

BARC NEWSLETTER



भाभा परमाणु अनुसंधान केंद्र
Bhabha Atomic Research Centre



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From the Editor's Desk

We would like to sincerely thank all the authors for uploading their articles through the SIRD portal, which has been made available recently. This has strengthened the process of review and the subsequent steps involved in the timely publication of the BARC Newsletter.

In this issue, we have covered five Articles and two Brief Communications. One of the major events in the month of May was the celebration of the National Technology Day (NTD) at BARC, with the theme, Food and Agriculture. Several dignitaries visited the Exhibition which was a part of the NTD programme. This event has been published under the News & Events Section.

Finally, BARC Newsletter needs your support in the form of contribution of quality articles, both full length as well as Brief Communications. Your feedback is essential to maintain and further improve the technical content of the BARC Newsletter and we at the Editorial team look forward to your comments and suggestions.

Dr. K. Bhanumurthy
On behalf of the Editorial Committee

Magnetic Nanoparticles-based Displacement Pump for Artificial Heart Support

Physics Group

The big disadvantage of the existing artificial heart pump support systems for failing hearts is that either air or current has to pass from outside to the device across the skin barrier of patients, and this may infect leading to infection complication.

To avoid this complicity, we have invented a displacement pump, where magnetic nanoparticles have been embedded into a medical grade biocompatible polymer. Nanoparticles of Fe_3O_4 as well as $\gamma\text{-Fe}_2\text{O}_3$ with particle diameter around 20-30 nm have been used. The back and forth motion of those magnetic membranes, suitable for the systolic and diastolic movements of heart, under externally applied magnetic force has been demonstrated. The superparamagnetic nature of these nanoparticles allows us to use the magnetic membranes under the action of an external magnetic force without any magnetic hysteresis effect at room temperature. With magnetic actuation, the energy for moving the diaphragm is delivered by a small electromagnet worn outside the body, without physically crossing the skin barrier. The present invention is, therefore, directed to a flexible magnetic (superparamagnetic) membrane based actuation system comprising electronic and electromagnetic

means adapted for regulating the actuation including the rate, force and wave triggering for coordinating with the desired end activity based on the to and fro motion of the membrane, and the details are shown in fig. There are several other important possible applications with this technology.

- (i) support for paralyzed diaphragm to facilitate the breathing process
- (ii) support for non-responsive sphincters to facilitate controlled discharge of urine/fecal matters
- (iii) in micro fluidics, as a fluid-based remotely controlled switch, etc.

Patent Publications:

United States Patent and Trademark Office
Publication No. US-2012-0323318-A1, Publication Date: 20-12-2012

European Patent Office

Publication No.: 10745016.5-1257, Publication Date: 8-10-2012

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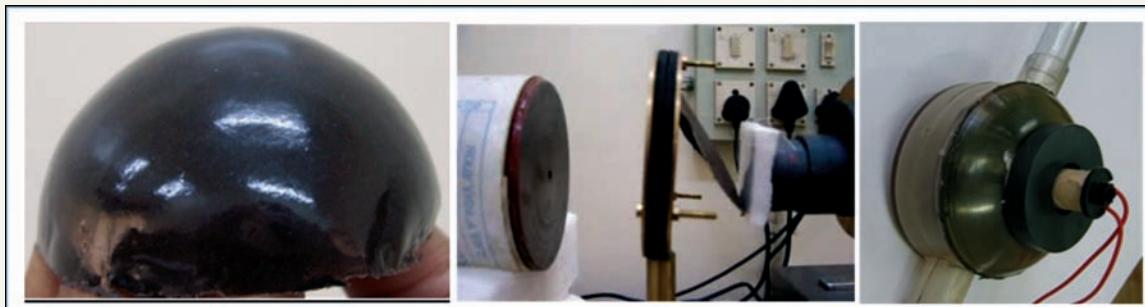


Fig.: Left: Magnetic nanoparticle loaded medical grade flexible membrane, Middle: membrane under the action of magnetic force, Right: Prototype displacement pump

Development of Gadolinium Aluminate based Ceramic for Nuclear Applications

Materials Group

Gadolinium has a very high thermal neutron capture cross section for (n, γ) reaction. The reaction product has a very low capture cross-section. The element is therefore, used as a "burnable" poison in the nuclear reactors to control the reactivity of fresh reactor fuel assembly. In a specific reactor requirement gadolinium was required to be used in the form of gadolinium aluminate. The material was required with high pycnometric particle density and a specified tap density. For the preparation of gadolinium aluminate, four different procedures were successfully tried. These were:

- Gellation process
- Co-precipitation process

- Melting of a precursor powder
- Calcination of a mixture of alumina and gadolinium oxide

After trying out the above four different techniques, a simplified flow sheet was developed for production of gadolinium aluminate and gadolinium aluminate-alumina composite powders on mass scale. With the help of computer simulation and modeling, the powder morphology was controlled so as to obtain powders of desired properties. The major achievement of this work was selection of suitable process and formulation of sequences of processing steps.

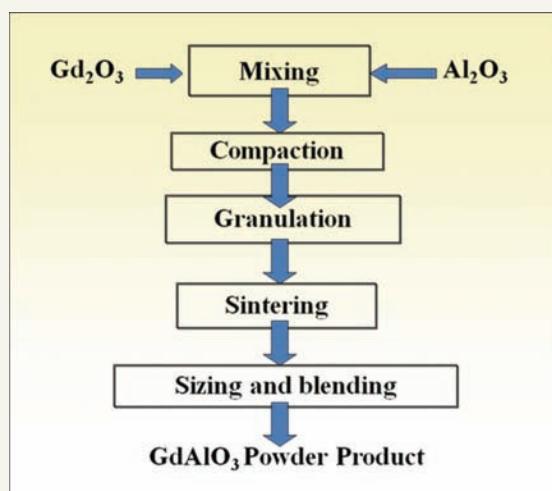


Fig. 1: Process flow-sheet for production of gadolinium aluminate powder product



Fig. 2: Particle morphology of sintered GdAlO_3 granules

Dr. G.J. Prasad, Senior Scientist, Nuclear Fuels Group, BARC, in conversation with members of the BARC Newsletter Editorial Committee

1. Fuel is the most important component of a nuclear reactor. There is a perception in the country in general, and nuclear community in particular, that non-availability of uranium has led to the underperformance of our nuclear power plants. Do you agree, if yes what measures have been/need to be taken to overcome this? Does the Indo-US Nuclear Deal provide us some relief to meet the shortage of uranium?

Yes, sometime in the recent past adequate uranium was not available to run the reactors to generate as much electricity as the achievable capacity and availability factors would warrant. Surely, the Indo-US Nuclear deal, international collaborations & agreements have improved the fuel supply position to some extent. Actual generation of nuclear electricity is steadily improving and is expected to improve further with the UCIL mills at Tummallapally, A.P coming into full operation (as this facility has just recently started and has supplied Sodium di-uranate to NFC where fuel pellets have been produced using this material). With the 700 MW PHWRs coming up in the near future, the demand for fuel is going to rise substantially. Further, with expansion proposals under plan projects getting approved in due course, milling capacity and fuel fabrication/ production at NFC will get a boost once these are implemented. More uranium ore deposits are being identified by the Atomic Minerals Directorate.

2. You may be aware that BARC is planning many research reactors such as R-6, HFRR, APSARA etc. What is our preparedness in meeting this growing demand?

APSARA reactor began operation in 1956 with imported HEU fuel. Subsequent to the international civil nuclear cooperation agreement and India-specific safeguards agreement with the IAEA, government decision was taken to remove the earlier HEU core and replace with indigenous LEU fuel core (2MW). During the implementation of this policy shift, while the Reactor Group, BARC, undertook the modification and upgrade work with respect to core & system design and regulatory consenting process aspects, the Nuclear Fuels Group initiated the LEU fuel development work and augmented the existing plate fuel development and fabrication laboratory in the Metallic Fuels Division, in the VI plan period. Based on the earlier experience of KAMINI plate fuel fabrication work, existing gaps were addressed to enable this facility to produce longer, thinner, more closely-spaced (2.5mm) - plates fuel assembly, containing much higher Uranium loading & volume fraction of fuel in the meat and with stronger alloy clad material in the individual plates including an innovative uranium silicide preparation technique. LEU fuel fabrication work is progressing well subsequent to the delivery of LEU metal powder from the Materials Group (UED). New techniques such as rapid digital radiography for better homogeneity assessment & metrology controls have also been developed and are being used. As far as the work related to the High Flux Research Reactor and the larger research reactor at the new BARC campus, Visakhapatnam is concerned, proposals mooted by the Reactor Group (under the XII & XIII plan periods) are being considered at various levels of approvals. Atomic Fuels Division and Metallic Fuels Division with their rich and long experience are engaged in this endeavour. Plans are under way to initiate development work in the Trombay campus and supply the initial core load and create a new facility in the new campus.

3. On the NPPs front, BARC is playing a major role in generating fuel for PFBR, PHWRs and AHWR. The fuel compositions and manufacturing procedures are different for these fuels. What steps need to be taken to meet these fuel challenges?

As you know, regular fuel requirement for the Indian NPPs are met by the NFC, Hyderabad. However, NFC & BARC (Nuclear Fuels Group, Materials and Chemical Engineering Groups) participate in a very active manner in the R & D programme related to fuel and core structurals. Also valuable Post Irradiation Examination work related to PHWR and uranium & thorium fuels is being done all these years and very interesting findings have been reported with respect to fuel microstructure, (features like grain size/growth, bubble size & distribution), fission gas retention/release), pin failure etc. apart from off-normal behavior/response of fuel pin failure analysis, NDT support etc. NFG also participates in collaborative development work with NFC in the area of PHWR fuels and AHWR fuel. Fabrication development work is being carried out both at the BARC's Advanced Fuel Fabrication facility at Tarapur (AFFF) and in RMD. However, new GB trains and facilities have to be created for regular production of fuel pins for the AHWR, once final decision is taken on the fuel type and the reactor.

MOX fuel development and fabrication work on a large scale is being done at AFFF since its commissioning in the early nineties where BWR, PHWR, FBTR mox fuels have been developed & fabricated. PFBR Prototype 37 pin assembly for irradiation in FBTR was made in AFFF which has seen 112GWD peak burn up successfully. Regular production of SS D-9 clad 21% PuO₂ MOX fuel pins is progressing satisfactorily and a large number of fuel pins have already been delivered to IGCAR, Kalpakkam, for storage and assembly fabrication

work by NFC. Production capacity is being augmented and additional manpower has been allotted on priority basis. Soon production of type 2 pins containing 28% PuO₂ will commence once the type 1 pins requirement is met. We at NFG are thankful to NRB for the continuous supply of the feed material and to NFC for the hardware & RU supplies. We are confident of meeting the schedules for the reactor attaining criticality and raised power operations of PFBR.

4.What was the motive in going for carbide fuels for our Fast Breeder Test Reactor (FBTR)? Subsequently, we have developed oxide fuels for our 500 MWe PFBR.

