synchronization of main beam with fiducial.
(b) Streak record of the fiducial and shock luminosity signals in 10 μm Al foil at laser intensity 1 x 10^{14} W/cm^2
(c) Plot of intensity profile of fiducial and shock luminosity. X-axis shows time in terms of pixel numbers
(1pixel = 6.56 ps) and Y axis shows intensity of the glow in numbers of pixels.

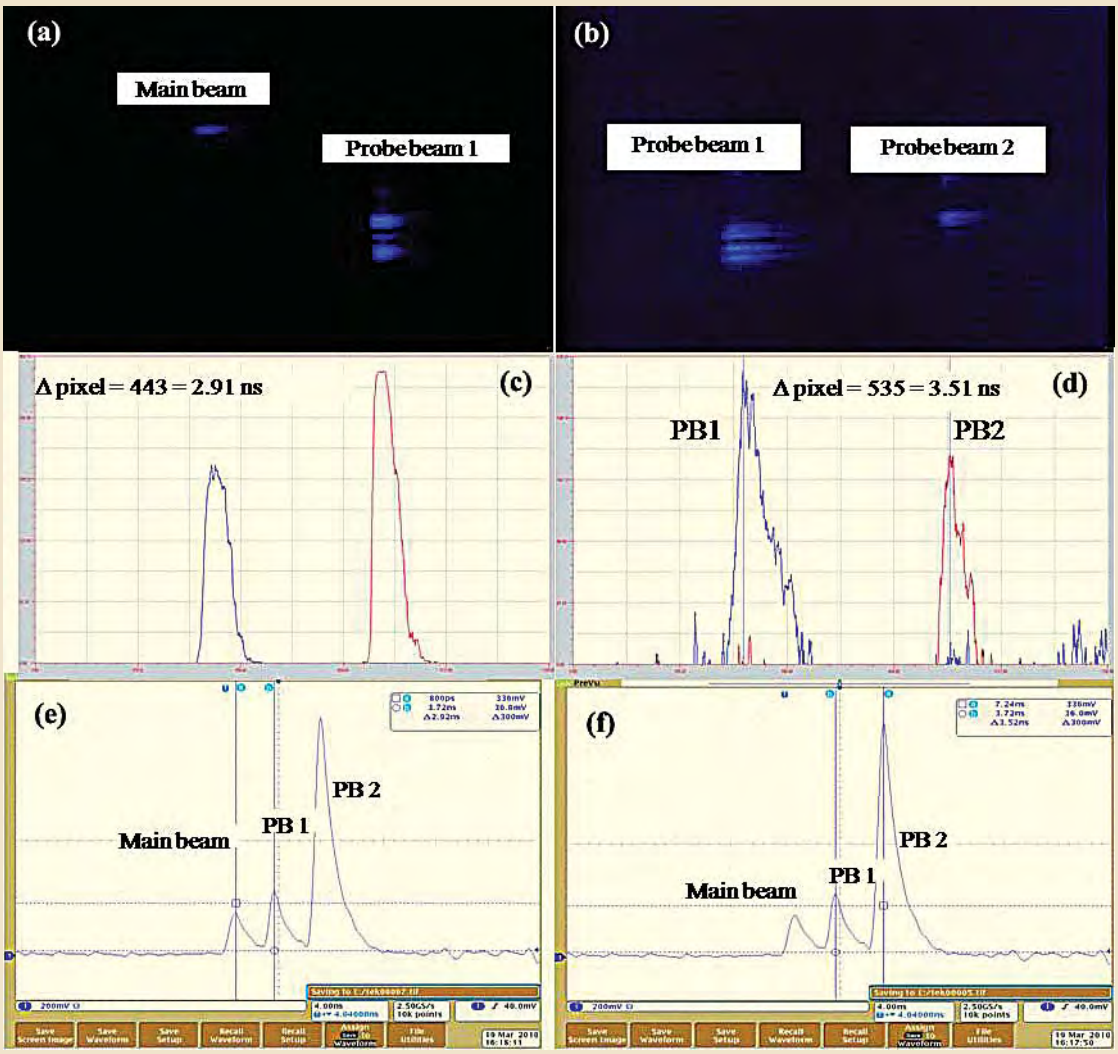


Fig. 3: (a) Streak camera measurement of delay between main beam to first probe beam and
(b) delay between probe beam 1 and probe beam 2. (c) and (d) are the processed results of the streak camera record using the software for streak shown in (a) and (b). (e) and (f) show the oscilloscope profile for the same delay as measured with the streak camera.

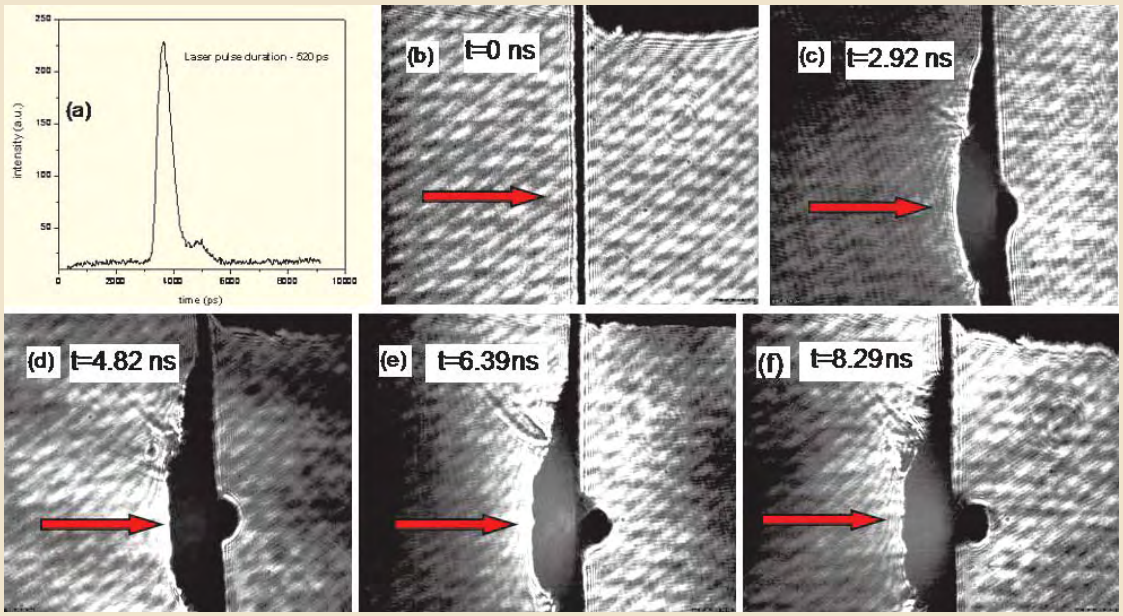


Fig.4: Shadowgram recorded of 10 μm Al foil irradiated with laser intensity 2.5 x 10^{14} W/cm^2 of laser pulse shape shown in (a) laser pulse duration measured with streak camera about 520 psec (FWHM), Rise time- 375 ps (b) un exposed foil target (c) at a 2.92 ns delay with respect to main laser beam (d) 4.82 ns delay (e) 6.39 ns delay (f) 8.29 ns delay. Arrow in these figures shows the direction of laser beam.

Results and discussion

In the experiments presented here, we have estimated shock pressure exceeding 20 Mbar at a focused laser intensity of 3 x 10^{14} W/cm^2 on a 10 μm Aluminum target foil. The laser intensity was varied from 5 x 10^{13} to 3 x 10^{14} W/cm^2. Shock velocity u_s was calculated from the known target foil thickness and the shock transit time. Free surface velocity of the target foil rear surface was measured using two frame optical shadowgraphy techniques as described in the last section. A typical plot of target foil movement at the four time delays, namely, 2.92 ns, 4.82 ns, 6.39 ns and 8.29 ns is as shown in figure 5a. Laser intensity in these two shots was 1.1x10^{14}W/cm^2. The slope of the plot gives the free surface velocity u_{fs} of the irradiated foil and is observed to be 2.8 x 10^6 cm/s. Further; the particle velocity u_p behind the shock has been taken as half of the free surface velocity. The scaling of the particle velocity with laser intensity is shown in figure 5b. A least square fit to experimental data can be represented as $u_p = I^{\alpha}$ where α= 0.61, which is close to value reported in the literature. Solid line in this figure shows the values calculated using one dimensional Lagrangian hydrodynamic simulation of the experiment. Shock pressure was calculated from the measured values of u_s and u_p using the formula given in (2).

Figure 6a shows the scaling of shock velocity u_s with laser intensity I. Solid red curve in this figure is the standard theoretical simulation for shock velocity in Aluminum. In figure 6b, the standard Hugoniot for Aluminum is shown in solid blue line. Experimental points are indicated as black squares. From this figure, we note that our experimental data for pressure are lower compared to simulation. This can be explained in terms of non-uniformity of shock in the Aluminium foil. This is demonstrated in figure 7a-d wherein we show the calculated space profiles of particle velocity, ion temperature, density

and hydrodynamic pressures in the foil. Various curves in this figure are at the marked time. It is observed from this figure that the shock builds upto its full strength at about 250 ps. The initial low strength of shock is because of time variation of incident laser pulse. The shock Hugoniot curve in figure 6(b) assumes a single strong shock of constant strength. Our measured shock velocity is in fact an average shock velocity in the target. This leads to slight under prediction of shock pressures. This problem can be mitigated using step targets in our future experiments.

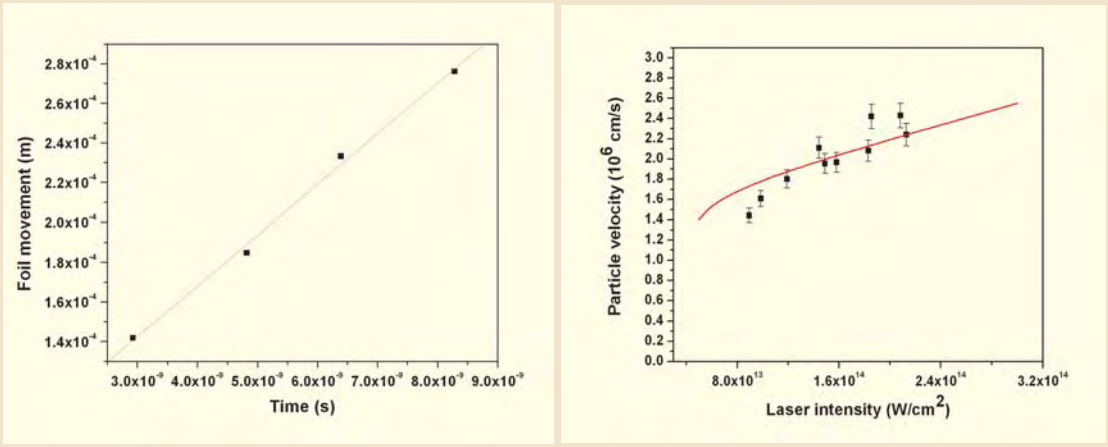


Fig.5: (a) Target foils movement with respect to optical delay of probe pulse at a laser intensity 1.1 x 10^{14} W/ cm^2. (b) Scaling of particle velocity with laser intensity. Points are the experimental values and line shows the theoretical calculation.

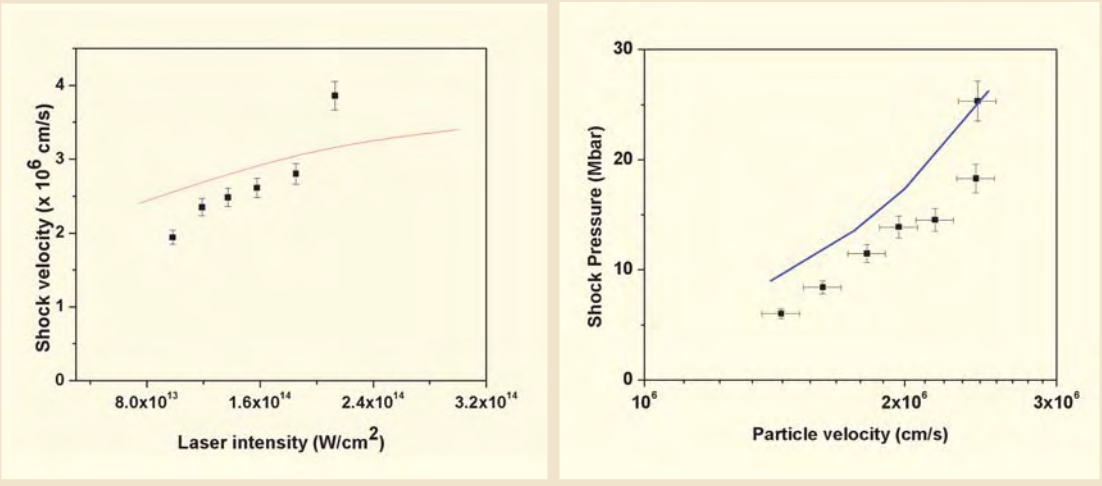


Fig. 6: (a) Scaling of shock velocity with incident laser intensity. Points are the experimental data and the red curve is the theoretically simulated results. (b) Points are showing the scaling of shock pressure with particle velocity measured with two frame optical shadowgraphy technique and line indicates theoretical Hugoniot curve for Aluminum.

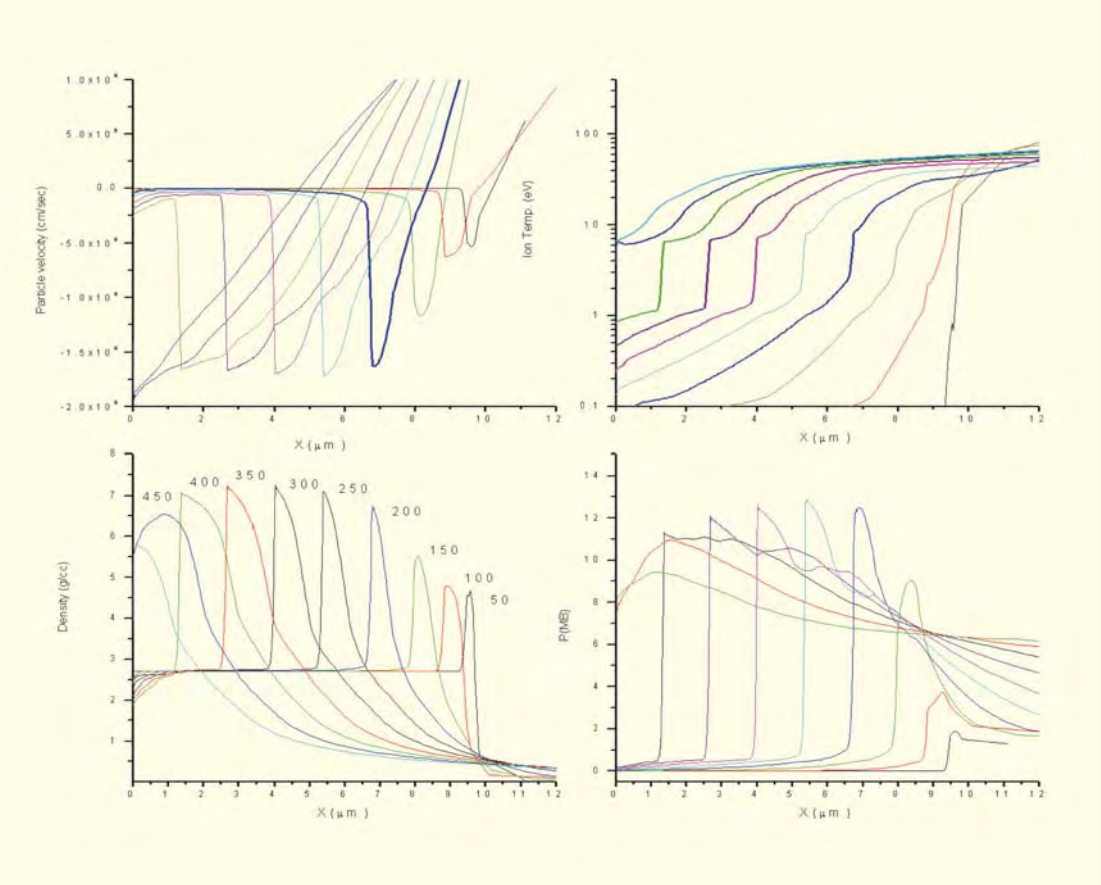
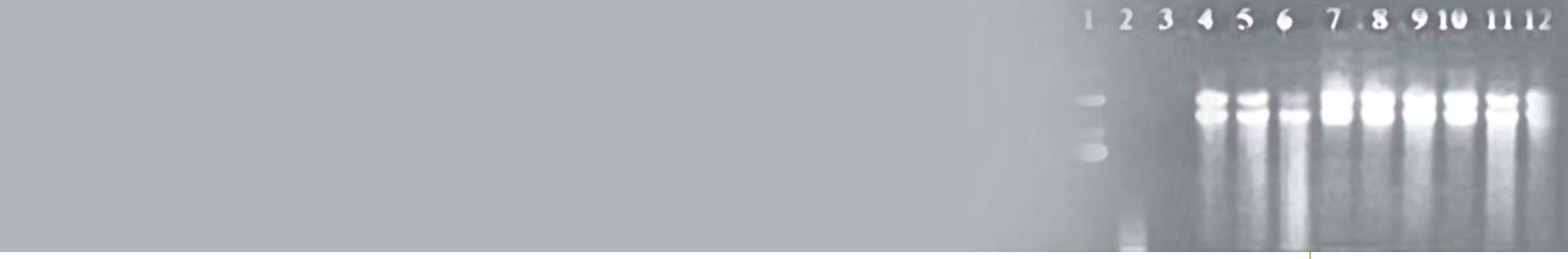


Fig.7: Space profiles of (a) particle velocity (b) ion temperature (c) density and (d) hydrodynamic pressure. Each curve denote in space profile at the marked time. These results are for laser power of 5 x 10^{14} W/cm^2 at pulse rise time of 375 ps.

Conclusion

We have successfully demonstrated that the new diagnostic technique, namely, the multi-frame optical shadowgraphy, with temporal resolution of 500 ps and spatial resolution of 12 μm can be used to accurately measure the free surface velocity (and therefore the particle velocity behind the shock wave) of a laser driven target. This diagnostics when used along with the optical streak camera can simultaneously measure the shock velocity and free surface velocity (particle velocity). The experimentally measured values of shock pressures in 10 μm Aluminum targets exceeded 25 Mbar when the 16 J/ 500 ps laser is focused to an intensity of more than 2.5 x10^{14} W/cm^2. The scaling of particle velocity with laser intensity has been determined and is observed to match with the values earlier reported by other authors and also with theoretical simulations. The scaling of shock velocity and shock pressure with laser intensity has been done. The shock Hugoniot data obtained experimentally is slightly lower than the standard Hugoniot curve for Aluminum. This is because of initial non-uniformity of the shock. Use of step targets can overcome this difference.



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RESEARCH ARTICLE

Challenges in core reactivity management and control optimization in physics design of Compact High Temperature Reactor

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Abstract

India is pursuing a comprehensive high temperature reactor program to fulfil its needs for several crucial applications of nuclear energy other than those for grid based electricity generation, such as - hydrogen production, unattended nuclear power packs etc. The Compact High Temperature Reactor (CHTR) is being developed as a technology demonstrator and a critical facility for this program. This article presents the salient features of the physics design of CHTR. Difficulties encountered in the physics modelling of the CHTR core are discussed. Some of the preliminary safety related studies carried out for the present core configuration of the reactor are also presented.

1. INTRODUCTION

Hydrogen as fuel can provide clean, reliable and sustainable energy for meeting the growing demand and to solve some of the negative effects of using fossil fuels, in which the carbon is released to the atmosphere. Bulk hydrogen is usually produced by the steam reforming of methane or natural gas but the process generates carbon dioxide (CO_2). Efficient and economical water splitting, thus, is the key technology component of a hydrogen economy. With continuously increasing demands, nuclear reactors will need to be utilized in future, to produce hydrogen. One of the most efficient methods to produce hydrogen from nuclear energy involves thermo-chemical cycles in which high-temperature heat (700 to 850°C) is used to convert water into hydrogen and oxygen. High temperature nuclear reactors are highly suited for supplying this process heat efficiently, in an eco-friendly manner, on a sustainable basis. In addition to process heat applications, high temperature reactors have higher efficiency for electricity generation as compared to conventional nuclear reactors.

Keeping this in mind, a program to design and develop a high temperature reactor system mainly for process heat and non-grid based electricity generation applications, has been initiated in India[1]. As a technology demonstrator and a critical facility for the high temperature reactor program, the 100 KWth Compact High Temperature Reactor (CHTR) is being designed on the basis of guidelines such as - use of thorium based fuel, passive core heat removal by natural circulation of liquid metal coolant, compact design to minimize weight of the reactor and longer core life[1,2]. CHTR is designed as a U^{233}-Th fuelled, lead-bismuth eutectic cooled and beryllium oxide moderated, vertical prismatic block type reactor.

2. PHYSICS DESIGN OF THE COMPACT HIGH TEMPERATURE REACTOR (CHTR)

A relatively high initial fissile content is required in the CHTR to generate 100kW$_{th}$ full power for 15 years of continuous operation, resulting in a large initial excess reactivity. Due to its compact core, space available for absorber rods for control and shutdown systems of CHTR is limited. As this large reactivity has to be controlled by a smaller number of control rods, the worth of the single control rod is high. In case of an inadvertent withdrawal of such a control rod, a larger positive reactivity will be added to the core leading to sharp rise in neutron flux/power. Therefore, the excess initial reactivity needs to be minimized. From reactor shutdown and safely point of view, the burn up reactivity swing, should be minimized which will result in lowering the required reactivity worth of shutdown systems.

A core management study was carried out to optimize the amount, location and type of burnable neutron absorbers, so as to control the initial excess reactivity. Mixing of small amount of gadolinium in central portion of fuel assembly was found to provide sufficient reduction in initial excess reactivity. Although a faster depletion rate of gadolinium leads to negligible burnup penalty (reduction in full power life due to residual burnable poison nuclides), it makes fuel temperature coefficient (FTC) less negative, which is less advantageous (FTC is the change in reactivity of the reactor per degree change in the fuel temperature and is a measure of the stability, more negative value of FTC means stronger negative feedback of reactivity with rise in the fuel temperature). The value of the FTC, thus, limits the amount of burnable absorber in the core. The fine balance of putting sufficient burnable absorber within the limits of permissible FTC, was achieved with the help of special absorber rods now named as Burnup Compensation Rods (BCRs), which were introduced in the fixed BeO reflectors (Fig.1).

2.1 CHTR core description

At the current stage of conceptual design of CHTR, its core (Fig.1) consists of 19 hexagonal BeO moderator blocks (Fig.2) containing centrally located graphite tubes. In the central portion of graphite tube, liquid metal (Pb-Bi eutectic) coolant flows upward between the top and bottom plenum and returning through down-comer tubes located outside the core. The outlet/inlet temperature of coolant is 1000/900°C. Each graphite tube carries within it the nuclear fuel which is placed inside 12 equispaced longitudinal bores of 10 mm diameter.

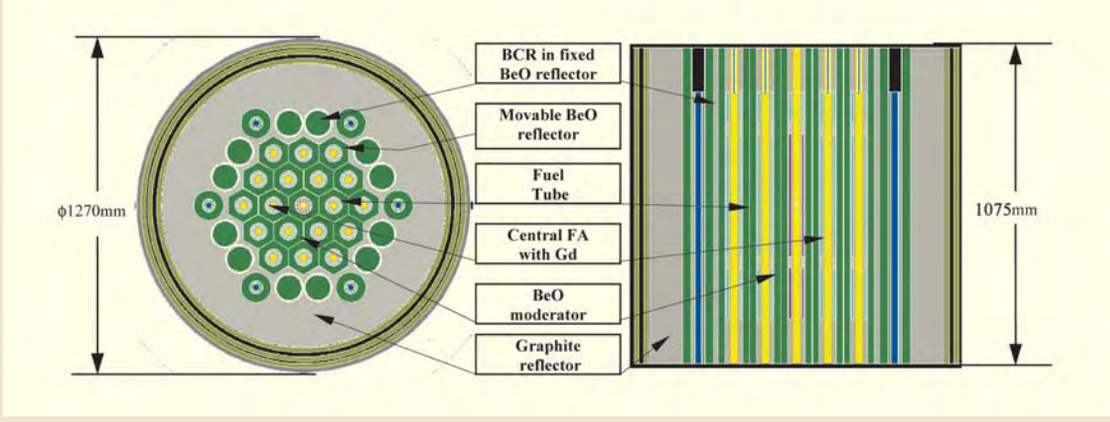

Fig. 1a: Cross sectional view of the CHTR core Fig. 1b: Axial view of the CHTR core

Fig. 1: View of the 100 kWth CHTR core

These fuel tubes have a length of 775 mm, of which, 700 mm length belongs to the fuel and remaining 75 mm is used for joining the fuel tube segments. These bores are filled with fuel compacts of approximately 35 mm length made from TRISO coated particles embedded in graphite matrix. The average fuel temperature is 1000°C. The TRISO particles (Fig.3) are in the form of micro-spheres of (U +Th) carbide kernel (250 μm radius) coated with three layers: soft pyrolitic carbon (90 μm thickness), SiC (30 μm thickness) and hard carbon layer (inner/ outer 30/50 μm thickness). Gadolinium as burnable poison is added in the kernel of the TRISO particles in the lower two fuel tube segments of the central fuel assembly[3,4]. To control the initial high excess reactivity, all Burnup Compensation Rods (BCR) are kept completely inside the core during initial life cycle.

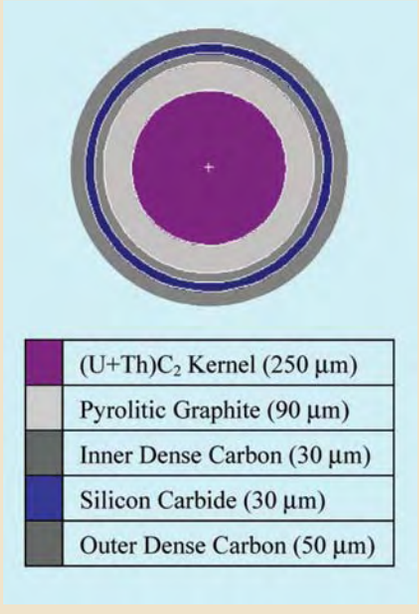

Fig. 3: TRISO fuel

2.2 Physics analysis methodology

The physics design simulation of the CHTR has been carried out with 2-stage calculations. In the first stage, for each type of fuel assembly containing fuel pins, structural material, clad, coolant and moderator, a very fine detailed neutron transport calculations were performed. In this stage, the energy groups of the neutron spectrum were also condensed. In the second stage, the reactor core, constructed with these homogenized cell types, was simulated. The neutron diffusion equation is solved for such a core and flux, criticality etc. are computed. The 22-energy-group cell-homogenized cross-sections were obtained with collision probability code ITRAN[5]. The code uses first flight Collision Probability/Interface Current methods. The calculations have been done using the 172-group ENDFB-VI library[6]. These 22-group cell homogenized cross-sections were used in triangular/hexagonal mesh diffusion theory code TriHTR[7]. Both the above codes were also used for burnup calculations. Preliminary transient analysis had been carried out with code called MRIF[8] which is based on point reactor model with thermal-hydraulics feedbacks.

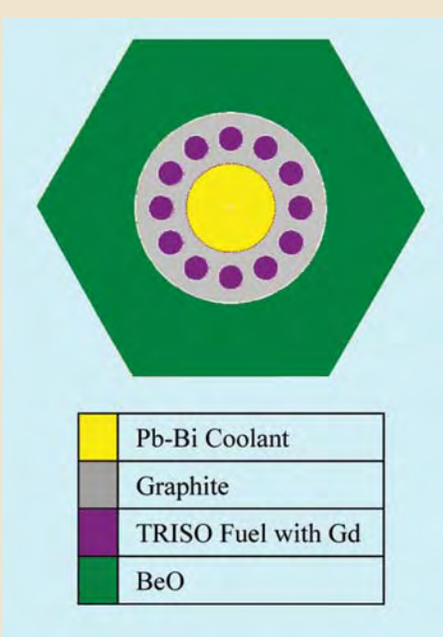

Fig. 2: Fuel Assembly

2.3 Core reactivity management schemes

Physics design of a reactor core with a very high operating temperature is a challenging task. Use of non-standard materials and non-availability of nuclear data at high temperatures pose several challenges. Moreover, the compactness of the core makes it very difficult to design the control and instrumentation systems. The current design of the CHTR core contains 2.9 kg U (93% U^{233} +other isotopes of U) in 8 kg of (U+Th) as nuclear fuel. A core life of about 15 full power years could be achieved with the above configuration. Table-1 shows the major design parameters of the core. It can be seen that the initial core reactivity is quite large even in the presence of BCRs (Fig.4). To control it, a small quantity (29.75 gm) of burnable poison gadolinium has been added to the fuel in the central fuel assembly. In Fig.4, the lower most curve (in blue colour) shows the variation of k_{eff} with burnup for the configuration with gadolinium and with all BCRs inside the core. Subsequently BCRs will be removed to compensate for reactivity loss with fuel burnup. The addition of gadolinium also resulted in better flux flattening in the core and also a lower radial/ axial power peaking (Fig.5).