The FBTR was based on Rapsodie design under the French collaboration using MOX fuel (70% HEU oxide with 85% enrichment and 30% PuO₂). After the Peaceful Nuclear Explosion in 1974, we were entirely on our own at a time when the only option available was to meet the entire fissile requirement using plutonium. Our enrichment programme was under development. There were specific performance related issues with plutonium rich MOX fuel of the required PuO₂ content (76%). Especially the formation of low density compounds with sodium & fuel post clad breach. Important fuel properties like thermal conductivity of MOX with this composition would be poor and fuel oxygen potential would be higher as more and more noble fission products are formed with increased burnup of plutonium which could lead to further problems. The plutonium rich carbide fuel development work carried out in the Radiometallurgy Division in the early eighties, showed very encouraging results and fuel-coolant compatibility experiments also produced good results. Results of calculations for clad carburization during irradiation done in collaboration with Materials Group were also encouraging. And to top it all, the big bonus was lower fissile

requirement. So it was a sort of win-win situation in favour of Pu-rich mixed carbide fuels at that time. However, large scale production of mixed carbide fuel for commercial fast reactor is an extremely challenging task. As the core size is large in this case, much lower level of plutonium in the mox is warranted say 20 to 30% which is a well proven composition. Also fabrication experience had already been gained at the AFFF, Tarapur while making MOX fuel for FBTR hybrid core and the prototype pin assembly of PFBR type for irradiation test in FBTR as mentioned earlier.

5. In this context, we have developed the reprocessing technologies for carbide fuels and closed FBTR fuel cycle as demonstration effort which was indeed a difficult task. Now we have introduced oxide fuels, do you think we have acquired expertise/ availability to handle the fuel from proposed commercial fast reactors with indigenously reprocessed plutonium?

As already explained, this work is progressing very well at AFFF, Tarapur and we at NFG are confident of meeting the challenges of fuel schedules of PFBR.

6. From oxide fuels, it is planned to shift to metallic fuels for future FBR. In what way will this shift to metallic fuels, be beneficial for India's nuclear power programme?

As you know the oxide-fuelled Fast reactors are marginal breeders and rapid nuclear power generation capacity build up would not be feasible. However it would provide a sound footing for the demonstration of a commercial scale liquid metal cooled fast reactor operation to enable the growth of the second stage of our nuclear programme in a substantial way. If by that time pyro-electro-reprocessing and remote fuel fabrication technology work being done in the IGCAR attains the maturity level to initiate integrated metal fuelled fast reactor

& fuel cycle programme, the country would be on a rapid nuclear electricity generation capacity growth path as metal fuels offer much higher breeding ratios and efficiency and lower doubling time & volumes of high level nuclear waste etc.

7. The third stage of the Indian Nuclear Programme envisages large scale use of thorium as the fertile component of fuel. When do you think that use of thorium on a commercial scale, with breeding ratios greater than one to make Fast Reactor Technology self sustainable, will be reasonably feasible? There are conflicting reports from the international community and what should be our reaction to this.

The fast reactor thorium fuel cycle is yet to be demonstrated on a large scale. As you know nuclear power generation option has been going through cycles of popularity, acceptance & rejection internationally and seen both as a panacea for the energy-hungry world and also feared as a source of big trouble by some people. This together with "incidents" has given rise to wide fluctuations in the pricing of uranium in the international market. Fortunately, in India the situation has been relatively steady and we in the nuclear community have been getting good sustained support. Perhaps our outreach programmes and not so visible R&D contributions to the non-power sector for societal benefits have helped us.

It is well known that to initiate thorium programme and grow, seed fuel on a significant scale and large quantities would be required. Moreover remote handling techniques and equipment have to be developed and industrially produced to meet the requirements at various stages. That will take some time. In the meantime it is necessary for us to achieve very significant progress in the second stage where Uranium utilization can be substantially enhanced to 60% (from under 1% in the first stage)

by successfully recycling thrice in the fast reactors preferably using metallic fuels as early as possible. Even this would take some more time although progress has been made in R&D areas both in BARC as well as in IGCAR.

8. During the years that you participated in the fuel development programme, the emphasis has shifted from research to development of advanced fuels. As a metallurgist, kindly highlight the achievements in this area.

Development and fabrication campaigns are examples of very good team work. This in my opinion is the main achievement and high point. Of course my colleagues in NFG have accepted challenges and delivered fuel to many reactor types over a long period and have helped create industrial scale facilities. The pioneering leaders have laid a very effective and mutually satisfying work culture which is still continuing. We also have good R&D multidisciplinary teams in all the divisions. Work goes on across these barriers.

9. Development of new structural materials and fuel has good scope. What are your suggestions to accelerate the programme?

In the areas of structural materials we should strengthen processing & fabrication. We should also have a good MTR (Materials Testing Reactor) in addition to access offered for experiments under international collaborations. We already have a strong PIE team.

10. What is your opinion on making available small research reactors like APSARA, in universities and expanding research programme, production of isotopes etc.?

Definitely this would be very helpful in increasing the size and spread of nuclear science, technology and applications activities. However, this would take time as new systems have to be put in place. A lot

more people have to be motivated in universities and institutions.

11. The BARC Newsletter has been the preferred channel of communication for BARC Scientists and Engineers for almost three decades now and in the last three years, it has undergone a major metamorphosis. Any suggestions to improve its quality and content?

I feel, "Reader's Forum" has to be strengthened where they could comment and make suggestions.

12. What are your personal memories that you would like to share so that young scientists and engineers get motivated and what is your future vision for BARC? Where do you see BARC 20 years from now?

I cherish the contribution & association of my friends and team members. All of them have enriched me and have stood by me and tolerated my failings and shortcomings. I also thank my seniors and mentors who have supported and guided me all these years.

The Younger generation is skilled, practical, equipped and has better background. However, it would take them a long way if virtues of patience and tolerance are also practised by them.

We have a strong road map and with better and faster implementation of plan projects, I am sure, BARC would have a very bright future both at Trombay and Visakapatnam

I thank you all for giving me this opportunity to discuss with you.

Development of ICMC-1.0 Monte Carlo Code for Neutron and Particle Transport

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and

P.P.K. Venkata
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Abstract

The Intra-nuclear Cascade Monte Carlo (ICMC) code for transport of neutrons, protons, pions and heavy ions has been developed at Nuclear Physics Division, BARC in the last few years, and further developments are underway. We have developed the code for low energy neutron transport using pointwise cross section data below 20 MeV of neutron energy. Constructive Solid Geometry model, based on solid bodies, is adopted to construct geometry. A module for repetitive structure for lattice, core calculations in reactors and detector simulations is developed. A Graphical User Interface (GUI) has been incorporated for making the input, construction and visualization of the geometry and analysis of the output. The code has been validated for simulating benchmarks of accelerator driven sub-critical systems, neutron shielding, heat and neutron flux distribution, and k_{eff} of the critical and sub-critical assemblies.

Introduction

The statistical nature of nuclear reactions and propagation of particles through matter can be best simulated using the Monte Carlo method. This method is most suited to solve multi-dimensional problems, involving complex geometries and variation of cross sections with energy. The accuracy is limited only by the uncertainty in the input data such as cross sections. It provides a solution to the integral equation using random sampling in space [1]. The Monte Carlo method, used in simulation of nuclear reactions, is based upon generation of individual particle histories using random sampling methods. It can provide estimates of desired quantities such as k_{eff} or flux which would be obtainable from a solution to the transport equation using random sampling in space without obtaining a detailed or complete solution of the transport equation. The probability of interaction is simulated with the help of random numbers and cross sections and these are primary input quantities which determine the accuracy of the method.

There are several Monte carlo codes named GEANT4 [2], FLUKA [3], PHITS [4], MCNP [5], MARS [6] for particle transport in matter. Some of these codes (GEANT4, FLUKA, and MARS) are suitable for detector optimization and high energy physics simulations. The other Monte Carlo codes viz. MCNP and TRIPOLI [7] use the continuous energy neutron cross-sections and are suitable for reactor simulations.

The Monali code [8] developed several years back uses multigroup cross section data library. Thus a need was felt to develop a continuous energy code in this centre.

The development of ICMC code along with GUI was started a couple of years ago. We have adopted Constructive Solid Geometry (CSG) model [9] for the construction of Geometry. Repetitive structure is introduced to perform lattice calculations. Continuous energy cross-section representation is used to take into account the details of the resonance structure. The article is organized as follows: Section 2 describes the implementation of

the geometry and the neutron transport is detailed in Section 3. Sec. 4 contains a description about the GUI. The high energy part of the code is described in Sec. 5. Conclusions and further developments are discussed in Sec. 6.

Construction of Geometry

The most important and difficult task in the Monte Carlo code is to build a complicated geometry in a user friendly manner. We have chosen the CSG model to build the geometry. In this model, there are simple basic geometrical bodies viz. Sphere, Cylinder, Box, Cone, Ellipse, Hexagon etc. Boolean operations (Union, subtraction and intersection) are used to construct complex zones using these bodies. We must also provide a universe that contains all the geometrical structures. Fig. 1 gives an example to construct the zones from the bodies. Eight heterogeneous zones from three spherical bodies and a universe are made which can be filled with various materials.

Scaling, rotation and translation of the bodies are used to make more complicated structures. Repeated geometry structures are invoked to perform lattice and core calculations of complicated reactor assemblies. Fig. 2 shows an example of repeated

structures which are made of different types of fuel rods. Bare minimum information viz. number of rods, radius of the ring on which rods are to be placed, and the center of the repeated structures has to be provided by the user. Reflective boundary conditions are used to do single lattice/cell or partial core calculations.

The transport algorithm is generalized for the non-intersecting assemblies/bodies (physically separated by vacuum), white/reflecting boundaries, and repeated structures. A geometry debugger is introduced to search overlapping/common volumes due to improper dimensions supplied by the user.

Low energy neutron transport

The Low energy neutron transport code has been developed recently. We have developed the package for reading pointwise cross sections for neutron in ACE (A Compact ENDF) format using arrays with dynamically allocatable memory. The ACE library generated using ENDF VII.0 is used for the present investigations. Interaction of neutrons is considered using the Monte Carlo method as per the following steps.

- 1) Identification of the initial zone number and point of interaction of the neutron,

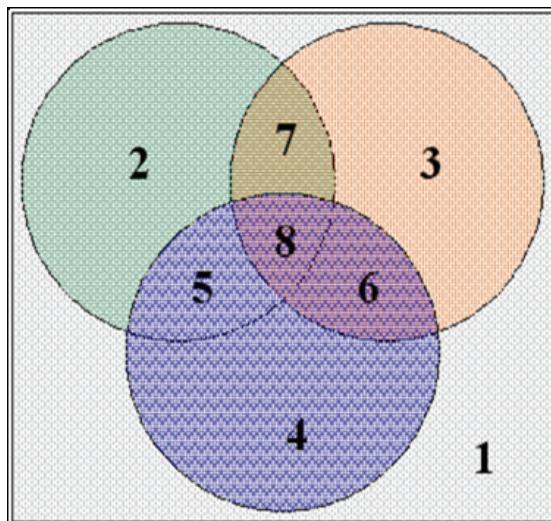


Fig. 1: CSG geometry model with four bodies consisting of one box as the universe and three spheres. Here eight zones (denoted by 1-8) are constructed with various Boolean operations (union, subtraction and intersection) on the bodies

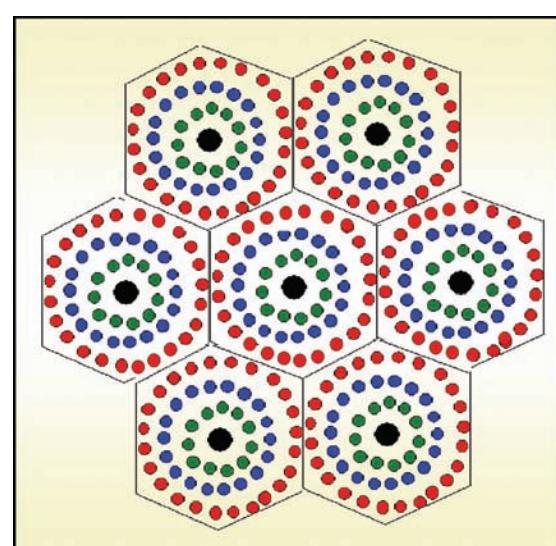


Fig. 2: Repetitive structure which can be created using translation operation. Four different colours (red, blue, green and black) represent different fuel elements

- 2) Selection of the collision nuclide,
- 3) Type of interaction (elastic, non-elastic, fission, capture, others).