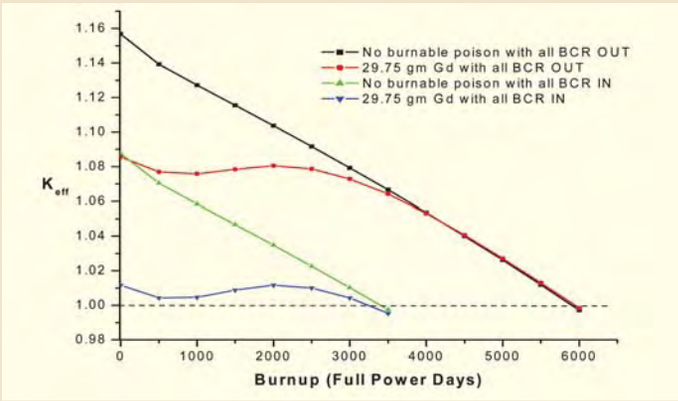

Fig. 4: k_{eff} with burnup for configurations with and without the gadolinium as burnable absorber and when burnup compensations rods are inside and outside the core.

2.4 Control and Shutdown Systems

The long term control of core reactivity is carried out by the combinations of burnable poison gadolinium and manual movement of BCRs in CHTR.

Table 1- Major design parameters of CHTR core

Thermal Power	100 kW_{th}
Core refuelling interval	15 effective full power years
Fuel	(U^{233} Th) C_2 based TRISO coated particles
Initial fissile inventory	2.71 kg
Burnable poison	29.75 gm Gd in the fuel of central FA
Coolant	Pb-Bi eutectic
Inlet/outlet coolant temperature	900 °C/1000 °C
Number of fuel tube	19
Hexagonal pitch	13.5 cm
Moderator	BeO
Reflector	BeO and graphite
Active core height	77.5 cm
Thickness of top/bottom reflector	15 cm
Core diameter	1.27 m

RESEARCH ARTICLE

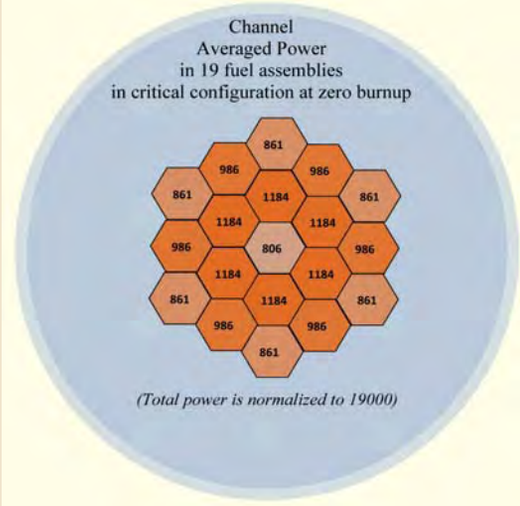

Fig. 5: Radial power distribution in CHTR at zero burnup.

After 3000 effective full power days of initial core life, BCRs will be taken partially out of the core in several steps and clamped at their axial position for few hundred effective full power days of reactor operation. To control/adjust small excess reactivity and to shut down the reactor if required, CHTR is designed to have the following control and shut down systems to provide sufficient negative reactivity throughout the core life (Table 2).

Fine adjustment of reactivity for power regulation and control of reactor is done by the control rods. The functions of control rods include automatic control of power and power distribution; reactor power setback; and supervised withdrawal of burnup compensation rods (BCRs). Six tantalum/tungsten rods in the inner six coolant channels act as primary shutdown system. The 12 axially movable BeO reflector blocks act as Secondary Shut-down System by allowing high leakage of neutrons when withdrawn out of the core. Both shutdown systems are independent of each other. The worths of shutdown systems, given in Table-3, are in most reactive core operating condition at '0' burnup and when all burnup compensation rods are inside the core.

Table 3: Worth of Primary & Secondary shutdown systems and burnup compensation rods in Hot and Cold operating condition at initial core life cycle

Reactor State	k_{eff}	
	Hot condition (1000^0C)	Cold condition (27^0C)
All control rods OUT *(when all BCRs IN, All PSRs OUT and all movable BeO blocks IN)*	1.0117	1.0536
Primary shutdown system activated *(with postulated one rod failure condition)*	0.8756	0.9173
Secondary shutdown system activated *(with postulated one block failure condition)*	0.8860	0.9267
6 burnup compensation rods OUT	1.0822	1.1285

Table 2: Control and Shutdown systems for CHTR

Control	12 control rods made from a mix of Tantalum and Tungsten (neutron absorber of high density and high melting point) in the coolant channels of the twelve outer fuel assemblies.
Primary Shutdown System	6 shutoff rods like control rod in inner six coolant channels (except central coolant channel)
Secondary Shutdown System	12 axially movable Cylindrical BeO blocks going out of the core.

The maximum worth of a control rod in critical condition has to be smaller than the delayed neutron fraction, β_{eff}, to prevent any postulated accidental situation of super criticality. The addition of Burnup Compensation Rods helped in reducing the maximum worth of a control rod in critical configuration as well as reduction in gadolinium content which lead to improved FTC. In the present core configuration it was found that maximum worth of a single control rod is 1.04 mk and FTC is $-5.65 \times 10^{-6}/{}^{0}C$, in hot operating critical condition at zero burnup.

3. ANALYSIS OF INADVERTENT CONTROL ROD WITHDRAWAL ACCIDENT

The effect of smaller single control rod worth and negative FTC can be gauged by analyzing a postulated accidental scenario in which an inadvertent withdrawal of a control rod in critical state is considered. A preliminary safety analysis based on point-reactor kinetics model with temperature feedback was carried out. The withdrawal introduces a positive reactivity of 1.04 mk in 5 second. This results in power rise and subsequent rise in fuel temperatures. A negative reactivity feedback is introduced by the rise in fuel temperature due to negative FTC and the power stabilizes at about 2.8 times the initial power (Figs. 6a, 6b).

4. CONCLUSIONS AND DISCUSSION

Development of the Compact High Temperature Reactor (CHTR) is an important step in the future technology road map for the development of Indian High Temperature Reactors. Detailed physics studies have been carried out to arrive at a feasible configuration for the CHTR. In order to achieve 15 effective full power years of CHTR core life, the uranium (93% U^{233}) requirement is found to be 2.9 kg, mixed with 5.1 kg of Th^{232} in the fuel. A higher fissile content for larger core life resulted in a high initial core reactivity which was controlled by devising a combination of burnable absorber (gadolinium) and the Burnup Compensation Rods (BCRs). This also resulted in a better flux profile and power distribution in core. A preliminary kinetics analysis has shown that in case of fast reactivity addition, the power rises sharply and then stabilizes at less than 3 times the initial power. More importantly, the fuel and coolant temperatures stabilize within the permissible limits. The worths of primary and secondary shutdown systems are

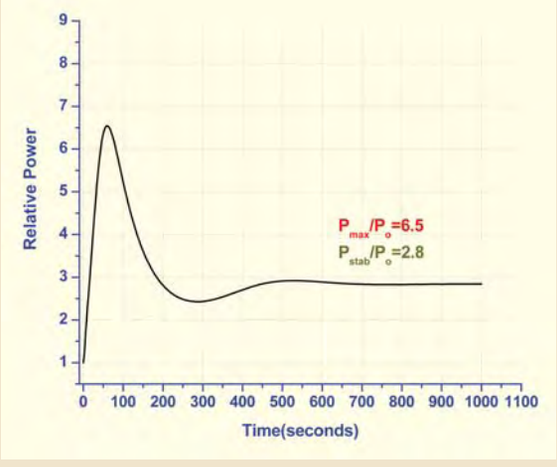

Fig. 6a: Variation of power when 1.04 mk added in 5 seconds.

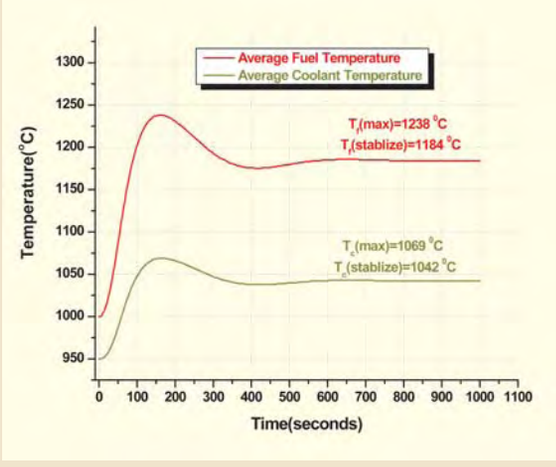

Fig. 6b: Variation of temperatures of fuel and coolant in fast transient.

found to be adequate to shutdown the reactor independently, even in case of one rod failure, in most reactive situations.

The design of CHTR is indigenous and various research activities are currently underway to meet the challenge posed by difficulties such as paucity of data at very high temperatures and use of non-standard materials such as BeO, Lead-Bismuth, Tantalum etc., There are several challenges such as simulation of microscopic TRISO particles, designing two independent shutdown as well as control system in a small core having high neutron leakage, obtaining more negative fuel temperature coefficient etc., which are being tackled. The lessons learned in the complex modelling of the CHTR will act as a stepping stone for the future high temperature reactors being designed in India.

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RESEARCH ARTICLE

Shelf life extension of Litchi (*Litchi chinensis*) and overcoming quarantine barriers to international trade using radiation technology

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Abstract

Litchi (*Litchi chinensis*) has a very short shelf life of 2-3 days at ambient temperature limiting its marketability. Gamma radiation processing in combination with low temperature storage was explored as a method to achieve shelf life extension and fulfil quarantine requirement for export. During storage, physical, biochemical, microbiological, organoleptic, antioxidant and radioprotective properties of two major commercially grown Indian cultivars of litchi, 'Shahi' and 'China', were analyzed. Radiation treatment reduced microbial load in a dose dependent manner. Radiation (0.5 kGy) treated and low temperature stored fruits retained the "good" organoleptic rating till 28 days of storage while maintaining other quality attributes.

Introduction

Litchi (*Litchi chinensis* Sonn) is a non-climacteric fruit of South East Asian origin [1, 2]. India is the second largest producer of litchi after China, with a cultivated area of 62,000 Ha and a total annual production of 0.5 million tons. India accounts for about one-fifth of the global production. In India, Bihar is the leading state in litchi production, which accounts for three-fourth of the total production of the country.

Shelf life of litchi at ambient temperature (26 ± 2°C) is less than 72 h. Postharvest losses are estimated to be 20–30% of the harvested fruit and could reach as high as 50% [3]. Besides shelf life extension, insect disinfestation of fresh commodities such as tropical fruits have become increasingly important for overcoming quarantine barriers with the expanding export market. Owing to the high radiotolerance of the *Angoumois* grain moth, *Sitotroga cerealella*, the most radiotolerant insect studied so far, a generic dose for class Insecta could be considered in the range of 500-600 Gy [4]. India has been exporting mangoes to the US applying a generic minimum dose of 400 Gy [5].

Indian contribution to global litchi export is insignificant due to poor shelf life and quarantine barriers. In this study, two major commercial Indian varieties of litchi, 'Shahi' and 'China' were used. 'Shahi' is a popular, early variety with round shape, deep red coloured and aromatic pulp. 'China' is late maturing, dwarf plant variety having large, conical, deep red coloured, pulpy fruit. Fruits in bulk (four batches each of ten thousand pieces) were procured from the farms near Muzaffarpur, Bihar, and airlifted to Mumbai. Damaged fruits were

removed manually and the healthy fruits (15 pieces) were packed in low density polythene packets and subjected to gamma radiation in a cobalt-60 Food Package Irradiator (AECL, Canada; dose rate 2.4 kGy/h; activity 1.97 PetaBq; dose uniformity ratio 1.25) at Food Technology Division, Bhabha Atomic Research Centre. Gamma radiation treatment was performed at different doses (0.15 to 2 kGy) and samples were stored at three temperatures [ambient (26 ± 2°C), 10 and 4°C].

Sensory analysis and physiological examinations indicated that fruits stored at ambient temperature could not last more than a week irrespective of the radiation dose used. Visible fungal growth and rotting of the fruit were observed in these samples. Similarly, samples stored at 10°C spoiled within two weeks. Nonirradiated control samples stored at 4°C did not last more than 15 days. Radiation treated samples stored at 4°C were observed to be in good condition during this period and hence, further study was carried out with these samples only. Since higher doses were found to induce early pericarp browning further detailed studies were performed with samples treated at 0.5 kGy keeping quarantine requirement in consideration.

Results and Discussion

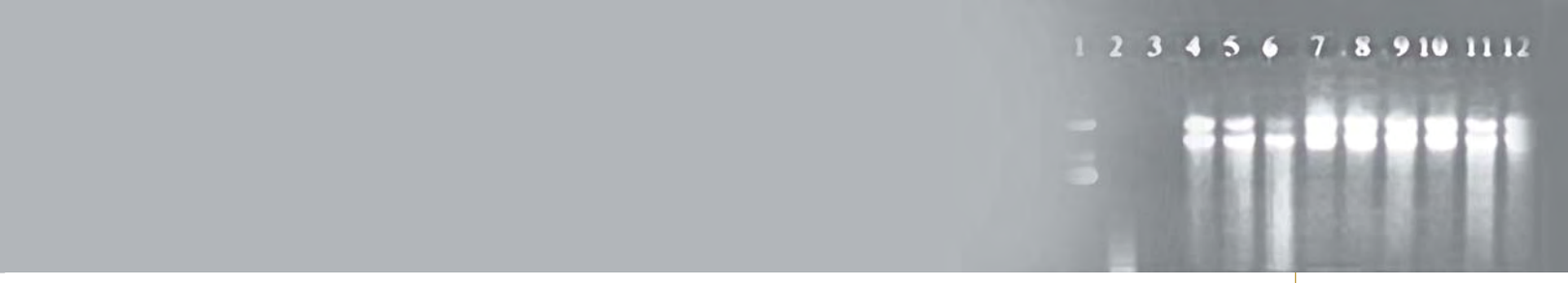
During storage physical, biochemical, microbiological, organoleptic, antioxidant and radioprotective properties were evaluated to standardize the optimal process parameters for shelf life extension of litchi.