ICMC-1.0 assigns the X, Y, Z, cos θ , sin θ , cos ϕ , energy (MeV), charge, and mass(MeV/C²) coordinates with each neutron. The code identifies the zone number constituted from the given bodies of the configuration defined in the input file. The macroscopic cross section is calculated to get the mean free path in the identified zone which is used to sample the distance to the next collision. The nuclide with which the collision takes place is identified using the fact that probability of interaction with a given nuclide is proportional to the total macroscopic cross-section of that nuclide. The final search is made for reaction type with the identified nuclide. One complete history consists of nuclear interactions; secondary particle production and their transport till predefined cutoff energies are reached. The neutron cutoff energy is defined to be 1×10^{-12} MeV in the present version of the code.

The criticality calculations in ICMC-1.0 are based on four methods (neutron population, Collision Estimator, Absorption Estimator, and Track Length Estimator). The k_{eff} is a ratio between the number of neutrons in successive generations in a fission chain reaction. For critical systems, $k_{\text{eff}} = 1$, for sub-critical systems, $k_{\text{eff}} < 1$ and for supercritical systems, $k_{\text{eff}} > 1$. The number of neutrons in successive generations is obtained from number of neutrons generated by fission. Whenever (n, xn) reactions occur, the neutrons generated are again transported within the same fission cycle. At present fission source points as well as neutron generations are as usual allowed as other reactions but stored for the next cycle. At the end of each cycle the total weight is maintained constant by increasing or decreasing weight of neutrons in case of ($k_{\text{eff}} > 1$) and ($k_{\text{eff}} < 1$), respectively. The maximum likelihood k_{eff} of the system from all four estimators is calculated using weighted mean where weight is given by inverse of the squared error from individual

estimators. Error in the mean k_{eff} is also calculated similarly. The prompt energy spectrum is used in place of the delayed energy spectrum in case the latter is not available. The criticality calculation requires number of inactive cycles which need to be skipped to get the fundamental mode of fission source, active cycles for actual k_{eff} , and number of source neutrons. Mono energetic neutron can be defined very easily in the input file and spectrum can be provided through a separate file. In case of high energy proton or other beam, the source distribution is generated using the high energy part of the code and that is transported below 20 MeV. More than fifteen problems for fast, thermal and ADS systems for criticality benchmark have been simulated. Some of the results for few problems are given in Table 1. The geometries for the first five problems are shown in Fig. 3. Brief description of the simulated systems is given below:

Prob.1 is an enriched ^{235}U (93.71%) sphere of radius 8.741cm consisting 52.42kg of mass and density 18.74g/cc rest is ^{238}U .

Prob.2 is an enriched ^{239}Pu (95.5%) sphere of radius 6.385cm consisting 17.02kg of mass and density 15.61g/cc rest is ^{240}U .

Prob.3 is an enriched ^{239}Pu (80%) sphere of radius 6.66cm consisting 19.46kg of mass and density 15.73g/cc rest is ^{240}U .

Table 1: Values of k_{eff} for some of the experimental assemblies along with MCNP values from literature [10] are given. Here errors are estimated with most likelihood method for all four estimators

Problem # / Code	ICMC-1.0	MCNP
1	0.9963 ± 0.0008	0.9962 ± 0.0009
2	1.0047 ± 0.0003	1.0052 ± 0.0006
3	1.0086 ± 0.0004	1.0097 ± 0.0002
4	0.9910 ± 0.0008	0.9915 ± 0.0005
5	0.9906 ± 0.0004	0.9908 ± 0.0006
6	0.8872 ± 0.0004	0.8865 ± 0.0001
7	0.9948 ± 0.0005	0.9952 ± 0.0003
8	0.9946 ± 0.0007	0.9951 ± 0.0006

Prob.4 is an enriched ^{235}U (10.9%) cylinder of radius 26.65cm, Height=119.392cm and density 18.63g/cc rest is ^{238}U .

Prob.5 is an enriched ^{235}U (14.11%) cylinder of radius 26.65cm, Height=44.239cm and density 18.41g/cc rest is ^{238}U .

Prob.6 is an enriched ^{239}Pu (100.0%) cylinder of radius=4.935cm, Height=6.909cm and density=18.80g/cc. It is surrounded with Natural uranium reflector of Thickness=5cm, Height=6.909cm.

Prob. 7 is an enriched ^{235}U (93.5%) sphere of radius 7.3984cm and density=18.6g/cc. The sphere is surrounded by graphite of 5.1cm thickness. The graphite consists of 99.5% Carbon, 0.34% iron and 0.16% sulfur. Density of graphite is 1.67g/cc.

Prob.8 is an enriched ^{235}U (97.67%) sphere of radius 6.5537cm consisting of 22.16kg mass and density 18.794g/cc. The sphere is surrounded by water tank of radius 30cm and height 70cm.

It is found that the calculated values from ICMC-1.0 are very close to the results obtained with another standard code like MCNP. The average value of k_{eff} is obtained from the maximum likelihood method of the values obtained from all four estimators.

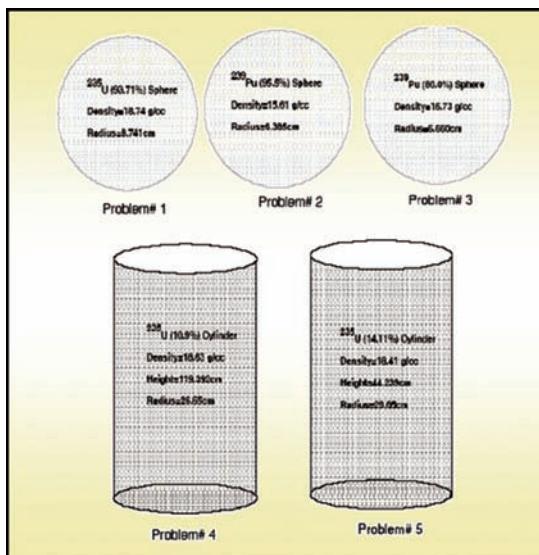


Fig. 3: Geometries of the critical assemblies simulated using ICMC-1.0.

Graphical User Interface

Graphical User Interface (GUI) along with data visualization is a powerful tool required for supporting such ambitious software. The GUI and the visualization modules are developed by Computer Division. Development of these modules is done in *Python* language using the base libraries of *Visualization Toolkit* [11] for visualization and *WxPython* for GUI. The communication between the GUI and the Monte-Carlo code is through loose coupling, i.e. both these modules are independent of each other and the communication is through external files. The GUI and visualization modules are developed for cross-platform usage, so that they can be run on all windows and Linux platforms. One snapshot of the geometry from Ubuntu Linux machine is given in Fig.4.

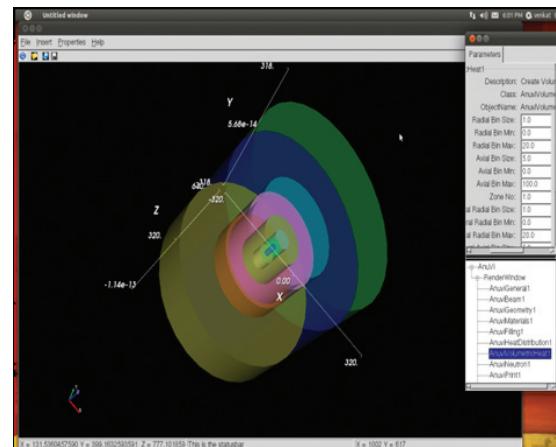


Fig. 4: Snapshot of ICMC-1.0 GUI depicting concentric cylinders

To construct the geometry, all Boolean operations viz. union, subtraction, intersection are available in this framework to make complex zones from the basic bodies. Scaling, rotation and translation of the basic bodies is supported. This information is saved in a text input file and then ICMC code can be run either through terminal/command prompt or from the GUI button itself. Standard features viz. showing 3D-axis around bodies, taking snapshots are provided.

The most important feature of the GUI is to visualize and correct the geometry in 3-dimensions. Overlapping regions (if any) after scaling, rotation, and translation can be easily identified and corrected before running the Monte-Carlo code.

High energy particle transport

Monte Carlo program ICMC-1.0 also has the capability of high energy particle transport which is borrowed from CASCADE.04 [12-14] and its further developments [15-16]. It incorporates Intra-nuclear Cascade, Pre-equilibrium, Evaporation and Fission models to simulate spallation reaction mechanism for thin and thick targets. Treatment of cutoff energy from Intra-nuclear to pre-equilibrium and next to evaporation stage was modified later [17].

Benchmark of spallation models for experimental values of neutron, charged particles, and pions double differential production cross-sections, particle multiplicities, spallation residues and excitation functions was organized by IAEA and is given in Ref. [17]. Heat Deposition algorithm for thick spallation targets and thin films was modified and benchmarked as mentioned in Ref. [13]. The code was further developed for the Neutron shielding and dosimetry applications and published [14]. The high energy part of this code can be used for single nucleus interaction for basic reaction studies and transport of particles in thick target. Energy loss of the charge particle is calculated during the transport through thick target.

The flow chart of the code is given in Fig. 5, where, particle transport as well as single nucleus interactions are mentioned. This is an integral code to study Accelerator Driven Sub-critical systems with user defined options to be supplied by the user.

Conclusion and Future Development

The Monte Carlo code ICMC-1.0 has been developed for ADS, Spallation reactions, reactor physics, dosimetry, and shielding applications. New CSG model with Union, Subtraction and Intersection Boolean operations is developed to make the heterogeneous zones. Scaling, rotation, and

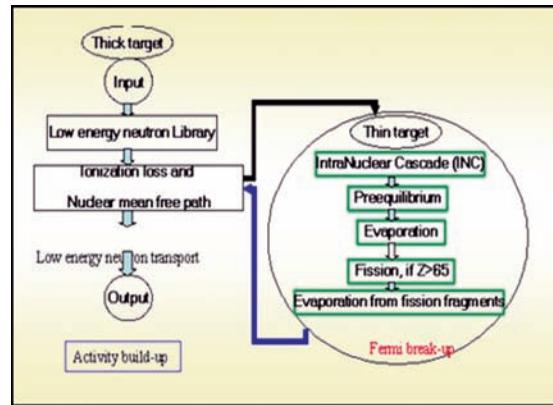


Fig. 5: Flow chart of the neutron/particle transport

translation operations are used to make more complex zones. Repeated geometry model has been developed for simulation of any complex reactor designs as well as the detector simulations. The pointwise cross section data for neutrons below 20MeV are used and we have developed a package for reading these cross sections in the ACE format using dynamically allocatable memory. The $S(\alpha, \hat{\alpha})$ scattering matrices for neutron energy $< 4\text{eV}$ is used if it is available in the library for the given compound element, otherwise Fermi-gas treatment is used. The code has been benchmarked for k_{eff} values simulated for many simple experimental assemblies and is under extensive benchmark for different assemblies including real Thorium Plutonium MOX fuel based AHWR system. List of fission products and their spatial distribution can be analyzed using this code at time $T=0$.