1. *Physical properties*

The average weight of a single ripened 'Shahi', and 'China' fruit was around 21, and 26 g, respectively. Pulp contributed around 64% of the total fruit weight, whereas, pericarp and seed, contributed around 18% each. Juice contributed ~82 ± 2% of the pulp weight. Specific gravity of the juice was found to be 1.05 ± 0.01. Other physical properties such as moisture content, pH, titratable acidity, texture and total soluble solids (TSS) were also determined for non-irradiated as well as radiation processed litchi fruits and findings are displayed in Table 1. As pericarp browning is one of the major factors which limit postharvest marketability of litchi, analysis of colorimetric parameters of litchi using LABCH system was also performed [6]. During storage at 4°C a marginal decrease in C* and h values was noticed indicating increase in the dullness

Table 1. Physical attributes of fresh litchi fruit.

Radiation dose (kGy)	Moisture (%)	pH	Titratable acidity (% citric acid)	Texture (g) (with pericarp)	Texture (g) (without pericarp)	Total Soluble Solids (°Bx)
			'Shahi'			
0	75 ± 4	4.3 ± 0.4	0.31 ± 0.01	103 ± 29	44 ± 27	15 ± 2
0.5	77 ± 3	4.1 ± 0.1	0.30 ± 0.02	133 ± 6	30 ± 11	17 ± 1
			'China'			
0	76 ± 5	4.0 ± 0.4	0.57 ± 0.01	177 ± 30	27 ± 5	15 ± 1
0.5	74 ± 1	3.8 ± 0.2	0.42 ± 0.05	140 ± 12	49 ± 18	15 ± 2



of colour which probably could be due to an increase in the polyphenol oxidase activity resulting in browning [7]. However, browning was less in 0.5 kGy irradiated samples. No significant variation in most of the physical attributes was observed due to radiation treatment or storage.

2. Biochemical properties

Litchi was also characterized for biochemical attributes such as total and reducing sugar, vitamin C, flavonoid, and phenol content as described earlier [8, 9] and results are displayed in Table 2. Sugar content in litchi fruits ranged between 10-13 g%. In var. 'Shahi' total vitamin C content was found to be around 17 mg%, whereas in 'China' it was 25 mg%. Flavonoid content in 'Shahi' and 'China' was around 31 μg catechin equivalents (CE)/g of fruit weight. The phenolic content in 'Shahi' was found to be 312 μg gallic acid equivalents (GAE)/g, whereas, in 'China' it was 318 μg GAE/g. No significant variation in most of the biochemical attributes was observed due to radiation treatment or storage.

3. Microbiological analysis

Surface bacterial load and yeast-mold count in litchi were found to be in the range of ~4, and ~3 log cfu/g, respectively (Table 3). Internal bacterial load was almost one log cycle/g less (~3 log cfu/g) at the beginning and increased to 4 log cfu/g during storage at 4°C on day 10. Interestingly, in 'China' surface and internal bacterial load was comparatively

Table 2. Biochemical and antioxidant properties of juice from fresh litchi fruit.

Radiation dose (kGy)	Sugar (g%)		Vitamin C (mg%)	Flavonoid (µg CE/g)	Phenol (µg GAE/g)	DPPH radical scavenging activity (%)	FRAP assay (A_{700nm})
	Total	Reducing					
				'Shahi'			
0	9.8 ± 2	9.7 ± 0.1	17 ± 0.3	31 ± 3	312 ± 7	89 ± 2	0.222 ± 0.01
0.5	11.5 ± 1	10.8 ± 0.4	12 ± 0.5	34 ± 3	312 ± 7	92 ± 5	0.274 ± 0.03
				'China'			
0	13.3 ± 1	12.9 ± 1	25 ± 0.4	31 ± 6	318 ± 7	85 ± 5	0.397 ± 0.06
0.5	14.6 ±1	13.1 ± 1	28 ± 0.3	26 ± 2	331 ±12	85 ± 5	0.321 ± 0.06

Table 3. Microbiological load (log cfu/g) in radiation treated and nontreated litchi stored at 4°C.

			Total bacterial count (TBC)			
			Surface			
0	4.3 ± 0.3	4.9 ± 0.2	Unusable	3.8 ± 0.2	2.9 ± 0.2	Unusable
0.5	3.0 ± 0.3	3.8 ± 0.1	4.1 ± 0.6	2.4 ± 0.2	2.5 ± 0.2	2.7 ± 0.7
			Internal			
0	3.1 ± 0.1	4.1 ± 0.4	Unusable	2.5 ± 0.2	1.9 ± 0.2	2.0 ± 0.4
0.5	2.4 ± 0.4	3.4 ± 0.01	3.1 ± 0.1	1.0 ± 0.01	0.8 ± 0.02	0.8 ± 0.7
			Yeast-Mold count (YMC)			
			Surface			
0	2.6 ± 0.6	3.9 ± 0.5	Unusable	2.3 ± 0.2	1.9 ± 0.2	Unusable
0.5	1.8 ± 0.2	3.0 ± 0.8	2.8 ± 0.2	1.3 ± 0.1	1.2 ± 0.1	1.2 ± 0.3
			Internal			
0	2.0 ± 0.04	3.3 ± 0.8	Unusable	2.4 ± 0.04	2.0 ± 0.2	Unusable
0.5	1.4 ± 0.3	1.8 ± 0.4	1.9 ± 0.5	0.7 ± 0.7	0.8 ± 0.04	0.1 ± 0.1

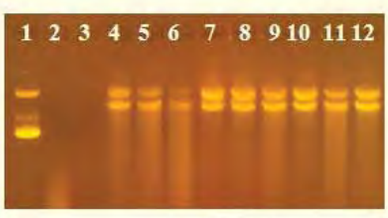
less than 'Shahi' and did not increase during storage at 4°C. Radiation treatment at 0.5 kGy reduced the surface microbial load significantly. Prakash *et al.* [10] have also reported that irradiation at 0.5 kGy can reduce the microbial counts of diced tomatoes substantially to improve the shelf life without any adverse effect on the sensory qualities.

4. Organoleptic analysis

Organoleptic (sensory) attributes reflect the efficacy of any food preservation technique. Sensory attributes of litchi such as appearance, colour, odour, flavour, after taste, texture, juiciness and overall acceptability were analyzed on a 7-point hedonic scale (7-excellent, 6-very good, 5-good, 4-satisfactory, 3-fair, 2-poor, 1-very poor). Sensory analysis was performed till the samples were visibly acceptable. On day 1, nonirradiated 'Shahi' fruit was rated in the range of 4.7 to 5.6 (good - very good) and on day 15, in the range of 3.8 to 5.2 (satisfactory - good). On day 28, irradiated fruit (0.5 kGy) was rated in the range of 4.6 to 5.5 (good - very good). Irradiated 'China' fruit was rated in the range of 4.5 to 5.5 (good - very good) on day 28. Thus these findings indicated that the radiation treatment of litchi did not affect the sensory attributes.

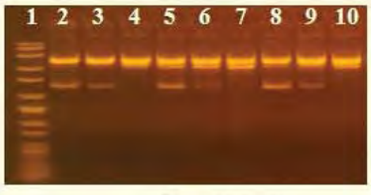
5. Antioxidant activities

Antioxidant properties were analyzed by measuring DPPH radical scavenging activity and ferric reducing antioxidant power (FRAP) assay as described earlier [9] and also compared with butylated hydroxytoluene (BHT) (Table 2). In fresh litchi fruit juice (dilution, 1:20), the DPPH radical scavenging activity was found to be 85-89%, which was equivalent to ~2.5 mM of BHT. The reducing power of 'Shahi' was 0.22, and 'China' was 0.39 which was equivalent to ~1, and 2 mM of BHT, respectively. Radiation treatment did not affect this property.



Lane 1: Nonirradiated DNA; **Lane 2-3**: 1 and 2 kGy gamma irradiated DNA, respectively; **Lanes 4-6**: Protection of DNA by juice from nonirradiated fresh fruits upon gamma radiation treatment **[4**: 1 kGy; **5**: 2 kGy; **6**: 5 kGy**]**; **Lanes 7:9** Protection of DNA by juice from fresh fruits treated with 0.5 kGy radiation [**7**: 1 kGy; **8**: 2 kGy; **9**: 5 kGy**]**; **Lanes 10-12** protection of DNA by juice from 0.5 kGy radiation treated fruits stored for 28 days [**10**: 1 kGy; **11**: 2 kGy; **12**: 5 kGy**]**.

A. 'Shahi'



Lane 1: DNA molecular weight marker; **Lanes 2-4** Protection of DNA by juice from nonirradiated fresh fruits **[2**: 1 kGy; **3**: 2 kGy; **4**: 5 kGy**]**; **Lanes 5-7** protection of DNA by juice from fresh fruits treated with 0.5 kGy radiation [**5**: 1 kGy; **6**: 2 kGy; **7**: 5 kGy**]**; **Lanes 8-10** Protection of DNA by juice from 0.5 kGy treated fruits stored for 28 days [**8**: 1 kGy; **9**: 2 kGy; **10**: 5 kGy**]**.

B. 'China'

Fig. 1: Agarose gel electrophoresis profile displaying radioprotection of pBR322 plasmid DNA by litchi juice.

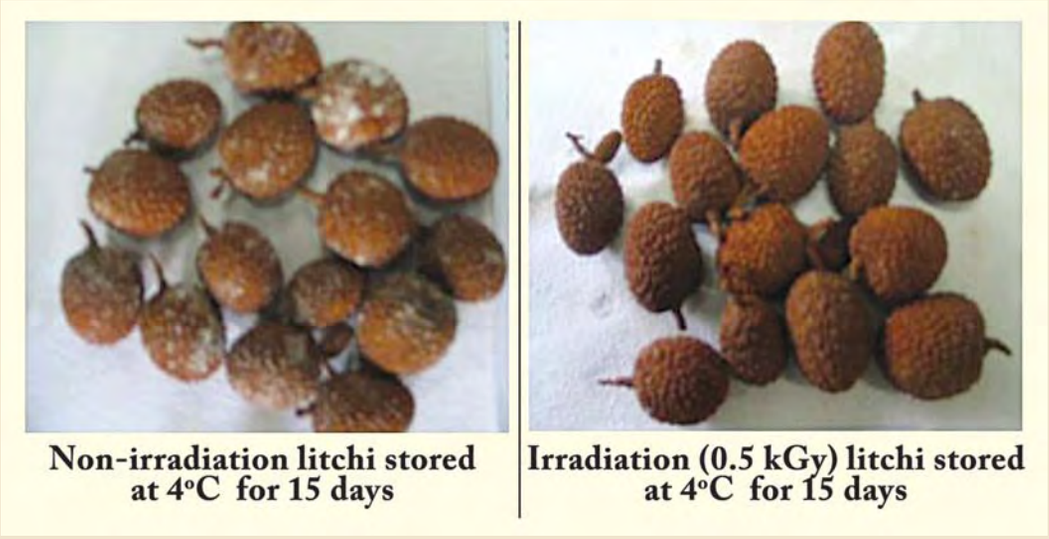


Fig. 2: Radiation processing in combination with low temperature storage increased the shelf life of litchi upto four weeks.

6. Radioprotective property

Radiation protection analysis was performed as described earlier [9]. The decimal reduction dose (D_{10}) for *E coli* in saline (0.85 %) was found to be 0.1 kGy and in the presence of litchi juice, the D_{10} increased to 0.27 kGy. When exposed to a 1 kGy dose of gamma radiation there was almost complete degradation of pBR322 plasmid DNA (Fig. 1A, lane 2), whereas, in presence of litchi juice, degradation was significantly inhibited indicating radioprotective ability of litchi juice (Fig. 1A and 1B).

Conclusion

Radiation treatment of litchi was aimed to achieve shelf life extension and quarantine treatment. The shelf life of the radiation (0.5 kGy) treated fruit was extended up to 28 days when stored at 4°C without affecting the overall quality attributes. On the other hand, nonirradiated fruit stored under similar storage condition spoiled within two weeks. Besides, litchi was also found to be a rich source of antioxidants, capable of protecting the cell and DNA from radiation induced damage. As the study was conducted on a large scale, the findings could provide basis for radiation processing of litchi to increase its shelf life for export and market access in developed countries.

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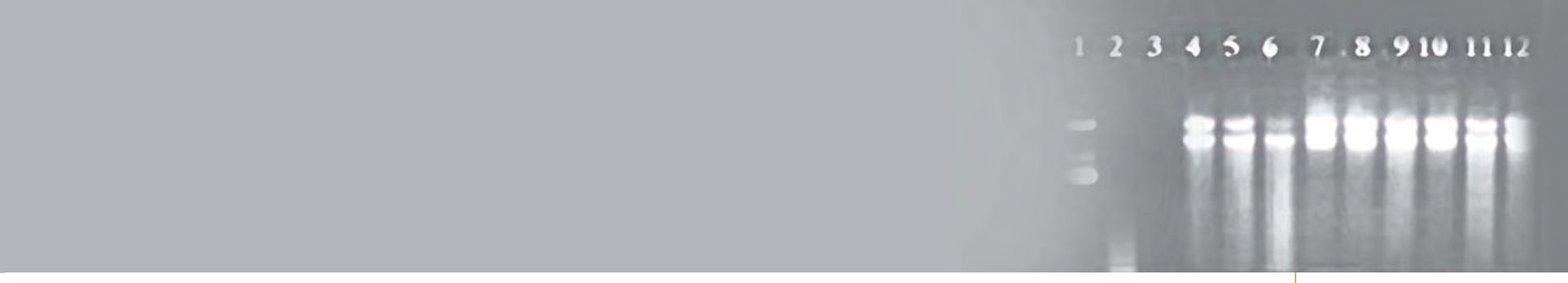

Development of a Novel Spent Fuel Chopper for PHWR fuel

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ABSTRACT

Decladding of spent PHWR fuel is achieved by mechanically chopping the spent fuel employing special purpose shearing machine. Spent Fuel Chopper based on progressive feeding, clamping and chopping has been in operation in the present operating reprocessing plants located in Tarapur and Kalpakkam. Valuable experience has been gained in operation and maintenance aspects of this equipment over the years. In order to increase the productivity and reduce the maintenance down time, a new spent fuel chopper based on gang chopping concept has been developed incorporating the good features of the existing model. The first spent fuel chopper designed and manufactured as per new concept has undergone cold commissioning in ROP Tarapur and hot commissioning is in progress.

INTRODUCTION

India has adopted closed fuel cycle strategy in its nuclear program for efficient management of available resources to meet the long term energy requirement of the nation. Closing the fuel cycle by reprocessing the spent fuel enables recovery of material that can be recycled. The technology for reprocessing has been developed and established indigenously on an industrial scale. Presently reprocessing facilities are in operation in Trombay, Tarapur and Kalpakkam.