The code will be further developed for reactor burnup, decay heat, and waste management issues. In this development, we have generated one library of ~ 3700 isotopes to simulate the decay quantities viz. decay heat, neutrino flux etc. This library is generated from the ENDF VII.0 in which isotopes up to nano-second half lives are included. The library includes decay through e^- , e^+ , EC, α and γ decay channels. Ingestion and inhalation toxicity is also included in this library to include these aspects of waste management. This work package will be completed after the development of decay model. The code is under development for photon and

electron transport. The parallel version of the code is also in progress.

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Development of Catalyst for Decomposition of Sulfuric Acid: The Energy Intensive Step in Sulfur-Iodine Thermochemical Cycle for Hydrogen Generation using Nuclear Heat

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Abstract

We report here the in-house catalyst development work undertaken at Chemistry Division on sulfuric acid decomposition reaction, the most endothermic step of Sulfur-Iodine (S-I) thermochemical cycle being pursued in the DAE for large scale hydrogen generation using the proposed Compact High Temperature Reactor (CHTR). Various catalyst systems like iron oxide, substituted iron oxide and ferrites were evaluated in the temperature range of 600-825°C employing indigenously developed glass setups. Owing to higher activity, iron oxide based catalysts were investigated in detail for their possible deployment in an integrated glass setup of S-I process at Chemical Technology Division. Comparative studies on iron oxide based catalysts (Fe_2O_3 & $\text{Fe}_{1.8}\text{Cr}_{0.2}\text{O}_3$) with a commercial Pt catalyst ($\text{Pt}/\text{Al}_2\text{O}_3$) have demonstrated that both Cr-substituted and un-substituted iron oxides are active for catalytic decomposition of sulfuric acid and are comparable to $\text{Pt}/\text{Al}_2\text{O}_3$ at temperatures above 750 °C and may therefore be a good substitute for the noble metal catalyst. The study has also established the poison resistant behavior of $\text{Fe}_{1.8}\text{Cr}_{0.2}\text{O}_3$ catalyst in presence of I/I_2 impurities which are likely to be present in the sulfuric acid phase produced in the Bunsen section of S-I process.

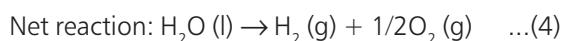
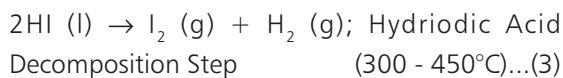
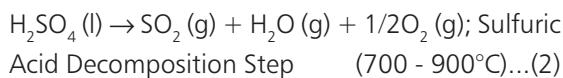
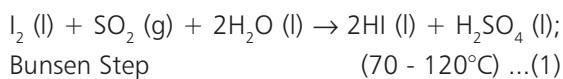
Introduction

Exploration of alternate energy resources has attained greater significance in recent times due to ever-increasing worldwide energy demands, depleting fossil resources and growing concern about global warming caused by the emission of greenhouse gases. Hydrogen, being a clean and renewable energy carrier, offers a promising alternative to the fossil fuels, particularly for the transport applications using fuel cell technology. At present, it is largely produced by steam reforming of hydrocarbons such as steam methane reforming (SMR) but the process suffers from a major drawback i.e. generation of CO_2 , a green house gas, as a by-product. More recently, two processes namely, thermochemical splitting and high temperature electrolysis of water have shown great potential towards efficient

production of hydrogen on industrial scale¹. Energy requirements for these processes are expected to be met by high temperature nuclear reactor or solar concentrator as viable alternatives to carbonaceous resources.

While thermal decomposition of water requires a temperature in excess of 2500°C ($\text{H}_2\text{O}=\text{H}_2 + 1/2\text{O}_2$; $\Delta G^0 = 237 \text{ kJ/mol}$), thermochemical cycles produce hydrogen from water through a number of chemical reactions involving intermediates that are fully recyclable^{1,2}. Among various thermochemical cycles proposed for hydrogen generation, Sulphur – Iodine (S-I) process is widely considered as a potential choice to produce hydrogen on industrial scale due to its attractive features such as higher energy efficiency (~47%), all fluids process

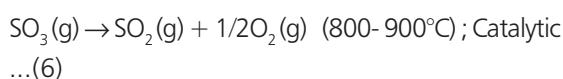
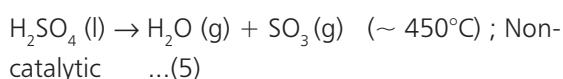
and adaptability with a high temperature nuclear reactor ($\sim 950^{\circ}\text{C}$)³. S-I thermochemical cycle, originally proposed by General Atomics, involves the following chemical reactions:



The free energy required for the net reaction is provided by the free energies of the individual reactions of the S-I thermochemical cycle. The most energy demanding step of this cycle namely, sulfuric acid decomposition (Eqn. 2) effectively utilizes the intense heat flux from the high temperature nuclear reactor and kinetics of this step has a strong influence on the efficiency of S-I thermochemical cycle.

Catalytic decomposition of sulfuric acid

Decomposition of sulphuric acid (Eqn.2) occurs in two steps, one non-catalytic and the other a catalytic one, as shown below:



The thermal decomposition of SO_3 encounters a large kinetic barrier⁴ ($E_a = 73 \text{ kJ mol}^{-1}$) and even at high temperatures such as that of the coolant gas ($600 - 950^{\circ}\text{C}$) carrying heat from nuclear reactor it does not take place without a catalyst. Thus to achieve high levels of chemical conversion in a rapid manner, an efficient catalyst would be essential for the SO_3 decomposition reaction.

Work reported in literature

Various catalysts reported to be active for decomposition of sulfuric acid include noble metal, metal oxides and mixed- metal oxides⁴⁻⁹. Besides activity, the stability of the catalyst is also very

important as the reaction environment is extremely hostile like high temperatures, presence of aggressive chemicals, including high temperature steam, oxygen and sulphur oxides. While noble metal catalysts like Pt/ZrO_2 , Pt/TiO_2 , Pt/BaSO_4 and $\text{Pt/AI}_2\text{O}_3$ are reported to be quite active for SO_3 decomposition reaction, phenomenon like oxidation of noble metal, sintering of metal particles, loss of active metal, sulfation of the support, have been observed during their long term use leading to their deactivation^{5,7}. The metal oxides were reported to be active only over the temperature region in which the corresponding sulfates were unstable. Tagawa and Endo⁶ have compared the activity of metal oxides for the sulfuric acid decomposition in the range of $600-950^{\circ}\text{C}$ and found the order as follows: $\text{Pt} \approx \text{Cr}_2\text{O}_3 > \text{Fe}_2\text{O}_3 > \text{CeO}_2 > \text{NiO} > \text{Al}_2\text{O}_3$. In a recent study involving complex metal oxides Ginosar et al⁸ have reported CuFe_2O_4 and $2\text{CuO} \cdot \text{Cr}_2\text{O}_3$ to be more active than 1.0 wt% Pt/TiO_2 at temperatures above 850°C .

Work at Chemistry Division, BARC

In view of the availability of high-grade heat from the proposed Compact High Temperature Reactor (CHTR), work on S-I cycle started at BARC in 2006. Studies on catalytic decomposition of sulfuric acid were also initiated in the same year at Chemistry Division with an objective to develop non-noble metal catalysts which are both active and stable under harsh reaction conditions existing over the long hours of operation of reactor heat extraction cum acid decomposition step of the S-I cycle. Various oxides/mixed oxides and ferrites were evaluated for this purpose⁹⁻¹¹. Among these, iron oxide based catalysts (Fe_2O_3 & $\text{Fe}_{1.8}\text{Cr}_{0.2}\text{O}_3$) were found to be promising and were investigated in detail for their possible deployment in an integrated glass setup for S-I process at Chemical Technology Division (CTD).

Following is an overview of the work related to catalytic decomposition of sulfuric acid carried out at Chemistry Division in recent past:

(i) Preparation of catalysts

Iron oxide and chromium substituted iron oxide ($\text{Fe}_{1.8}\text{Cr}_{0.2}\text{O}_3$) catalysts were synthesized by precipitation/co-precipitation routes employing respective nitrates as metal precursors and ammonium hydroxide as a precipitating agent followed by drying at 80°C in air oven and calcination at 700 °C⁹. The synthesized powder samples of the catalysts were processed in the granular form (4-6 mm) using polyvinyl alcohol (PVA) as a binder¹⁰. ECMS, Vashi, Navi-Mumbai, established the fabrication procedure of Fe_2O_3 & $\text{Fe}_{1.8}\text{Cr}_{0.2}\text{O}_3$ granules. The ferrites (AFe_2O_4 , A = Co, Ni, Cu) were synthesized by gel combustion method using aqueous solution of corresponding metal nitrates and glycine ($\text{NH}_2\text{CH}_2\text{COOH}$) as per the procedure described elsewhere¹¹.

(ii) Development of acid decomposition setups

Two glass setups, as shown in Fig. 1, were developed in-house^{10,11} to study the catalytic decomposition of sulfuric acid at lab scale in temperature range of 600–850 °C. The setup shown in Fig. 1 A&B, primarily used for screening the powder samples (0.2-0.5 g, 200-300 mesh), employed nitrogen to carry sulfuric acid vapours (produced in the pre-heater via injection of concentrated sulfuric acid through a syringe pump) to the catalyst in a fixed bed reactor. The other set up (Fig. 1 C&D), on the other hand, had an integrated boiler, pre-heater and acid decomposer and was used for long-term performance evaluation

of a granular catalyst (20 g, 4-6 mm diameter nearly spherical granules).

(iii) Development of analytical methods for product analysis

Iodimetry and acidimetry were used for ex-situ product analysis of SO_2 and un-reacted sulfuric acid, respectively. In a typical analysis protocol SO_2 formed during the decomposition reaction was collected in an iodine trap (0.1 to 0.6 M Iodine in KI) at room temperature and the un-reacted iodine was titrated with sodium thiosulfate solution (0.1 M) using starch indicator while sulfuric acid formed during reaction of SO_3 (unreacted) and water vapour was estimated by potentiometric titration employing NaOH as a titrant. An alkali trap (0.1 N NaOH) was also employed in some of the experiments for trapping SO_2 . Percentage SO_2 yield was calculated as given below:

$$\text{Percentage SO}_2 \text{ Yield} =$$

$$\frac{\text{No. of moles SO}_2 \text{ produced}}{\text{Total moles of Sulfuric acid used}} \times 100$$

(iv) Screening of catalysts for decomposition of sulfuric acid

Among iron oxide based catalysts (Fe_2O_3 , $\text{Fe}_{1.8}\text{Cr}_{0.2}\text{O}_3$) and ferrites (CuFe_2O_4 , CoFe_2O_4 , and NiFe_2O_4), the former exhibited higher activity for sulfuric acid decomposition reaction (Fig. 2) and hence subjected to detailed investigations and comparison with a commercial $\text{Pt}/\text{Al}_2\text{O}_3$ catalyst for their possible deployment (in granular form) in an integrated glass setup of S-I process at CTD.



Fig. 1: Sulfuric acid decomposition setups: (A) For powder catalyst, (C) For granular catalyst. (B) and (D) are the schematics of setup (A) & (C).

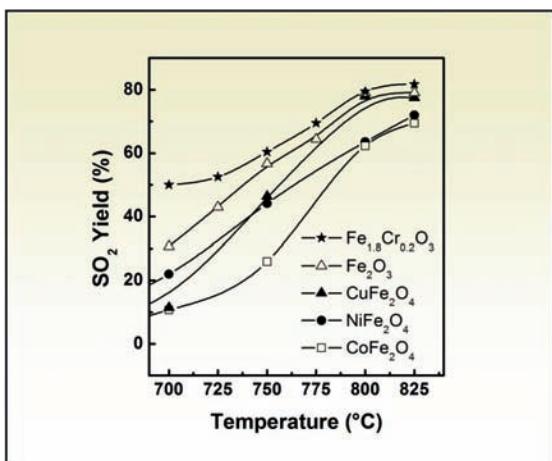


Fig. 2: Temperature dependent SO₂ yield during decomposition of sulfuric acid over different powder samples. Catalysts amount: 0.2 g; Acid (liquid) feed rate: 0.05 ml min⁻¹ in N₂ carrier gas (flow rate: 40 cc/min).

(v) Comparative studies on Fe₂O₃ based catalysts and a commercial Pt/Al₂O₃ catalyst
Comparative studies on catalyst performance as a function of temperature, time and acid flux were carried out on granular Fe₂O₃, Fe_{1.8}Cr_{0.2}O₃ and Pt (0.5 wt. %)/Al₂O₃ catalysts under identical conditions. Table 1 presents comparative activities of these catalysts as a function of temperature. As can be seen in Table 1, at temperatures \leq 700 °C, Pt/Al₂O₃ yielded higher amount of SO₂ than that observed on both Fe₂O₃ and Fe_{1.8}Cr_{0.2}O₃ while at higher temperatures (\geq 750 °C) the activities of the Fe_{1.8}Cr_{0.2}O₃ and Pt/Al₂O₃ catalysts were found to be comparable.

Long-term performance of Fe₂O₃, Fe_{1.8}Cr_{0.2}O₃ and Pt/Al₂O₃ catalysts for sulfuric acid decomposition

Table 1: Activity comparison of Fe₂O₃, Fe_{1.8}Cr_{0.2}O₃ and Pt/Al₂O₃ catalysts for sulfuric acid decomposition (20 g granular catalyst in 2.5 cm column; acid flux: \sim 0.6 ml min⁻¹)

Temp.(°C)	Fe ₂ O ₃	% SO ₂ Yield Fe _{1.8} Cr _{0.2} O ₃	Pt/Al ₂ O ₃
700	7.5	24	33.7
725	21.3	55.5	56.5
750	42.7	62.5	62
775	62.6	70	70.5
800	70.5	78	77.5
825	76.5	82	81.7

reaction evaluated at 800 °C during 100 h run using an acid flux of \sim 0.6 ml/min revealed negligible deterioration in the catalytic activity, as shown in Fig. 3. However, with increasing acid flux (> 1 ml/min) deterioration in the activity at 800 °C was more drastic for oxide catalysts and followed the order: Fe₂O₃ > Fe_{1.8}Cr_{0.2}O₃ > Pt/Al₂O₃.

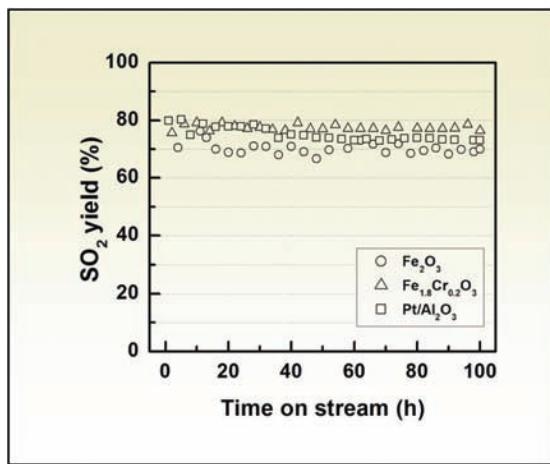


Fig. 3: Prolonged performance of Fe₂O₃, Fe_{1.8}Cr_{0.2}O₃ and Pt/Al₂O₃ catalysts for sulfuric acid (acid flux: \sim 0.6 ml min⁻¹) decomposition during 100 h run at 800 °C (20 g granular catalyst in 2.5 cm column; see setup (Fig. 1C&D)).

(vi) Poisoning studies on Fe_{1.8}Cr_{0.2}O₃ catalyst

Poisoning studies carried out, in the temperature range of 700 - 825 °C, in the presence of HI (x_{HI} : 4.5×10^{-5} - 3.8×10^{-3}) and I₂ (x_{I_2} : 2.5×10^{-5} - 9×10^{-4}) impurities (likely to be present in the sulfuric acid phase produced in the Bunsen section of the S-I process) showed no deterioration in the performance of Fe_{1.8}Cr_{0.2}O₃ catalyst at temperatures $>$ 700 °C. SO₂ yield in presence of these impurities remained almost constant at \sim 78% at 800 °C during 20 h run, which is quite close to the equilibrium yield value (80%) at this temperature.

(vii) Characterization of spent catalysts

Table 2 presents results on textural characterization of fresh and spent catalysts. As compared to the fresh Fe₂O₃ and Fe_{1.8}Cr_{0.2}O₃ XRD, IR, XPS and SEM-EDX examination of the used samples showed (a) sintering of catalyst, and (b) presence of sulfate species¹². Similar results were observed with used

Table 2: Textural characterization of fresh and used catalysts

Sample	BET surface area (m ² g ⁻¹)	Crystallite size* (nm)	Metal Dispersion (%)
Fresh Fe ₂ O ₃	17	50	-
Used Fe ₂ O ₃	13	67	-
Fresh Fe _{1.8} Cr _{0.2} O ₃	18	48	-
Used Fe _{1.8} Cr _{0.2} O ₃	4	80	-
Fresh Pt (0.5 wt%)/ Al ₂ O ₃	261	51 ^a	71
Used Pt (0.5 wt%)/ Al ₂ O ₃	145	137 ^a	1

*- calculated from XRD data using Scherer's formula

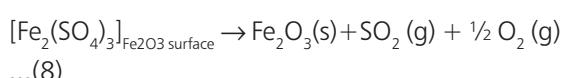
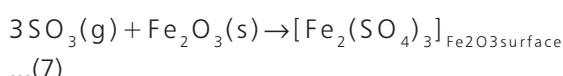
^a- γ-alumina crystallites

Pt/Al₂O₃. In addition agglomeration of platinum particles (Fresh catalyst- 2-5 nm; Used sample: up to 80 nm) was revealed during TEM study of used catalyst.

(viii) Mechanism of sulfuric acid decomposition

- *Iron oxide based catalysts*

The presence of surface sulfate species on the used iron oxide based catalysts suggested their role in the sulfuric acid decomposition reaction. A plausible reaction mechanism involving formation and decomposition of metal sulfates proposed for SO₃ decomposition is given below¹⁰:



In comparison to Fe₂O₃, higher activity observed for the Cr-substituted iron oxide is attributed to the improved redox behaviour and lower stability of the sulfate species^{9,10}.

- *Platinum/alumina catalyst*

SO₃ to SO₂ conversion is reported to occur on supported platinum surface¹² via adsorption and formation of adduct [SO₂.O] on the active sites followed by decomposition to the products SO₂ and O₂. It is further reported that prolonged exposure to the acid vapor at high temperature results in agglomeration of Pt particles, sulfation of support and leaching of Pt leading to deterioration of catalytic

performance^{7,12}. In the present study, agglomeration of Pt particles, sintering of alumina support and presence of sulfate species on the used Pt/Al₂O₃ catalyst though observed there is negligible deterioration in the performance (Fig. 3). The retained activity during 100 h run of the supported platinum catalyst could be explained by the involvement of the substrate, the sub-surface of which contains Pt atoms that are accessible by the acid vapor. The post analysis of the used catalyst in fact shows the evidence of sulfate/oxysulfate [Al₂(SO₄)₃/Al₂O(SO₄)₂] species.

Conclusions

Work on catalyst development for decomposition of sulfuric acid at Chemistry Division was focussed on non-noble metal systems and involved screening of iron oxide, Cr-substituted iron oxides and ferrites (nickel, cobalt and copper ferrites) in an indigenously developed decomposition setup in temperature range 650-825 °C. Owing to higher activity, iron oxides based catalysts (Fe₂O₃ and Fe_{1.8}Cr_{0.2}O₃) were investigated in detail and also compared with a commercial Pt/Al₂O₃ catalyst for their possible deployment in an integrated glass setup of S-I process at Chemical Technology Division, for which about a kilogram each of the granular catalysts has been made available. The results have shown that iron oxide based catalysts can be a suitable substitute for noble metal catalysts at temperatures above 750 °C and may play an effective role in utilization of intense heat flux from the high temperature

nuclear reactor for decomposition of sulfuric acid towards realization of the goal of S-I process for large scale hydrogen generation.

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Engineering Scale Demonstration Facility for Actinide Partitioning of High Level Waste

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Abstract

The Indian nuclear power programme is sustained by the adoption of a closed fuel cycle wherein the fissile and fertile materials are recycled by reprocessing of spent fuel. The reprocessing step leads to the generation of high level waste (HLW) which is presently vitrified using borosilicate matrices. With the nuclear power profile on the verge of an exponential increase, it becomes imperative to consider and adopt cross-cut technologies that would not only lead to a substantial reduction in repository capacity both in terms of volumes and thermal loads but also lead to a reduction in radiotoxicity of the waste forms. Partitioning of high level waste is the first step towards achieving the above objectives. Towards these objectives, an engineering scale demonstration facility for partitioning of actual high level liquid waste (HLLW) from reprocessing of PHWR fuel has been set up at BARC, Tarapur. Not only will this facility address routine recovery of residual uranium from HLLW leading to higher waste loading in glass, but also serve as a test facility for partitioning of minor actinides from uranium lean HLLW. With the successful cold commissioning of this facility, a milestone has been achieved towards induction of partitioning technology for radioactive high level liquid waste.

Introduction

The Actinide Separation Demonstration Facility (ASDF) has been set up at BARC, Tarapur with an objective of testing the partitioning processes with actual HLLW waste on an industrial scale. The facility has been designed based on a structured R&D being pursued on laboratory scale followed by bench scale and inactive engineering scale. This has culminated

into a three step solvent extraction process for adoption with actual waste. The three steps, engineered as corresponding cycles, with the respective solvent system are detailed in Table 1 along with their developmental status. Operational experiences of this facility are expected to serve as a benchmark for induction of this technology in future back-end facilities.