Spent fuel dissolution is the initial step of reprocessing during which, the core of spent fuel is exposed to leach acid, which calls for decladding of spent fuel. The Aluminum clad fuel used in the research reactor is decladded using chemical process. The PHWR fuel with zircaloy cladding, however, is subjected to mechanical decladding. Development of high throughput equipment for our reprocessing program has been the priority for last few years and development of a rugged and reliable Spent Fuel Chopper has been the first step in this regard.

SPENT FUEL CHOPPER (SFC)

Spent Fuel Chopper is used for shearing the fuel bundle or pins into small pieces thereby exposing the fuel for chemical dissolution making it amenable for further extraction process. The SFC used in present operating plants is based on a concept of progressive feeding, clamping and cutting of fuel with a single shear blade. The spent fuel chopper based on this concept was first installed in PREFRE, Tarapur. This chopper was imported from France. A similar SFC with minor modifications was later indigenously manufactured and installed in KARP, Kalpakkam. A SFC essentially consists of:

- Fuel Feed System,
- Fuel Shearing System,
- Fuel Distribution,
- Hydraulic System and
- Control system

The spent fuel which is loaded in to the fuel magazine is pushed into shear unit using fuel pusher drive mechanism operated from outside the cell. The chain magazine which houses the chain for the fuel pusher is connected to the fuel magazine with its actuating devices from outside the cell. In shear unit the fuel is pre-clamped by auxiliary gag and then rigidly clamped by main gag prior to the shearing the fuel in set lengths. The chopped fuel is fed into the distributor with the distributor door in open condition and then the chopped fuel is diverted to dissolver limb 1 or 2 using the clapper door. A typical layout of the spent fuel chopper housed in a dissolver cell is shown in Fig. 1.

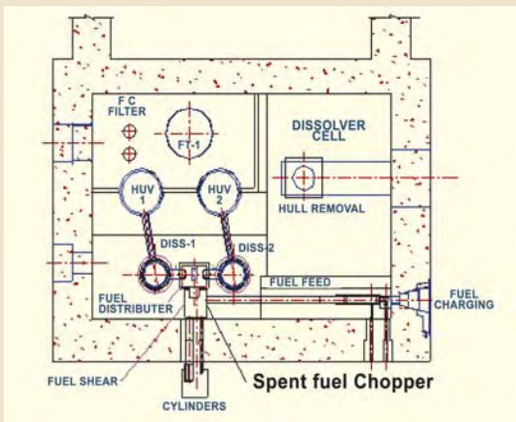


Fig. 1: Typical layout of spent fuel chopper in dissolver cell

Valuable experience has been gained through operation and maintenance of these SFC's over the years. These experiences helped in conceiving a novel SFC based on a new concept, while retaining the proven aspects of the existing design for higher throughput and lower down time for maintenance.

GANG CHOPPING - A NEW CONCEPT

Gang cutting is an operation involving multiple cutting blades in order to save time and labour. It was seen that the shorter length of PHWR fuel (compared to LWR/BWR fuel) can be utilized to our advantage by adapting the concept of gang chopping. Mock trials were conducted with simulated fuel (Zircaloy cladded fuel filled with heavy density concrete) to assess the tonnage of the hydraulic system and quality of cut. These were found to be within practical and acceptable ranges. As the gang chopping involved cutting of a complete fuel bundle in single stroke, the requirement of gagging (clamping) system could be eliminated, thus simplifying the shear internals. Similarly a single actuator in place of multiple actuators (for gagging and cutting) also meant easier and reduced maintenance requirements.

SPENT FUEL CHOPPER BASED ON GANG CHOPPING

Based on the studies and the experience gathered with the existing SFC, a new spent fuel chopper has been developed to suit the existing site layout of ROP, Tarapur and P3A Kalpakkam. It has been designed to receive and handle a batch of 10 (220 MW) PHWR fuel bundles. A brief description of the features of SFC is given below.

The structure and the layout of the new SFC are kept similar to SFC already in use as the plant layout had been frozen already. The major changes are as follows:

a) Fuel Shear Unit: A single module of fixed and moving blades assembled on carrier plates in a guided fashion which on actuation by the hydraulic ram, shears the complete fuel bundle into multiple segments of desired length (Fig. 2).

b) Hydraulic actuator for fuel feed: Fuel pushing is actuated by hydraulic motor accompanied with pressure sensor and rotary encoder for precise control of torque and position (Fig. 3).

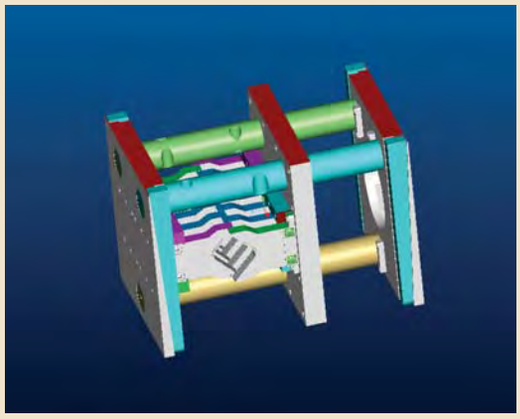


Fig. 2: Shear module with multiple blades

Fig. 3: Fuel feed system with hydraulic drive

c) Fuel positioning unit: Also known as Component Transfer Assembly, it is a new addition to the existing design for receiving the complete fuel when pushed by the fuel feed system and positions it between the cutting tools (Fig. 4)

d) The hydraulic ram design: A single hydraulic cylinder assembly with moving cylinder and stationary piston arrangement for transmitting the force to moving tool assembly via a pusher rod. (Fig. 5)

e) Controls with safety features: Introduction of PLC based controls with safety interlock based on the feedback from the field sensors like reed switches and limit switches.

f) Provision for remote viewing of SFC : Introduction of transparent windows on the shear zone , fuel feed and distribution system for facilitating the viewing through CCTV camera for continuous monitoring of the functioning of components in order to have visual feed back.

Fig. 4: Component Transfer Assembly

Fig. 5: Hydraulic Ram

All the components within the hot cell like the shear module components transfer system, pneumatic cylinders for distributor and distributor doors etc have been designed for remote handing employing equipment such as in-cell crane, master slave manipulator, power manipulator etc. The hydraulic actuators and power packs, PLC and control panel are located in operating area freely accessible for maintenance. All the major components employed for the new SFC has been sourced indigenously.

MANUFACTURING, TESTING AND INSTALLATION

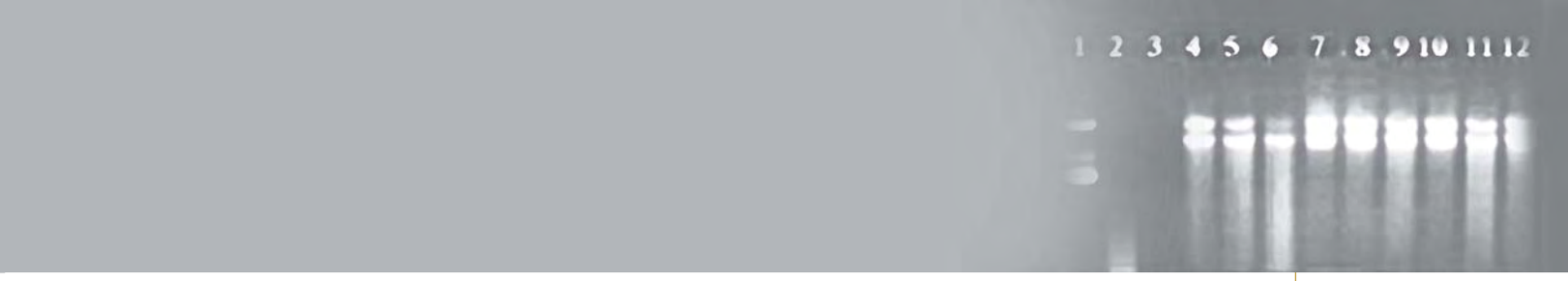
Based on the in house design, a new SFC with a capacity of 200 Te was manufactured by M/s HMT Ltd under an MoU with BARC. The manufacturing activity was completed as per an elaborate quality assurance plan. Extensive testing of individual subassemblies and complete assembly with and without loads were carried out (Fig. 6). Simulated fuel using cold worked SS 304 tubes as clad material filled with Alumina cement/steatite pellets were used for carrying out load trials. Verification of the control logics for simulated accidental conditions considering the safety aspects were also carried out. Subsequent to the final acceptance of SFC, it was installed and commissioned at ROP Tarapur. Remote maintenance trials of individual subassemblies were also carried out as a part of commissioning trials (Fig. 7). The SFC has undergone cold commisioning with non-reactor grade, PHWR fuel bundle and is presently under hot commisioning.

Fig. 6: SFC at HMT during trials

Fig. 7: Remote handling trial of shear module of SFC at ROP, Tarapur

SUMMARY

Indigenous development of the spent fuel chopper based on this new gang chopping concept should help in planning new reprocessing plants for higher through put. The modular design of individual sub system will enable easy maintenance and reduced down time. The newly developed SFC will significantly improve the capacity of head end process of reprocessing and the availability of machine for longer duration without failure.



U-Ti alloy as a promising storage material for hydrogen isotopes

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Abstract

Conventionally, uranium metal is used for the storage of heavier isotopes of hydrogen (D and T). However, it has several disadvantages with respect to handling due to the formation of very fine powder which leads to high pyrophorocity. It has also very low retention power for ^{3}He at ambient temperature. Uranium alloys are better choice with respect to above properties. This paper summarizes some aspects of storage behavior of hydrogen isotopes in uranium-titanium alloy.

Introduction

Storage of hydrogen isotopes (H, D and T) in the solid state is the safest and most advantageous method over other conventional methods like gaseous storage in high pressure gas cylinders and liquid storage in cryogenic tanks. Hydrogen and its isotopes can be stored in the solid state by combining it with a solid state material through physisorption, chemisorption or by chemical reactions. At elevated temperatures, hydrogen reacts with many transition metals, f-block elements and their alloys to form hydrides. The nature of the chemical bond determines the thermodynamic stability of the hydride, the hydrogen stoichiometry of the material, and the mechanisms for hydrogen absorption and release. For the metal hydride to be used as a storage medium, it should satisfy certain requirements such as high hydrogen storage capacity, facile reversibility of hydride formation and decomposition reactions, compatible absorption-desorption kinetics, resistance to deactivation etc. In recent years, some selected metal hydrides are chosen as potential medium for hydrogen storage.

Storage of ^{3}H isotope as metal hydrides

The heaviest isotope of hydrogen (^{3}H or T) is one of the critically important elements in the field of fusion reactor technology. It is radioactive in nature and does not exist in significant amount. Therefore any equipment used for the storage of this isotope should be designed in such a way that it does not release it easily into the environment under ambient conditions. In this sense, T-storage equipment using metallic beds is rated to be more suitable than that using either the gaseous or liquid form of storage. Some of the metallic systems used for T-storage are alloys of titanium, zirconium, lanthanum and uranium. However, for the appropriate absorption-desorption of T_2 at intermediate temperature range of 300-400°C, only ZrCo and some of the uranium

alloys are suitable candidate materials. In particular, ZrCo alloy absorbs reversibly an appreciable amount of hydrogen isotopes (maximum H/ZrCO = 3), exhibits low hydrogen release pressure under ambient conditions and resistant to pyrophorocity and hence considered as a suitable material for storage and transport of hydrogen isotopes in the international thermonuclear experimental reactors (ITER). Research on storage and release behavior of ZrCo alloy with respect to H_2, D_2 and T_2 has been carried out in our laboratory [1] and it was demonstrated that this alloy has favorable dissociation pressures and reaction kinetics for this ITER application. However, under high hydrogen pressure at high temperatures or during repeated absorption-desorption, this alloy loose its hydriding ability. Under thermal cycling, ZrCo undergoes hydrogen induced disproportionation into more stable hydride ZrH_2 and hydrogen non-absorptive intermetallic compound $ZrCo_2$, thus reducing its storage and recovery ability.

On the other hand, uranium bed, in particular, is predominantly used to pump, store and purify T_2 in gaseous form because: (i) large quantities of T_2 can be stored in the smallest volume (T/U atomic ratio upto 3); (ii) it exhibits a dissociation pressure less than 10^{-3} Pa at 298 K, thus preventing the release of T_2 to the atmosphere under ambient conditions; (iii) the pressure of T_2 can be controlled by adjusting the uranium bed temperature. Typically at 700 K, it exhibits a dissociation pressure sufficiently high to release T_2; (iv) the PC isotherms show a wide plateau, assuring a constant release pressure over a wide hydrogen concentration range; (v) fast uptake of T_2 even at low pressures is possible; (vi) surplus T_2 can easily be recovered at room temperature from the vacuum system and be reabsorbed back onto the getter for later use thereby reducing the discharge to the environment by orders of magnitude; (vii) the decay product ^{3}He which has accumulated during storage can simply be pumped off.

However, U easily disintegrates into fine powder on hydrogenation. Such powdering reduces its heat conductivity and hence temperature control of specimens becomes difficult. Further, in an accidental situation, the powder may ignite on coming in contact with leaking air. Therefore, U is desired to be improved as to its hydrogen storage property by alloying. The hydrogen storage behavior of uranium alloys has been studied to a limited extent and hence opens up a new area of research. In particular, U-Zr and U-Ti alloys are thought to be promising materials for T-storage [2, 3]. The U-Ti system comprises of an intermetallic compound U_2Ti. As titanium exhibits high durability to powdering on hydrogenation, the U_2Ti intermetallic compound may possess an excellent durability to powdering. The ^{3}He retention capacity of uranium bed is very low even at ambient conditions whereas that for titanium is very high. Hence, U_2Ti alloy is expected to have intermediate capacity for retention of ^{3}He.