Table 1: Summary of the R&D Programme on Actinide Partitioning of High Level Liquid Waste

Step	Solvent System	Developmental status
Cycle I: Removal of residual U and Pu	PUREX (TBP) 30% TBP in n-dodecane	<ul style="list-style-type: none"> Laboratory : using actual HLW Engineering scale: using simulated waste
Cycle II: Bulk Separation of minor actinides with lanthanides	TRUEX (CMPO) 0.2 M CMPO + 1.2 M TBP in n-dodecane	<ul style="list-style-type: none"> laboratory :using actual HLW Engineering scale: using simulated waste
	Amide (TEHDGA) 0.2 M TEHDGA + 30% isodecyl alcohol in n-dodecane	<ul style="list-style-type: none"> Laboratory: using actual HLW Engineering scale: using simulated waste
Cycle III: Actinide Lanthanide Group Separation	TALSPEAK (D ₂ EHPA) 0.2 M D ₂ EHPA in n-dodecane	<ul style="list-style-type: none"> Laboratory: using actual waste Engineering scale: using simulated waste
	Polydendate(aza-amide)	Evaluation in progress

Facility Description

The facility has been designed as per the conventional basis of design of radiochemical plant to demonstrate the partitioning process on a throughput to match vitrification capacities (~30LPH). As the actinide separation demonstration facility had to be retrofitted in one of the existing hot cells, the choice of the contactors had to account for the limited head room



Fig. 1: Actinide Separation Demonstration Facility,
BARC, Tarapur

available and relatively larger number of stages required for the separation process. Suitably designed Combined Air Lift based mixer settler contactor (CALmsu) has been therefore deployed in the facility. The three independent cycles have been engineered for simultaneous operation of extractor and stripper with the solvent in recycle mode. While Fig. 1 shows the photograph of the ASDF Facility, Fig. 2 depicts the schematic of the uranium separation cycle as an example of a typical cycle.

It is well recognized that operation of such a facility will lead to generation of secondary streams that have to be suitably addressed including spent solvents from the three cycles. In this regard, ASDF Facility has a spent solvent management facility co-located with it (Fig.3) to address management of PUREX solvent and to serve as a test facility for other solvent systems (including their decontamination & reuse). Fig. 4. gives the overall block diagram of the integrated facilities.

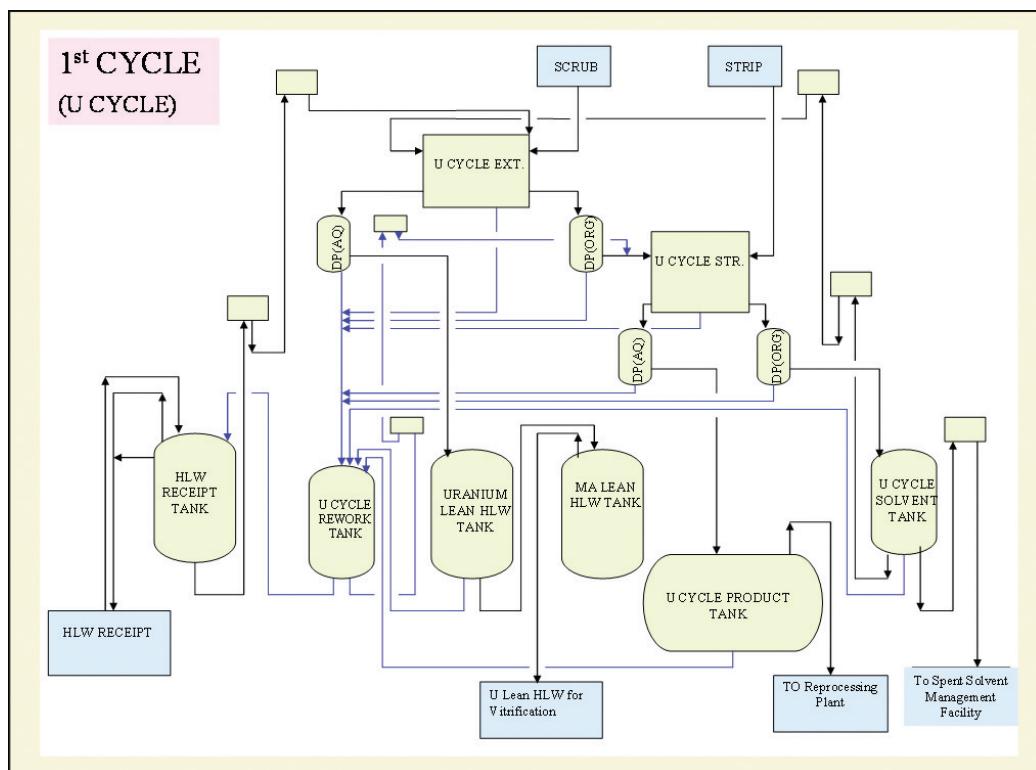


Fig. 2: Schematic of a typical Cycle (Cycle 1)



Fig. 3: Spent Solvent Management Facility integrated with ASDF

The uranium rich product stream of the first cycle will be sent to the reprocessing plants via pipelines on a routine basis. The streams containing the product of interest (Minor actinide) will be stored inside the cell itself. Provisions have been made to transfer these solutions into shielded glove boxes to facilitate further R&D work.

Overall Process Description

The active facility has been designed based on the following process developed in-house. As a pretreatment step, HLW will be first contacted with 30% TBP to separate the residual uranium and plutonium from HLW. The recovered uranium and plutonium will be recycled back to the reprocessing facility.

The raffinate of the first cycle, namely, U lean HLW will be contacted with diglycol amide based solvent THEDGA, resulting in separation of all trivalent actinides along with lanthanides from HLW. The stripped product from this cycle containing almost all the lanthanides and actinides associated with HLW will be taken up for further processing. The actinide and lanthanide depleted HLW which forms the raffinate of the second cycle will be sent back for vitrification. This cycle can also be used for demonstrating the process using CMPO based TRUEX solvent as against TEHDGA. Validation of these two steps on laboratory scale batch

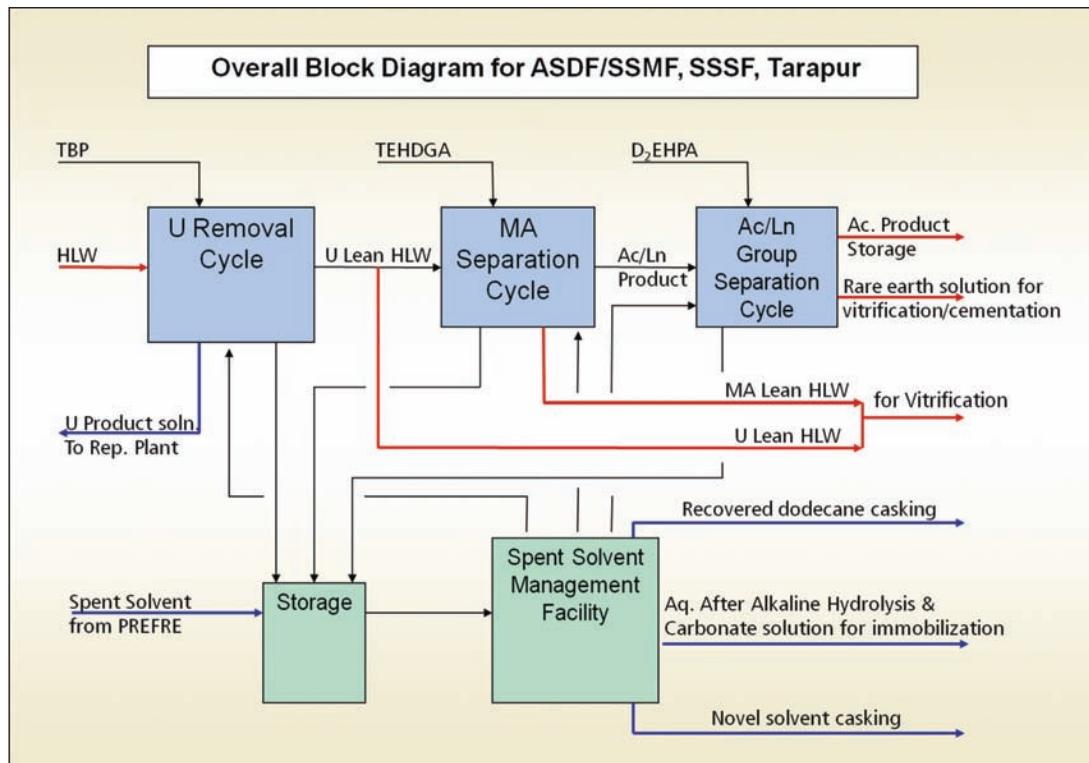


Fig. 4: Overall Block diagram of the integrated facilities

equilibration tests with actual high level waste from reprocessing of short cooled fuel is given in Table 2. The decrease in $\beta\gamma$ activity observed on contact with TEHDGA solvent was mainly on account of co-extraction of the rare earths elements along with minor actinides. Strontium and ruthenium were some of the other fission products extracted to a smaller extent.

Table 2: Process Validation with actual HLW (laboratory studies) (100 times dilution of HLLW)

Cycle I

30% TBP in dodecane :

Phase ratio (A/O) 2:1 (2 contacts)

Cycle II

0.2 M TEHDGA + 30% isodecyl alcohol :

Phase Ratio(A/O) : 3:1 (3 contacts)

in n-dodecane

Solution	U (g/L)	Gross α (Bq/mL)
Feed (HLLW)	10.9	217100
Raffinate (TBP)	0.05	215000
Raffinate (TEHDGA)	ND	ND

The stripped product of the second cycle rich in minor actinides & lanthanides will form the feed for the third cycle. The present flow sheet has been developed based on laboratory experiments carried out, the results of which are given in Table 3. In view of the challenges that An-Ln separation pose, provisions have also been made to test processes that would develop in the future, by integrating shielded glove boxes to the facility.

Table 3: Comparative data on trivalent An-Ln group separation

Solvent	Distribution ratio			
	Am^{3+}	La^{3+}	Ce^{3+}	Eu^{3+}
DADA (0.1M in n-octanol) (aq. pH 2.5)	2.0	0.03	0.08	0.75
D ₂ EHPA (0.2M in n-dodecane) (aq. pH 2.5, containing 0.05 M DTPA & 1.0M Lactic acid)	0.08	36	6.7	4.2

Cold Commissioning of the Facility

As a part of cold commissioning activities all the three cycles have been tested with inactive surrogates to assess the overall performance of the three cycles. These runs were undertaken to establish the hydraulic/mass transfer performance of these cycles along with the instrumentation parameters. All the operations were carried out from the control room as per the design intent. Besides, these runs also established the operating procedures as envisaged during design. Fig. 5 gives the live control room indications especially with regard to mixer-settlers and its allied metering.

While nitric acid served as surrogate for the first cycle, inactive rare earths in overall concentration as found in concentrated HLW were used as surrogates in the second cycle. Group separation of actinides from the co-extracted lanthanides has been successfully simulated using TALSPEAK based process with neodymium as marker. All the three cycles were tested with about \sim 1000 lts of aqueous feed and the respective solvents in closed loop as envisaged during actual operations.

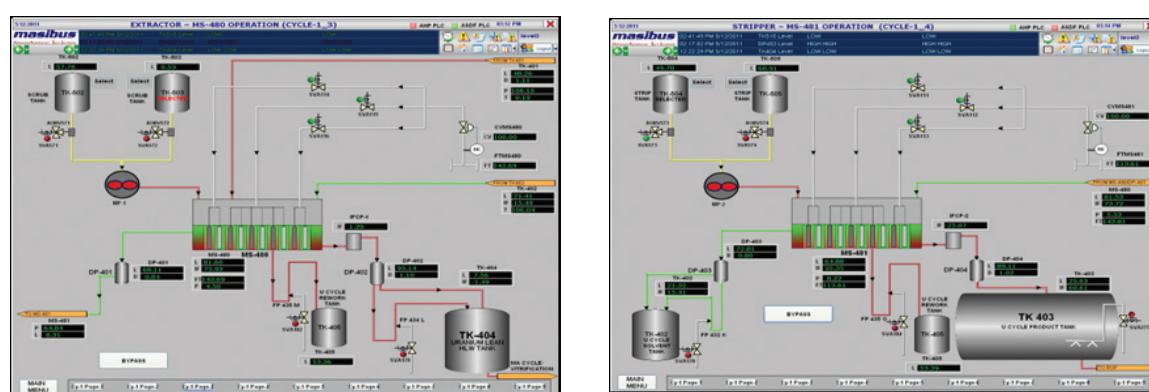


Fig. 5: Remote operations of the extraction cycles from control room

(i) Process Performance for residual uranium separation (Cycle I)

Continuous operation of the first cycle with 4 M nitric acid, 30% TBP as the extractant and water as the strippant yielded acid pick up in tune with those predicted by computer code SEPHIS. These results have established satisfactory performance of the first cycle. These runs were followed up with simulated waste containing natural uranium and other rare earth nitrates. Table 4 gives the summarised results of this run.

Table 4: Summarized cold commissioning results: Cycle I

Solvent system : 30% TBP in n-dodecane.
Aqueous feed : 4 M Nitric Acid with natural uranium and RE nitrates
Strip solution : Water
Flow rates A/O/S : 35/13/14 (LPH); Solution processed 1600 lts

Sr. No	Stream	Acidity (M)	Uranium (mg/L)
1	Feed	4.0	7140
2	Raffinate	3.7	3-10
5	Stripped prod.	0.8	17850

(ii) Process Performance for Bulk separation of trivalent actinides & lanthanides (cycle II)

For the purpose of testing the second cycle, about 800 lts. of feed solution was prepared with the rare earth composition as given in Table 5. Start up conditions was initially established with 4 M nitric acid solution in extractor and DM water in stripper. After stabilizing the complete loop with solvent, rare earth containing solution was fed into the extractor and DTPA containing strippant was fed to the stripper. Density/interphase indications in the various feed and raffinate density pots served to assess the process. The online density readings were in conformity to laboratory results ascertaining the design basis of the facility.

Exit aqueous samples were collected and analyzed for the rare earth concentration by ICP-AES. Typical results after attaining steady state is given in

Table 5. The results indicate an extraction & stripping efficiency of >99.9%. These runs have established satisfactory working of the second cycle

Table 5: Summarized cold commissioning results: Cycle II

Solvent system : 0.2 M TEHDGA + 30% isodecyl alcohol in n-dodecane.
Aqueous feed : ~ 1890 mg/L of rare earths in 4 M nitric acid
Flow rates A/O/S : 36/18/18 (LPH) ; Solution Processed : 800 lts

Stream	Ce (mg/L)	La (mg/L)	Nd (mg/L)	Pr (mg/L)	Sm (mg/L)	Y (mg/L)
Feed	785	511	422	113	58	7.4
Raffinate	0.052	0.032	0.034	<0.2	<0.1	<0.1
Stripped Product	1622	1027	827	223	108	12.2

(iii) Process Performance for Separation of actinides from lanthanides (cycle III)

The product from the second cycle amounting to about 450 lts was diluted with virgin DTPA-lactic acid solution and the overall pH was adjusted to 2.6 by addition of NaOH solution. The total volume of the feed thus constituted was 1000 Liters. In the pH region that the cycle is to be operated, it is expected that the trivalent actinide will be preferentially complexed by DTPA and hence will have very low extractability in the D₂HPA solvent. Among the rare earths, Neodymium has been observed to have the lowest distribution coefficient in this pH range and hence served as a marker during these engineering trials. Subsequently, the extractor and stripper were stabilized with feed solution for extractor and 2 M nitric acid in stripper. Density/interphase indications in the various feed and raffinate density pots served to assess the process as in the previous cycles. Exit aqueous samples were collected and analysed for the rare earth concentration by ICP-AES. A typical result after attaining steady state is given Table 6. While lanthanum was completely extracted, a small amount of neodymium was left behind (served as a marker for americium). Near total stripping was established

during the operation. No pH drift was observed at the exit of the extractor, obviating any need for pH adjustment within the system. These results have established satisfactory performance of the third cycle.

densities from control room indications were in accordance with measured values. The interface in all the extractors and strippers could be detected and maintained as required. Periodic samples were collected and analyzed by ICP-AES. Overall results indicate separation efficiency of > 99.8% for

Table 6: Summarized cold commissioning results: Cycle III

Solvent system : 0.2 M D₂EHPA in n-dodecane.
 Aqueous feed : 0.05 M DTPA + 1 M Lactic acid solution (stripped product of the second cycle with pH adjusted to 2.6 and diluted with respect to rare earths)
 Strip solution : 2 M HNO₃
 Flow Rates A/O/S : 45/30/15 (LPH); Solution Processed: 1000 L

Stream	Ce (mg/L)	La (mg/L)	Nd (mg/L)	Pr (mg/L)	Sm (mg/L)	Y (mg/L)	Am ²⁴¹ (cps)
Feed*	521.8 (357)	343.4 (116)	273.8 (226)	75.96 (20.6)	34.72 (153)	3.97	nil (31.12)
Raffinate*	2.21 (0.94)	0.07 (ND)	10.13 (10.3)	0.57 (0.22)	2.86 (5.52)	<0.1	nil (29.26)
Stripped Product	1562	1033	731.6	222.6	93.72	8.90	nil

*The quantities in parenthesis are the values obtained during Am 241 spiked lab scale mixer settler trials, where Am losses to the loaded organic was observed to be < 6 %

(iv) Integrated testing of the three cycles with natural uranium

This trial was carried out to test the process performance of the three cycles in a manner similar to actual operating conditions with simulated waste solutions. The simulated feed comprised of 4 M nitric acid with 7.14 g/L of uranium and ~ 1500 mg/L of rare earth nitrates along with appropriate quantities of strontium and molybdenum. While cycles I & II were operated continuously in tandem, the third cycle (cycle III) was operated independently after adjustment of pH as per the design intent. These runs were undertaken at a throughput of about 35 LPH (simulated waste) and the runs spanned ~45 hrs of continuous operations. The terminal

uranium and rare earths. Based on these successful trials the facility is presently being prepared for warm commissioning.

Acknowledgements

This work detailed out is a consolidation of efforts undertaken in Nuclear Recycle Group and Solvent Development Section of Materials Group. Working as a team member, the contribution of Shri.J.N.Sharma,SO/G,MPD in the synthesis and development of novel solvents is noteworthy. Acknowledgements are due to FRD laboratories where the lab. studies & analysis work have been carried out. The support of the Nuclear Recycle Board in erection, installation & commissioning of the facility is deeply acknowledged.

Development of TIMS for Isotopic Ratio Analysis of Boron

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Abstract

A magnetic sector based Thermal Ionisation Mass Spectrometer (TIMS) has been developed at Technical Physics Division, for high precision isotope ratio analysis of Boron (in the form of Sodium Meta-borate) at the Boron enrichment facility, Heavy Water Plant, Manuguru. The performance of this indigenously developed TIMS has been tested for sensitivity, isotope ratio precision and accuracy for different levels of enrichment in the plant samples. The sensitivity of this instrument was found to be 1 ion per 200 atoms. The internal and external precision for natural concentration levels Boron isotopes were better than 0.05%.

Introduction

Thermal Ionization Mass Spectrometry is a widely accepted technique for precise isotopic ratio measurements of materials of interest in the fields of nuclear technology and geochronology [1-2]. Technical Physics Division (TPD) has been developing these instruments [3-5] for various needs within the Department of Atomic Energy (DAE) covering a wide range of applications. Boron is one of the important elements in the nuclear field. It is used in the form of homogeneous solution of boric acid or boron trioxide in the moderator system of nuclear reactors to control the reactivity. It is also used as elemental Boron, Boron carbide and as alloy in various stages of operation of a nuclear reactor. Since the reactivity control depends on the content of minor isotope of Boron viz. ^{10}B , the precise isotopic measurement of Boron is very important. TPD earlier had developed and deployed one TIMS (similar to ref [6]) for Heavy Water Plant, Talcher, to monitor the content of ^{10}B in the product samples of boron enrichment facility. Subsequently, one more TIMS was required at the Heavy water Plant, Manuguru, for similar purpose but with some advanced features. The new instrument (Fig.1) has been developed with main additional features such as: (i) a turret housing 12 filament assemblies for increasing the sample

through-put, (ii) a modified source for improved sensitivity, (iii) collectors having wider apertures for improved collection efficiencies and hence a wider flat topped peak shape and (iv) a more compact and reliable electronics housed in a single table top rack, thus reducing the overall foot print of the instrument. Table 1 gives the main specifications of this instrument. This article discusses the design features and performance evaluation of this instrument.

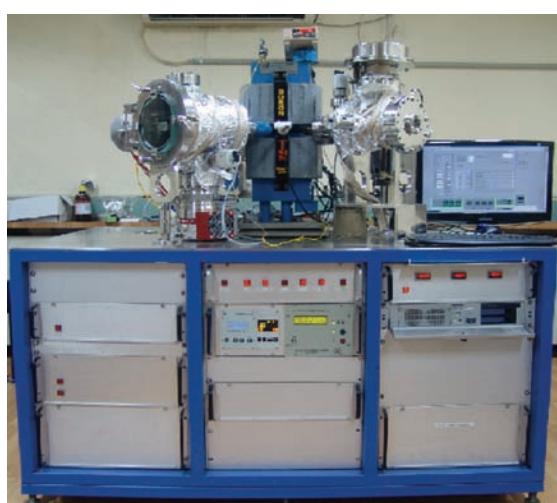


Fig. 1: Photograph of the Instrument

Table 1: Specifications of the Instrument

Resolution	: 150 (at 10% valley)
Mass Range	: Up to 220 amu
Precision (for natural Boron)	: 0.01% (internal), 0.04% (external)
Accelerating voltage	: 5 kV
Analyser	: Electro-magnet, 90° deflection 15cm radius, Stigmatic geometry
Collector /nos.	: Faraday/3

Theory

The ionization in TIMS is achieved by surface ionization of the sample on a metallic surface of high work function (Rhenium, Tungsten etc). The ionization efficiency is governed by Saha Langmuir equation:

$$n^+/n_i = g_i/g_i [(1-r_i)/(1-r_i)] \exp \{-(W-I)/KT\}$$

Where n^+ & n_i are the number of positive ions and neutral species, r_i & r_i are reflection coefficients and g_i & g_i are the statistical weights of the ionic and atomic states, W is the work function of the filament, I is the ionization energy, T is the temperature of the surface and K is the Boltzman constant.