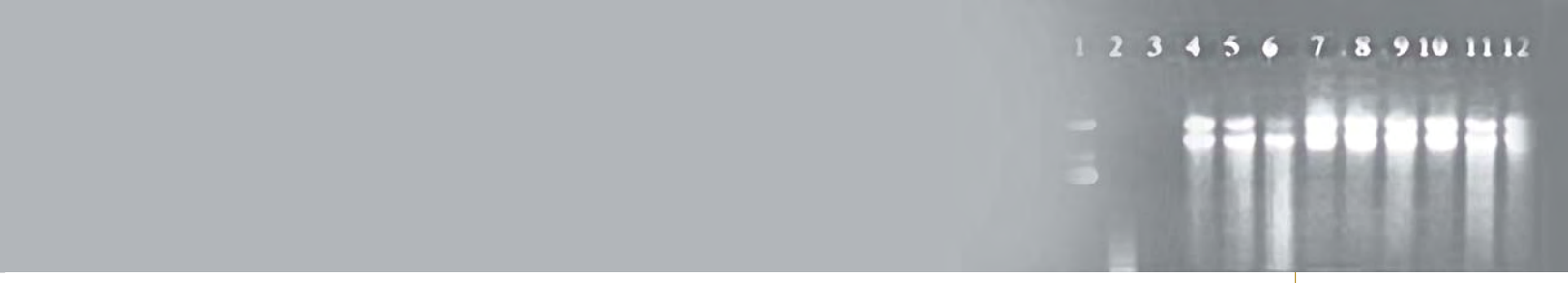
We have studied the hydrogen absorption-desorption behavior of U_2Ti, and its application as a storage material. In order to get an insight into the T_2 storage behavior of U_2Ti, we first carried out a detailed study of its hydrogen storage behavior, and subsequently extrapolated our results to draw conclusions regarding its T_2 storage property.

Thermodynamics of hydrogen absorption-desorption

In general, the metal-hydrogen reaction can be expressed by the following reaction:

$$M(s) + \frac{x}{2}H_2(g) \rightarrow MH_x(s) + Q \qquad (1)$$

where, M is a metal, a solid solution or an intermetallic compound, MH_x is the metal hydride, 'x' is the ratio of hydrogen to metal denoted as H/M and Q is the heat released during reaction.



The hydrogen absorption reaction is generally exothermic. Metal hydride formation comprises of the following five essential processes: (1) physisorption of hydrogen molecules; (2) dissociation of hydrogen molecules and chemisorption; (3) surface penetration of hydrogen atoms; (4) diffusion of hydrogen atoms through the hydride layer; either by an interstitial or a vacancy mechanism and (5) hydride formation at the metal/hydride interface. For dehydrogenation, the process is the reverse.

The behavior of metal-hydride systems can be best represented by pressure-composition isotherms (PCIs). The host metal initially dissolves some hydrogen as a solid solution (α-phase). As the hydrogen pressure together with the concentration of H in the metal is increased, interactions between hydrogen atoms become locally important, and we start to see nucleation and growth of the hydride (β) phase. While the two phases coexist, the isotherms show a flat plateau, the length of which determines how much H_2 can be stored reversibly with small pressure variations. In the pure β-phase, the H_2 pressure rises steeply with the concentration. At higher H_2 pressure, further plateaus and further hydride phases may be formed. The two-phase region ends in a critical point T_C, above which the transition from α to β phases is continuous. The plateau or equilibrium pressure depends strongly on temperature and is related to the changes in enthalpy and entropy of the metal-hydrogen reaction. Stable hydrides require higher temperatures than less stable hydrides to reach a certain plateau pressure.

Thermodynamic parameters like changes in standard free energy ($\Delta_r G^o$), enthalpy ($\Delta_r H^o$) and entropy ($\Delta_r S^o$) of metal-hydrogen reaction are calculated from PC isotherms, using the following equations:

$$\Delta_r G^o = -RT \ln K_p = \frac{x}{2} RT \ln P_{H_2} \qquad (2)$$

$$\Delta_r G^o = \Delta_r H^o - T\Delta_r S^o \qquad (3)$$

$$\ln P_{H_2} = \frac{2}{x}\frac{\Delta_r H^o}{RT} - \frac{2}{x}\frac{\Delta_r S^o}{R} \qquad (4)$$

From a number of measurements of plateau pressures $P(H_2)$ at different temperatures, a van't Hoff plot is constructed by plotting $\ln P(H_2)$ as function of $(1/T)$. The $\Delta_r H^o$ and $\Delta_r S^o$ are evaluated from the slope and intercept using equation (4). As the entropy change corresponds mostly to the change from molecular hydrogen to dissolved hydrogen, the entropy for all metal hydrogen systems under consideration is approximately same.

Hydrogen Isotope Effect on dissociation pressure of metal-hydrogen systems

It is well known that the pressure-composition isotherms (PCIs) of metal or intermetallic compound-hydrogen systems are affected to some extent by the type of hydrogen isotopes. The isotope effect arises from the interplay of two thermodynamic factors namely, entropy and enthalpy that control the relative stabilities of the corresponding isotope hydrides. Since the absolute entropies of hydrogen isotopes in the gas phase follow the order $S^o(T_2) > S^o(D_2) > S^o(H_2)$, therefore the $\Delta_f S^o$ of the heavier isotope hydride is more negative than the lighter ones leading to a '*positive or normal*' isotope effect. The enthalpy of hydrogenation reaction also decides the nature of isotope effect. When the $\Delta_f H^o$ of the lighter isotope hydride is more negative than the heavier isotope hydrides, a *normal* isotope effect is always observed. In this case the plateau pressure of the hydrogen isotopes will follow the trend: $p(T_2) > p(D_2) > p(H_2)$ at all temperatures. On the other hand, when the $\Delta_f H^o$ of the heavier isotope hydride is more negative than the lighter ones, a temperature dependent isotope effect is expected. Below a certain temperature, *inverse* isotope effect will be observed whereas above this temperature the isotope effect is normal.

The U-H system shows *positive* isotope effect. Literature data on this system shows that the enthalpy of hydrogenation of uranium metal is nearly same (within 1 kJ/mole) for H_2, D_2 and T_2. Hence, the difference in equilibrium plateau pressure for these three isotopes arises due to the difference in entropy of reaction. Hence, by knowing the van't Hoff relation for only one hydrogen isotope in the uranium system and the isotopic effect on the entropy of hydrogenation reaction, one can predict the equilibrium plateau pressures of higher isotopes D_2 and T_2.

Studies on hydrogen storage behavior of U-Ti system

In the present investigation, the hydrogen absorption-desorption behavior and the Pressure-Composition Isotherms (PCIs) of the intermetallic compound U_2Ti was investigated using a Sievert-type volumetric apparatus (Fig.1).The apparatus essentially comprises of: (1) a cylindrical sample holder of known volume; (2) a kanthal wire wound resistance furnace; (3) a hydrogen reservoir of known volume; (4) Piezoresistive-type pressure transducer of range 0 - 0.15 MPa to monitor system pressure; (5) a rotary vacuum pump backed by a diffusion pump; (6) a pirani gauge with gauge head to measure vacuum pressure; (7) K-type thermocouples to measure the temperature. The reaction vessels are made of quartz while the other parts are made mostly of stainless steel. The maximum attainable vacuum is of the order of 10^{-5} Pa.

Hydrogen absorption-desorption properties of U_2Ti

Typical hydrogen absorption-desorption curves for three successive hydrogen absorption-desorption cycles are shown in Fig.2 which indicate two-stage absorption-desorption for this alloy. From the hydrogen concentration measurement, it is inferred that the high-temperature absorption is primarily due to the reaction:

$$U_2Ti + \frac{2.4}{2} H_2 \rightarrow U_2TiH_{2.4} \qquad (5)$$

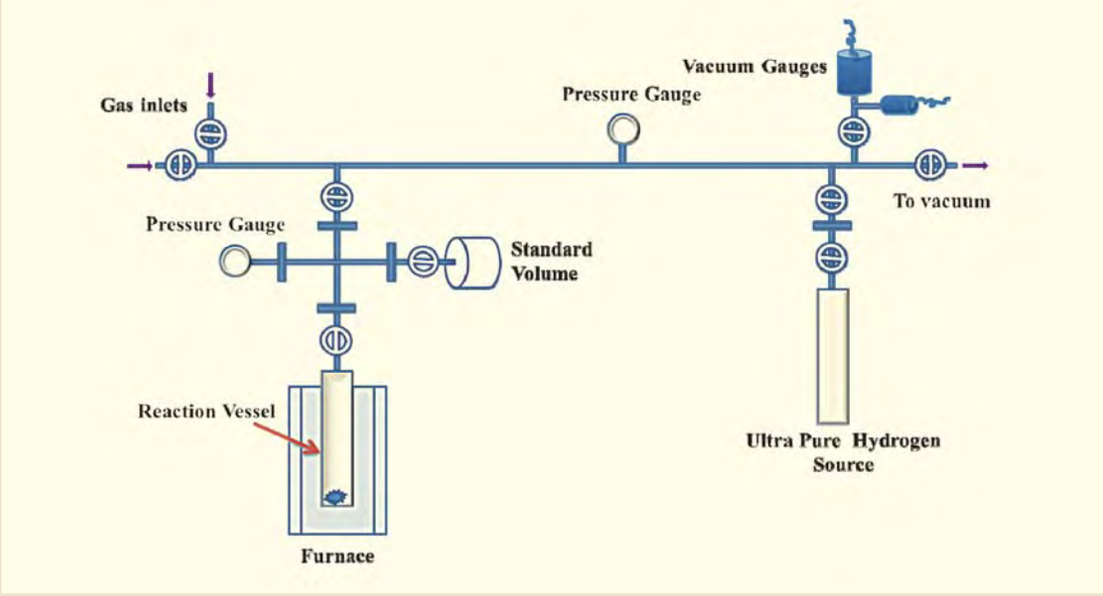


Fig.1: Schematic of Sievert's type volumetric apparatus

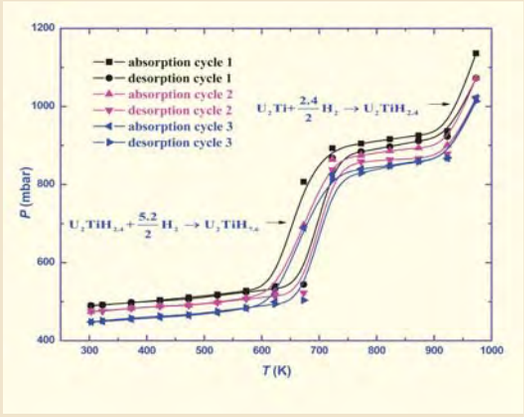


Fig. 2: Hydrogen absorption-desorption cycles of U_2Ti

whereas the low temperature absorption is due to the reaction:

$$U_2TiH_{2.4} + \frac{5.2}{2}H_2 \rightarrow U_2TiH_{7.6} \qquad (6)$$

A misfit was observed between the absorption and desorption curves indicating the presence of hysteresis. From this figure, it can also be seen that after each cycle there was a decrease in the final pressure of the system due to partial decomposition of U_2Ti matrix to β(Ti) and γ(U) phases. The extent of decomposition increased with number of thermal cycles. Also, the extent of hysteresis is observed to decrease with each successive cycle, indicating conversion of the macrocrystalline alloy to a microcrystalline form.

Pressure-Composition Isotherms of U_2Ti

In this study, Pressure-Composition-Isotherms for U_2Ti-H system were generated at three different temperatures 616, 647 and 678 K which are shown in Fig.3. In all the three cases, only one plateau was observed in this temperature region which can be attributed to the reaction:

$$\frac{2}{5.2}U_2TiH_{7.6} \rightarrow \frac{2}{5.2}U_2TiH_{2.4} + H_2 \qquad (7)$$

However, the plateau corresponding to desorption from $U_2TiH_{2.4}$ to generate U_2Ti was not observed at these temperatures but based on the absorption-desorption studies (Fig.2) it is expected to be observed at higher temperatures. Investigation of the second plateau is in progress and hence not reported here.

Using the plateau pressures of these three isotherms a van't Hoff plot was constructed and is shown in Fig.3. From the van't Hoff plot, temperature dependence of the plateau pressure was found to be expressed by the equation:

$$\ln(p_{eq}/p^0) = (-10140/T) + 13.86 \qquad (8)$$

From this relation, the enthalpy change and the entropy change of the reaction (7) for decomposition of $U_2TiH_{7.6}$ to $U_2TiH_{2.4}$ were deduced

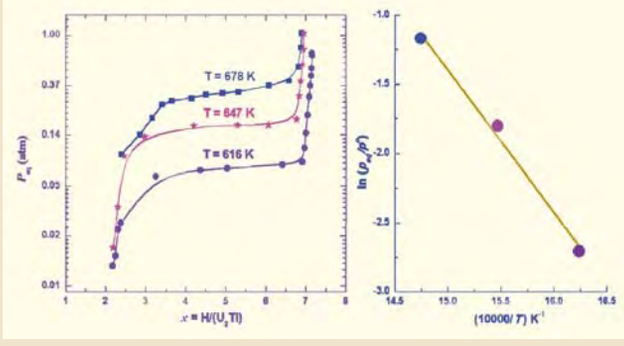


Fig.3: Pressure-Composition-Isotherms and the van't Hoff plot.

to be 83.7±6.4 kJ/mol H_2 and 116.6±9.9 J/(mol H_2·K), respectively. These values are in good agreement with the values reported in literature [2]. The values of dissociation pressures of reaction (7) and those of UH_3 from literature [4] are compared in Fig.4 which shows a higher dissociation pressure for UH_3.

From the experimental data, the increment in entropy of hydrogenation reaction of uranium metal

Table 1: Summary of isotope effect on the plateau pressures of U-H and U_2Ti-H systems.

Equilibrium reaction	van't Hoff equation: $\ln\left(\frac{p_{eq}}{p^0}\right) = \frac{-A}{T} + B$					
	$\frac{2}{5.2}U_2TiH_{7.6} \rightarrow \frac{2}{5.2}U_2TiH_{2.4} + H_2$			$\frac{2}{3}UH_3 \rightarrow \frac{2}{3}U + H_2$		
	A	*B*	This study	*A*	*B*	Ref. [4]
Hydride	10140	13.86	Experimental	10421	14.71	Experimental
Deuteride	10140	14.16	Predicted	10363	15.01	Experimental
Tritide	10140	14.30	Predicted	10297	15.15	Experimental

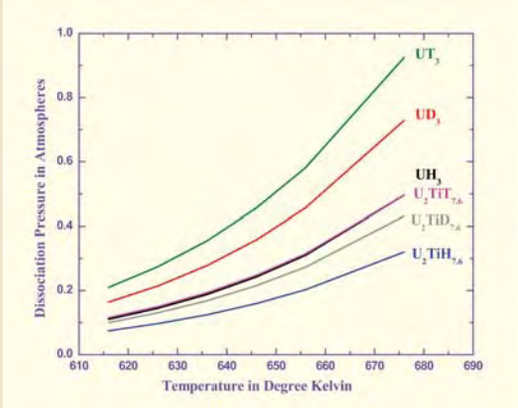


Fig. 4: Comparision of dissociation pressures in U-H and U_2Ti-H systems U-H system Ref.[3], U_2Ti-H system (this study)

is 2.49 J/(mol H_2·K) from H_2 to D_2 and 1.16 J/(mol H_2·K) from D_2 to T_2. Using the same experimental entropy increment value and the experimental enthalpy of reaction obtained in this study, we have calculated the equilibrium plateau pressures of D_2 and T_2 for the reaction (7) and compared them in Fig.4. However, it is important to validate these predictions with experimental data and hence the PCT experiments with heavier isotopes of hydrogen are in progress.

Conclusions

The hydrogen absorption-desorption cycles of U_2Ti showed hysteresis with two-step absorption-desorption. With each cycle, a slight decrease in the final dissociation pressure was observed which was attributed to the partial decomposition of U_2Ti phase to β(Ti) and α(U) phase. The Pressure-Composition Isotherms were generated at 616, 647 and 678 K and from the van't Hoff plot the enthalpy and entropy change of the reaction for decomposition of $U_2TiH_{7.6}$ to $U_2TiH_{2.4}$ were deduced to be 83.7±6.4 kJ/mol H_2 and 116.6±9.9 J/(mol H_2·K), respectively. Using positive isotope effect, the equilibrium plateau pressures of the heavier isotopes D_2 and T_2 were predicted.

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Report on DAE-BRNS Theme Meeting on Advanced Applications of Physiological Variability (AAPV-2010)

The DAE-BRNS Theme Meeting on Advanced Applications of Physiological Variability (AAPV-2010) was held during 28th – 29th October 2010 at the Multipurpose Hall, Training School Hostel, Anushaktinagar, Mumbai 400 094. This meeting was attended by nearly 100 delegates including experts from allopathic, homoeopathic and ayurvedic systems of medicine from all over the country, representatives from medical instruments manufacturing industries and scientists from BARC.

Mr. R.K. Patil, Associate Director (C), E&I Group, in his welcome address, emphasized the need for such theme meetings. It helps in focused discussion on the subject and preparing a road map. He expressed his happiness over the participation by experts from different systems of medicine.

Dr. R.K. Sinha, Director, Bhabha Atomic Research Centre, inaugurated the theme meeting and said that BARC has been developing simple, low-cost and effective medical instruments for the past 30 years and many of them are being manufactured by private industries. He specifically mentioned about Cardiac Output Monitor, Oxygen Saturation Monitor, Non-invasive Blood Pressure Monitor, Impedance Cardio-vasograph, Medical Analyzer, Bhabhatron and Handheld Tele-ECG; which are

Dr. R. K. Sinha, Director, BARC delivering the inaugural lecture

commercially available. He also expressed his pleasure at the deployment of Mobile Based technology used in Tele-ECG for radioactive material detection in public places and tele transfer of the information to remote server. On the topic of the theme meeting i.e. physiological variability, he stressed that these new modalities would reveal the effect of diseases and corrective therapy on the human body. He expressed his happiness over the usefulness of this modality not only in allopathy but also in ayurveda and homoeopathy.

Dr. K.B. Sainis, Director, Biomedical Group, released the Handbook on Physiological Variability on this occasion. The book contained introduction, measurement techniques and clinical applications of physiological variability. The inaugural session ended with a vote of thanks by Dr. P.N. Jangle, Head, Medical Services, BARC Hospital. The following sessions were conducted during the theme meeting.

Session II: Principles and practices of physiological variability.

Session III: Clinical applications of physiological variability, was chaired by Dr. V. Karira, Head, Medical Division, BARC.

Session IV: was chaired by Prof. Mr. Nath Rao, Principal, Father Muller Homoeopathic Medical College, Mangalore. In this session uses of physiological variability for fundamental research in homoeopathy were discussed.

The last session of the day **(Session V)**, on live demonstration, was chaired by Mr. Rohit Mehta, General Manager, Larsen & Toubro Ltd. and Head, Medical Equipment System Business.

Session VI was a panel discussion on Medical Instrumentation – Vision and Perspective. Panel discussion was chaired by Prof. Alaka K. Deshpande, from Grant Medical College and J.J. Group of Hospitals, Mumbai.

The last session, on Physiological Variability in Ayurveda, was chaired by Dr. Bhaskar Sathaye, Ex. Director, Maharashtra Ayurvedic Council.

The theme meeting ended with thanks from the Convener.

Vigilance Awareness Week at BARC

As per the Directives of Central Vigilance Commission, the Vigilance Awareness Week was observed in BARC from 25th October to 1st November 2010. In addition to taking of the Vigilance Pledge, various programmes like One Act Play, Elocution Competition and Quiz Competition were also organized. A Panel discussion on 'Transparency and Fair Play in Government' was also organised on 1st Nov. 2010. The programme was concluded with special address by Additional Secretary, DAE followed by distribution of Prizes to the winners of the contests. The following programmes were also organized as part of the observance of Vigilance Awareness Week :-

1. A Documentary film on vigilance exhibited on 25th Oct. 2010
2. One Act Play on vigilance staged on 26th Oct. 2010
3. Elocution competition on 'Role of youth in eradicating corruption' for Std. IX & X students of AECS held on 27th Oct. 2010
4. Quiz competition conducted on 28th Oct. 2010.

On the concluding day, on 1st Nov. 2010, a panel discussion on the topic entitled "Transparency and Fair Play in Government" was organized at the Central Complex Auditorium, BARC, Trombay, during which the following dignitaries were invited:

a) Mr. N.D. Sharma, Controller, BARC.
b) Mr. H.C. Soni, Director, DPS
c) Mr. N.S.Gabhane, Director, DCS&EM
d) Mr. A. Ramaiah, IFA, BARC
e) Mr. Narayan Verma } Both RTI Activists
f) Mr. Chetan Kothari }

The Panel Discussion was conducted by Mr. Goverdhan Rao, HPD, BARC.

The week long Vigilance Awareness week was thus concluded with a special address to the gathering by Additional Secretary, DAE, followed by distribution of prizes to the winners of the various contests.

Controller, BARC and other dignitaries at the inaugural function

Development of a networked patient call system for BARC Hospital

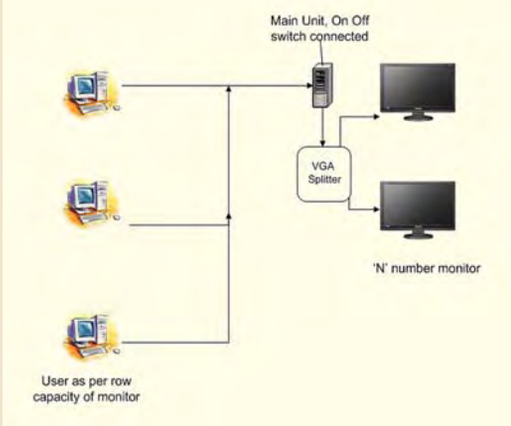
Arnab Jana, S.C. Srivastava, Vineet Kumar and N. Roy

Abstract

Information systems do not usually incorporate public serving interfaces, to obviate the necessity of physical queues. This is because information systems and queuing systems address two entirely unconnected domains. The requirements of queuing and load balancing for serving the public faster and efficiently can be quite complex. The token indication systems available in the market are generally stand alone, bulky and are generally not designed to cater to complex queuing requirements. The hardware (already available owing to requirements of Information system) could be synergically utilized, to provide complex queuing solutions, through networking while such a solution remains a separate entity from the information system. On these lines we have developed a patient call system for BARC Hospital and installed a prototype system at the Surgical Unit.

Introduction

Hospital Information system (HIS) has been in operation at BARC Hospital for dealing with clinical information on patients. This required availability of networked personnel computers at the desk of all the consulting doctors, while requirement of patient call is met through token indicators available in the market. However the queuing requirement such as the need to accommodate urgent cases and the need to adjust late reporting within regular queue of appointments of the day is very difficult to meet through a single ended token indicator. To provide this facility, we have developed a networked patient call system which can take care of complex queuing requirements while utilizing the existing network and user end computers. The system exists as separate entity on the existing hardware with the user end, whereas for the display purpose, a dedicated computer is used to serve 5 doctors at a time, while the number and size of displays can be tailored to suit diverse requirements.



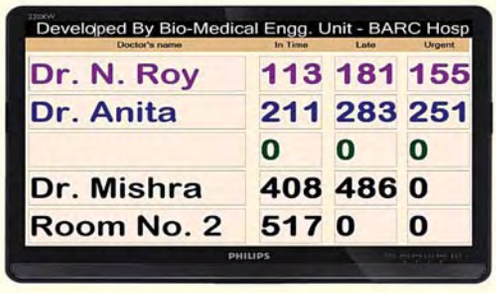
System Description

The Patient Call System (PCS) has been developed using dot-net framework. The system consists of one dedicated PC interfaced with an expandable set of LCD Monitors (at present 3 Monitors have been connected) using VGA splitters. This system

is networked with the existing LAN for HIS to communicate with various users' PCs. The display is configured for 5 doctors with their Name/ Room Number and 3 series of token numbers in their row, to distinguish the patient category (Routine, Urgent and Missed in three different blocks) of the patient. The dedicated computer is used to display token numbers and names of the doctors on its multiple LCD Patient Call Display screens. The software automatically adjusts to various screen resolutions and sizes. Some modification in the booting programme is incorporated, to start and shutdown the Patient Call System directly, with the help of two external buttons attached to it and thus key board and mouse can be removed from the CPU unit to give it the look of an equipment and also to prevent inadvertent/unauthorized access. A fully customized Windows based Graphic Patient Call Entry Screen to be installed at doctors PC is designed, to enter the text data for Doctor's Name/ Room Number and numeric data for token number etc. Each Entry Screen bears a fixed address and is loaded on the desktop of doctor's PCs. The token number entered by the doctor is displayed on the LCD screens connected with the PCS. There are 4 input boxes one for doctor's name and other three for token numbers viz: 'with appointment', 'Late arrived and without appointment patients, cases. Latest token number update is highlighted with a change of background colour and simultaneous audio alarm. The Entry Screen can be minimized after entering the token number on the windows tool bar, making the window screen free to carry out any other function on the desktop.

Presently a 19"LCD monitor has been used for display of token numbers which can accommodate a maximum of 5 rows for five users, with a font size of 75 pixels. For better view, more than one monitor at different locations can be connected in parallel, using VGA splitter depending on the size of the waiting area. Each row is configured to receive the data from the Patient Entry Screen installed on the user's PC and display on the respective field. The Number display lights up the latest changed token number for a few seconds.

(Graphic Key Board loaded on user's desktop)

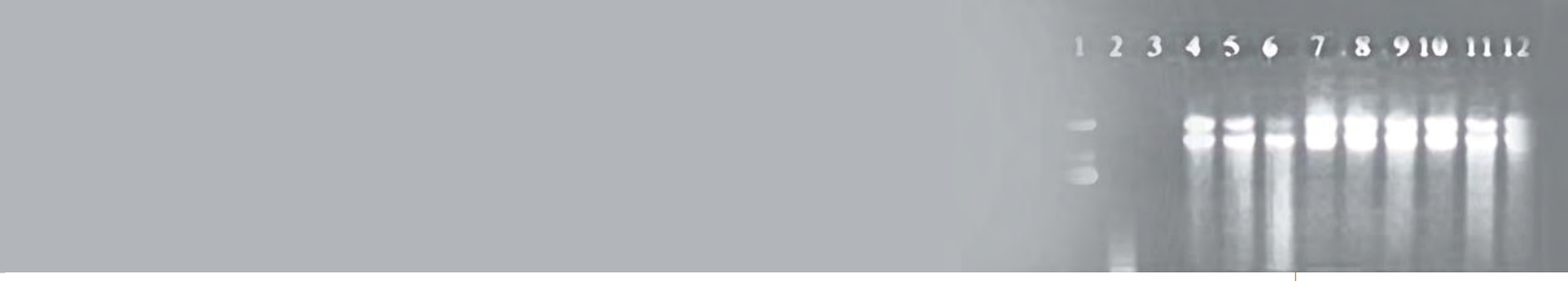


Monitoring of Radioactive Waste Drums using various techniques (RWDM - 2010): Report of a theme meeting

A theme meeting on "Monitoring of Radioactive Waste Drums using various techniques" was held at AFFF Lecture Hall, BARC, Tarapur on July 22, 2010. The meeting was organized by the Indian Association of Nuclear Chemists and Allied Scientists, Tarapur Chapter, in association with the Board of Research in Nuclear Sciences (BRNS), Department of Atomic Energy, Government of India. This was the first major event organized by IANCAS, Tarapur Chapter since its formation in September, 2008. The meeting was inaugurated by Mr. H.S. Kamath, Director, Nuclear Fuels Group. Mr. Kamath in his inaugural speech, stressed the need of adopting a common methodology for assaying the waste drums by using a waste drum monitor. This was followed by presidential address of Dr. V. Venugopal, Director, Radiochemistry and Isotope Group and President, IANCAS, Mumbai. He detailed the activities of IANCAS. He emphasized the important theme of the topic of containment and surveillance, as an important aspect of nuclear safeguards. Dr. Anil K. Pabby, Secretary, IANCAS, Tarapur chapter proposed a vote of thanks.

The meeting was divided into two sessions. In Session-I, eminent speakers from various units of DAE delivered their lectures. Mr. R. Natarajan, Director, Reprocessing Group, IGCAR, Mr. Kanwar Raj, Head, WMD, Dr. Umesh Kumar from IAD, BARC, Dr. A. Goswami, RChD and Dr. Sarbajit Singh from RChD BARC, Trombay, Mumbai

Dr. V. Venugopal, Director, RC&I grp., Mr. H. S. Kamath, Director, Nuclear Fuels Grp. and other faculty members



presented the invited lectures. A number of papers on work carried out in different laboratories of DAE were presented.

Seven contributory papers were presented in Session II. All the presentations dealt with experimental data generated during monitoring of waste drums using various techniques.

In the concluding session, a panel discussion was conducted in which Dr. V. Venugopal, Director, RC &I Group, Mr. H.S. Kamath, Director, NFG, Mr. R. Natarajan, Director, Reprocessing Group, IGCAR, Dr. Gurusharan Singh, Head, IAD and Dr. Jose Panakkal, Head, AFFF and Chairman, IANCAS, Tarapur chapter participated. Mr. H.S. Kamath appreciated the role of IANCAS Tarapur Chapter for bringing together the experts from different laboratories for the theme meeting. He mentioned that gamma spectrometry was good for simple matrix. When the matrix is complex, one has to use neutron counters. This was very important to categorise radioactive waste.

Dr. V. Venugopal said that monitoring of radioactive wastes and their classification is an important step in the processing of nuclear materials. Waste drum monitoring is one of the important NDA techniques and needs to be explored to its fullest extent.

Dr. Gurusharan Singh opined that there are many difficulties encountered in the development of Digital Radiography and Tomography due to embargo. There is a need for indigenous development to keep pace with the fast emerging NDE technology.

Dr. R. Natrajan emphasized that the bottleneck for waste drum monitors is the manufacture of HPGe detectors. Though, it is possible to manufacture the low resolution detectors like NaI(Tl), CsI(Tl) and cerium doped lanthanum bromides indigenously, attempts should be made to develop the manufacture of Cd Te or Cd ZnTe detectors. As there is a world wide shortage of supply of He^3 and with the higher enrichment of Boron being available, BF_3 detectors can be utilized for neutron detection though there would be a penalty with higher minimum detection limits.

Dr. J.P. Panakkal, Head A3F said that Non Destructive Assay (NDA) of radioactive materials plays significant role in the assaying and accounting of the nuclear materials. The aim of the theme meeting RWDM 2010 was to bring together the professionals working in this area. The meeting provided an opportunity for the participants to interact and suggest a common methodology for development of a waste drum scanner which can be used in all the laboratories.

All the speakers provided their perspective about RWDM-2010 and on the future direction of radioactive waste monitoring. They appreciated IANCAS, Tarapur Chapter for bringing together the experts from various institutions of DAE.

More than 100 delegates from various units of DAE participated in the theme meeting.

Status and Trends in Thermal Reactor Spent Fuel Reprocessing in India: Report on DAE-BRNS Theme Meeting

The Fuel reprocessing Division organized a one day theme meeting on " Status and Trends in Thermal Rector Spent Fuel Reprocessing in India" on 22nd October, 2010 at Multi purpose Hall, Training School Hotsel, Anushakti Nagar. The main objective of the meeting was to share the experiences gained over the last 4 decades in thermal reactor spent fuel reprocessing. One thermal reactor spent fuel reprocessing plant at Tarapur is under advanced stage of commissioning and construction and work on another plant at Kalpakkam is in progress. In addition, an integrated plant with higher capacity of reprocessing and waste management facilities is being planned at Tarapur. This theme meeting was successful in reviewing the performance of the existing reprocessing plants and identifying key areas required for enhancing their safety as well as their capacities.

About 150 participants of NRG, NRB, FCD, ACD, NFG, HS&EG and AERB from Trombay, Tarapur and Kalpakkam, participated in the theme meeting. The theme meeting was inaugurated by Dr. R.K. Sinha, Director, BARC. Mr. S.D. Misra, Director, Nuclear Recycle Group spoke about the perspectives of the theme meeting. Mr. S. Basu, Chief Executive, Nuclear Recycle Board presented on overview of the projects under construction/ planning.

Mr. S.V. Kumar, Former Vice Chairman, AERB described the evolution of reprocessing in India and the expectations from the new projects. Mr. Kumar covered the various development efforts undertaken before and during the construction and operation of the first reprocessing plant in India. He also stressed the need for continuing R&D work to further improve the operational and safety performance of the reprocessing plants.

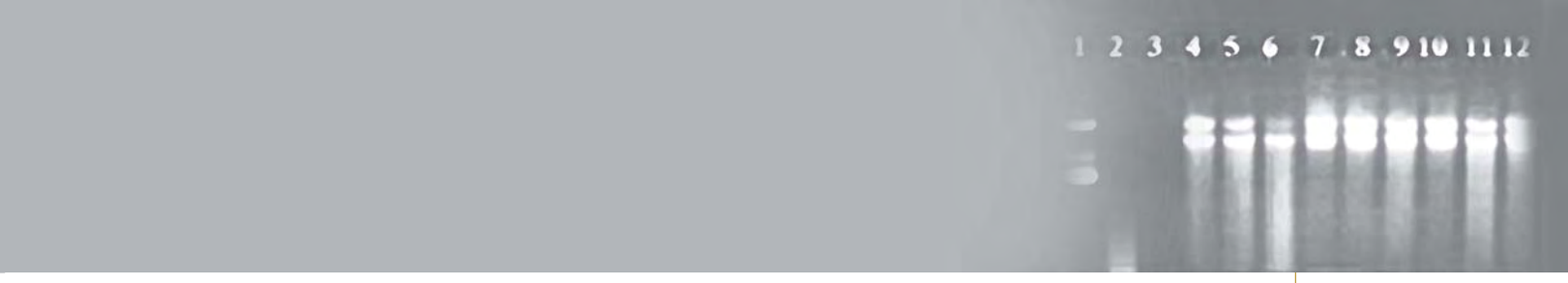
The second lecture was delivered by Mr. P.K. Dey, Head, Fuel Reprocessing Division on the reprocessing programme of India. In addition to the thermal reactor reprocessing, fast reactor spent fuel reprocessing, scheme for three component separation of AHWR spent fuel etc. were covered in this lecture.

Mr. Kanwar Raj, Head, Waste Management Division presented the various processes for management of high level, intermediate level and low level liquid wastes arising from reprocessing plants, management of spent organic and alpha waste etc. In his talk, Mr. Raj stressed the need for further efforts in reducing the radioactive waste in radiochemical plants.

The fourth lecture was delivered by Mr. K.A. Pendharkhar, former Head, Health Physics Division. Mr. Pendharkhar has a very long association with the reprocessing plants and covered various safety issues associated with the design and operation of reprocessing facilities. Mr. Pendharkhar explained the various engineered safety features provided at the design stage of reprocessing plants along with the administrative measures required for maintaining the sfatey status of the plants during the operational stage.

Mr. S.K. Munshi, Chief Superintendent, Reprocessing facilities, Nuclear Recycle Group presented the operational experience of Plutonium Plant, Trombay. Mr. Munshi highlighted the various measures taken in the plant over the years, to improve the process and safety performance of the plant as well as aging related issues continued safe operation of the Plutonium Plant.

The technical sessions were chaired by Mr. D.S. Shukla, Raja Ramanna Fellow and Former Director, Chemical Engineering and Technology Group and Mr. H.S. Kamat, Director, Nuclear Fuels Group.



Third Supervisory Training Programme on Spent Fuel Reprocessing at BARC Trombay: a report

The supervisory training programme on "Spent Fuel Reprocessing" was designed and formulated mainly for the supervisors, who are working in reprocessing plants and either have not received any formal training or had received training about 10-12 years back. In addition, this programme was also designed for those supervisors who are associated or are working in fuel fabrication, reactor operation, waste management plants etc. Supervisors are the vital link for any organization between the management and the workforce. They also provide guidance and instruction to the workforce for carrying out the job in a proper, safe and efficient manner. Training to the supervisors brings positive results with respect to various safety and operation parameters such as person-mSv consumption, safe working statistics and efficient and timely completion of jobs. In the normal case, the supervisors are working in their plants and have expertise in carrying out their own jobs efficiently. However, this type of training and periodic re-training provides uptodate knowledge in their own fields. Thus, this training programme on a specific subject, such as Spent Fuel Reprocessing, gives a complete acquaintance, knowledge, familiarization related to all aspects of spent fuel and its reprocessing and recent advances.

The first and second supervisory training programmes, in this series, on Spent Fuel Reprocessing, were conducted at BARC, Trombay in August 2007 and at Centralized Waste Management Facility (CWMF), Kalpakkam, in October 2008, respectively. The Third Supervisory Training Programme in this series was conducted at BARC Trombay during March 15-26, 2010.

During the inaugural programme, on 15th March 2010, Mr. H. N. Mishra welcomed the gathering. Mr. R.G. Yeotikar, Officer-in-Charge, Training and organizer of this programme, introduced the syllabus of the programme and explained the importance of the selected subjects. Mr. S. K. Munshi, CS, RF, PP, FRD, Mr. R. K. Gupta, Head, Hot Cell Development & Engineering Section and Mr. Kanwar Raj, Head, Waste Management Division addressed the trainees and emphasized the importance of training and its usefulness in updating knowledge in various aspects of spent fuel reprocessing. Vote of thanks was given by Mr. Prahlad Patange.

After inauguration, there was an invited talk by Mr. S.K. Munshi, who highlighted the processes adopted for spent fuel reprocessing in India. In the training programme Mr. P.K. Dey, Head, Fuel Reprocessing Division, also presented an invited talk on the subject "Basic philosophy for spent fuel reprocessing and future perspective". He explained the closed fuel cycle option and why we have adopted the same for self sustaining nuclear power programme of India. He also elaborated on all aspects of spent fuel reprocessing, considering the closed cycle fuel programme of India. This included, type of fuel and cladding material, types of reactors, generation of spent fuel and necessity for reprocessing of spent fuel including thorium-based fuel. He also emphasized the safety aspects of reprocessing plants in India with respect to general safety, radiation safety and criticality aspects.

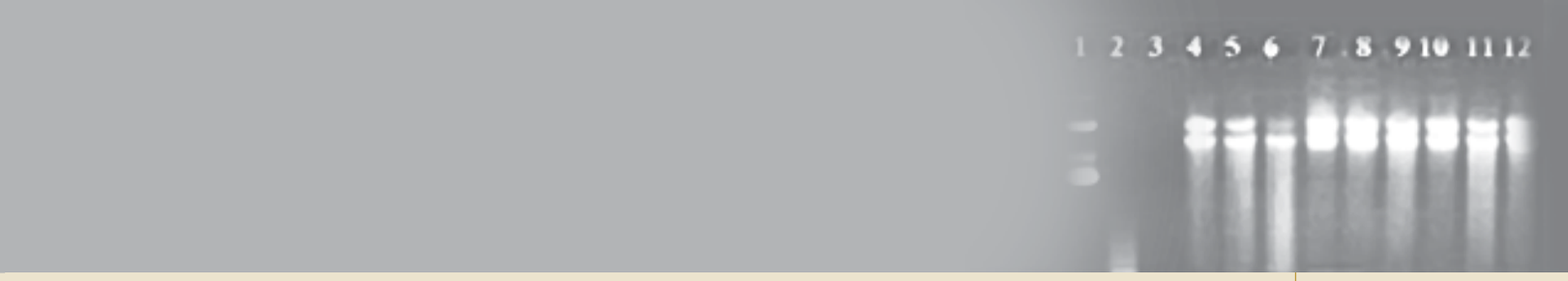
The training programme was designed and organized by Mr. R. G. Yeotikar, Officer-in-Charge, Training, NRG and conducted and coordinated by Dr. S. Shankar, Mr. P. Patange and Mr. H.N. Mishra. A total of 68 participants attended this supervisory training programme. Majority of them belonged

to reprocessing plants /facilities/ projects from Trombay, Tarapur and Kalpakkam. Few supervisors from waste management plants such as WMF Trombay; CWMF Kalpakkam and WMF Tarapur and from other projects also attended the course. Apart from these, supervisors from other Divisions of BARC, Trombay, such as ROD, RCD, AFD, RMD, FCD, UED etc. also attended this course. As per request from AERB, few of their participants also attended this training programme. All the participants were given this training for complete acquaintance of various aspects of spent fuel reprocessing. They were junior engineers, supervisors and senior technicians. The training programme was carried out by way of classroom lectures, demonstrations and visits to various plant / facilities at Trombay such as Plutonium Plant, Waste Immobilization Plant, RSMS, ETP, AFD and Dhruva reactor. Faculty members, who are specialists in their fields with many years of experience, were invited from all three sites of NRG and from AFD, ROD, IHSS, Hospital, Fire Services Section, etc., to deliver lectures.

This training programme covered various aspects of nuclear fuel, spent fuel and spent fuel reprocessing such as fuel fabrication, generation of spent fuel, transportation, spent fuel storage, different steps for reprocessing, various auxiliary systems in reprocessing plants, flow sheets and process schematics, conversion of oxides of Pu and U, analytical requirements for process control, future / advanced techniques for reprocessing, radiological safety, industrial safety, handling of radiological/ fire/medical emergencies, etc. The programme also covered new project activities related to reprocessing, new emerging solvents for reprocessing, advanced methods of reprocessing and reprocessing aspects of thorium based fuels.

The certification ceremony and valedictory function was held on 26th March 2010 and was graced by Mr. P. K. Dey, Head, Fuel Reprocessing Division, Mr. J.S. Yadav, Supdt. Operation, PP and senior officials of PP, Trombay. The feedback was taken from all the participants about the subjects selected for training, plant visits and overall training programme, for improvement of the future training programme. Mr. R. G. Yeotikar, Officer-in- Charge, Training, answered and responded to this feedback. Thereafter certificates were awarded to all the participants. Dr. S. Shankar gave vote of thanks after the valedictory function.

Mr. R.G. Yeotikar, Officer-in-Charge, Training, Nuclear Recycle Group, responding to the feedback during certification ceremony and valedictory function on 26th March 2010. Others on the dais (from left to right) are Dr. S. Shankar, Training Coordinator, Mr. P.K. Dey, Head, FRD and Mr. J.S. Yadav, Dy PS, PP, Trombay.



BARC Scientists Honoured

Name of the Scientist	:	**Madhumita Halder and S.M. Yusuf** **Solid State Physics Division**
Title of the Paper	:	"A Crossover from Short-range to Long-range Exchange Interaction in $TbCo_{2-x}Fe_x$"
Award	:	Best Poster Award
Presented at	:	Conference on Advances in Magnetism: Phenomena and Materials (AMPM 2010) held at Manali, India, during June 3–5, 2010.

Name of the Scientist	:	**P.K. Manna, A.K. Bera and S.M. Yusuf** **Solid State Physics Division**
Title of the Paper	:	"Tunable Structural and Magnetic Properties of Multifunctional $La_{1-x}Ce_xCrO_3$ ($0.0 \leq x \leq 1.0$) Nanoparticles"
Award	:	Best Poster Award
Presented at	:	Conference on Advances in Magnetism: Phenomena and Materials (AMPM 2010) held at Manali, India, during June 3–5, 2010.

Name of the Scientist	:	**N. Thakur, S.M. Yusuf and A. Kumar** **Solid State Physics Division** and **J.V. Yakhmi, Physics Group**
Title of the Paper	:	"Prussian Blue Ananlogue based Molecular Magnets: Controlling Structural Disorder and Magnetic Properties"
Award	:	Best Poster Award
Presented at	:	Conference on Advances in Magnetism: Phenomena and Materials (AMPM 2010) held at Manali, India, during June 3–5, 2010.

Name of the Scientist	:	**Onkar S. Gokhale** **Reactor Safety Division**
Title of the Poster	:	"Study of Induction Heating of Fuel Bundle Simulator using COMSOL Multiphysics"
Award	:	Best Poster Award - Popular Choice
Awarded at	:	2nd National COMSOL Conference 2010, 29-30 Oct, 2010, Banglaluru

Dudah Palm (Flowering phase)

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