Generally Re ribbon is used for ionization because of its high work function (~ 5.2 eV) and melting point (3180° C). The ions hence produced are accelerated and passed through magnetic field of suitable geometry whereby they are deflected and

separated as per their m/e ratio as shown in Fig.2. Subsequently the separated ion beams corresponding to respective isotopes of an element are collected by Faraday collectors electrically connected to electrometer amplifiers for the ion beam measurements.

The entire ion optical elements viz. ion source, analyser magnet and the

collectors were simulated using computer software SIMION 7.0 to optimize their design. The main subsystems of the instrument are discussed below.

Ion Source

It consists of a circular disc (called as turret) with 12 filament assemblies. The filament assembly has alumina base with three pairs of SS pins on which three filaments can be spot welded. This can be used for analysis involving triple filaments which uses side filaments for sample loading and centre filament as ionization filament. Specifically for boron sample only centre filament was used for sample deposition as well as ionization. Each filament assembly is mounted in SS enclosure called shield cup having exit aperture of 1.5mm (width) x 10 mm (height) for ion extraction. Ions are produced by heating the filament at a current of 1.5-1.7A and extracted out of shield cup by potential gradient produced by voltage applied on D plate (Fig.3). Further Y/Y_r and G plates are used to focus, accelerate and steer the ion beam in horizontal plane to align it with the final slit of size 0.3 mm (width) x 6 mm (height). The vertical alignment of ion beam is achieved by optimizing potentials of Z_u/Z_d plates. R plate is used to enhance the insulation capability of the ion source without affecting the focusing. For the high transmission of the ion source the ion beam should focus properly at the source slit which requires the mechanical fabrication and assembly errors to be within 10 micron. For this all electrodes were fabricated by EDM/wire cutting technique and assembled using dowel pins.

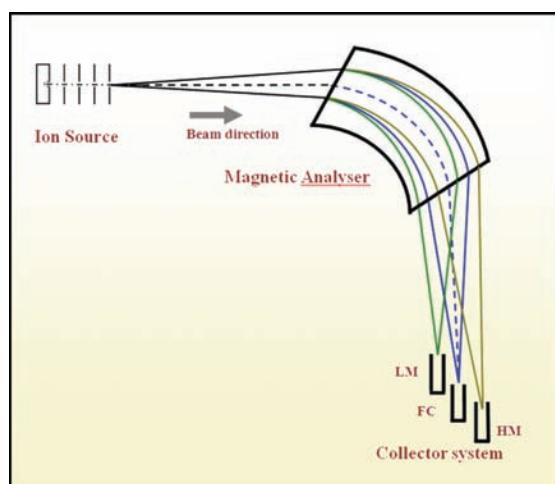


Fig. 2: Schematic of the Instrument

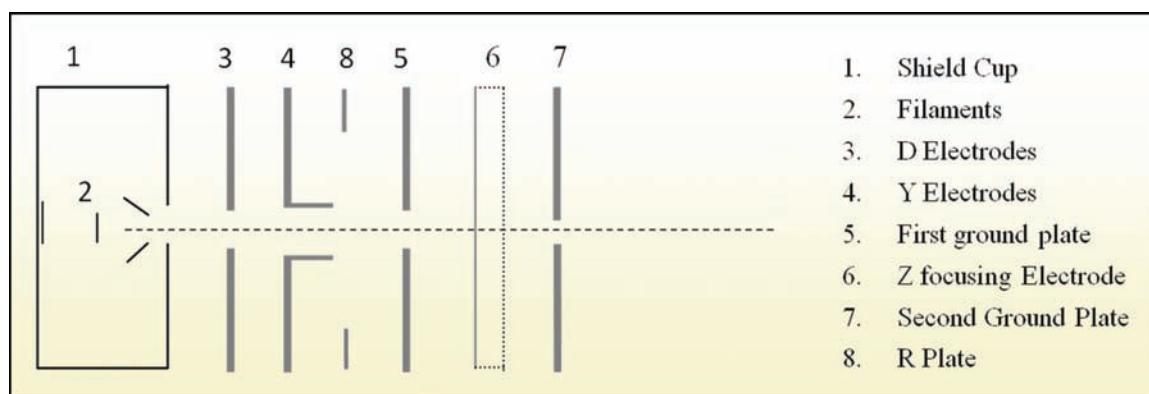


Fig. 3: Schematic of the Ion Source

Analyzer Magnet

It is an indigenous model (RRCAT, Indore, India) with a mean radius of 15 cm radius, 90° deflection angle having stigmatic geometry (26.5° ion beam entry/exit angles) and can produce a magnetic field up to 1 Tesla. Field is controlled by very stable current source with stability better than 5 ppm. Field homogeneity within the pole gap is better than 500 ppm in the median plane in the good field region of the magnet. The exit angle of the magnet is mechanically adjustable by an angle of $\pm 5^\circ$ to finely adjust focusing position of the ion beam at the collector.

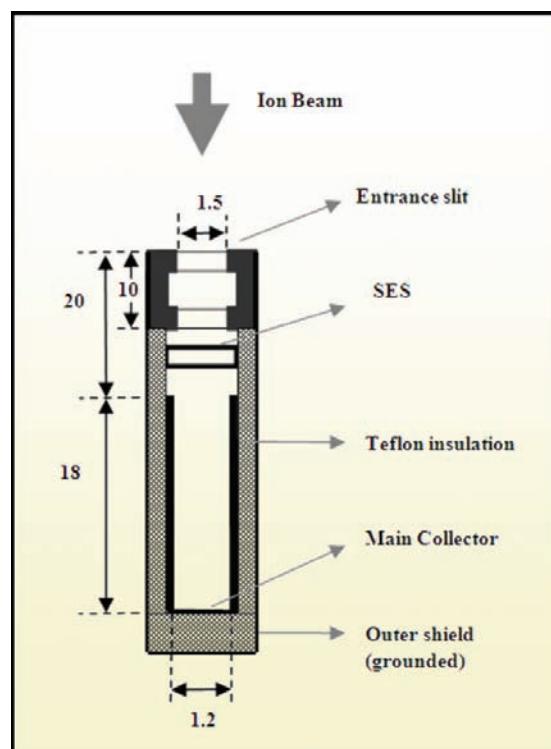
Collector system

It consists of three Faraday collectors each having apertures of 1.5 mm (width) x 15 mm (height). The central collector (FC) is fixed and each of the other two (LM and HM for low and high mass respectively), mounted on either side of the fixed one, is movable. The side collectors are mounted on linear motion mechanical feed-throughs with position adjustability of 20 microns. Each Faraday cup (Fig. 4) is equipped with the entrance aperture having double slits with a depth of 10 mm. This is followed by secondary electron suppressor (SES) floated at negative potential of 150 volts for suppressing the secondary electrons generated within the cup due to the impact of high energy ions on main collector. The main collector cup (1.2 mm wide x 18 mm deep x 16 mm high) is placed behind SES at a depth of 20 mm from the entrance

slit using Teflon mounting arrangement. The whole assembly is insulated by Teflon sheet (0.1 mm thick) from the outer grounded body. All above parts of collector are fabricated using EDM/ wire cutting method with mechanical tolerance of ± 10 micron.

Vacuum system

The turret chamber is pumped by a turbo molecule pump (TMP) with pumping speed of 300 l/s. This is backed by a rotary pump with speed of 100 l/min. The same rotary pump is used for the pumping of

Fig. 4: Schematic of Faraday collector;
(all dimensions shown above are in mm)

the amplifier chamber. The collector side has one Ion Pump with 35 l/s speed which is kept on continuously. The collector and source side are separated by an electro-pneumatically controlled gate valve. A vacuum of better than 1.5×10^{-7} torr is maintained throughout the system under normal operating conditions.

Electronics and Software

The electronics used in this instrument is similar to the one described in ref [7]. The filament currents are controlled through high stability (better than 10 ppm) filament current regulators (range: 7Amps; compliance voltage: 7 Volts). Independent high voltage power supply modules of 5 kV and 1kV (stability <25ppm and ripple <50mV) are used for accelerating and focusing the beam by different electrodes (Shield, D, Y, Z etc.). The electromagnet is controlled by a current regulated DC power supply with output currents up to 20 A which corresponds to 1 Tesla magnetic field. Regulator module uses op-amp based proportional and integral controller, IGBT bank, DCCT, μ C, ADC, DAC and wireless link to PC and teslameter. Beam current is measured by using electrometer amplifier and FPGA based data acquisition card. Electrometer amplifier can measure as low a current as 10^{-15} A with time constant (δ) of less than 50 msec and noise of $20 \mu V_{rms}$ (for integration time of 5 sec). Data acquisition software supports multiple analysis modes, automated ratio calculation, optimized data presentation, background correction, amplifier calibration and outlier corrections during data analysis etc. Intermediate results are also displayed at the end of every scan and block.

Testing and Evaluation

For precise and accurate measurement, it is essential that the ion beam should properly focus at the collector aperture and collected well within the collector. To verify this, the ion beam was scanned across the collector by varying magnetic fields in fine steps of 0.2 gauss and the peak shape was recorded. A well focused ion beam with a cross

section smaller than the collector aperture should produce a flat top peak in this scan. Beam width is measured using this scan by measuring the flat top width and base width which further can be used to calculate the resolution of the instrument.

Sensitivity is measured by taking 1 microgram of the sample and integrating the signal on amplifier till whole of the sample is consumed. This gives the total number of ions collected on Faraday collector. The ratio of total number of atoms deposited and ions measured is termed as sensitivity of the instrument.

To check the performance of the instrument, few natural boron standards were analysed for isotopic ratio measurement of $^{10}B/^{11}B$. Nearly 2 microgram of Boron sample in the form of $Na_2B_4O_7$ was loaded on single rhenium filament and dried at 1.7 A in the atmosphere. In the ion source, it was heated to a current of around 1.5 A in 15 minutes. Subsequently the source potential tuning and peak centering was carried out followed by data acquisition for isotopic ratio for 88 and 89 masses which corresponds to $Na_2BO_2^+$ ions for ^{10}B and ^{11}B respectively. Each data represents the average of 50 ratios (5 blocks of 10 ratios) collected on each assembly with amplifier integration time of 2 seconds. The internal precision for each data is calculated as relative standard error on 50 ratios. External precision was calculated as relative standard deviation on averages ratios of separate loadings of same sample on ten different assemblies. Few plant samples were also analysed for their isotopic content to differentiate minor variation in their isotopic content.

Results and discussion

Very stable signal of 89^+ in the range 1 – 1.5 volts (across 10^{11} ohm amplifier resistance) was obtained at the filament current around 1.5 A on all the assemblies. The flat top peaks on all the collectors were obtained (Fig. 5) with peak flatness of within 100 ppm of maximum peak height within a mass scan of 4500 ppm on the peak top. The beam width calculated from the peak shape is ~ 0.5 mm

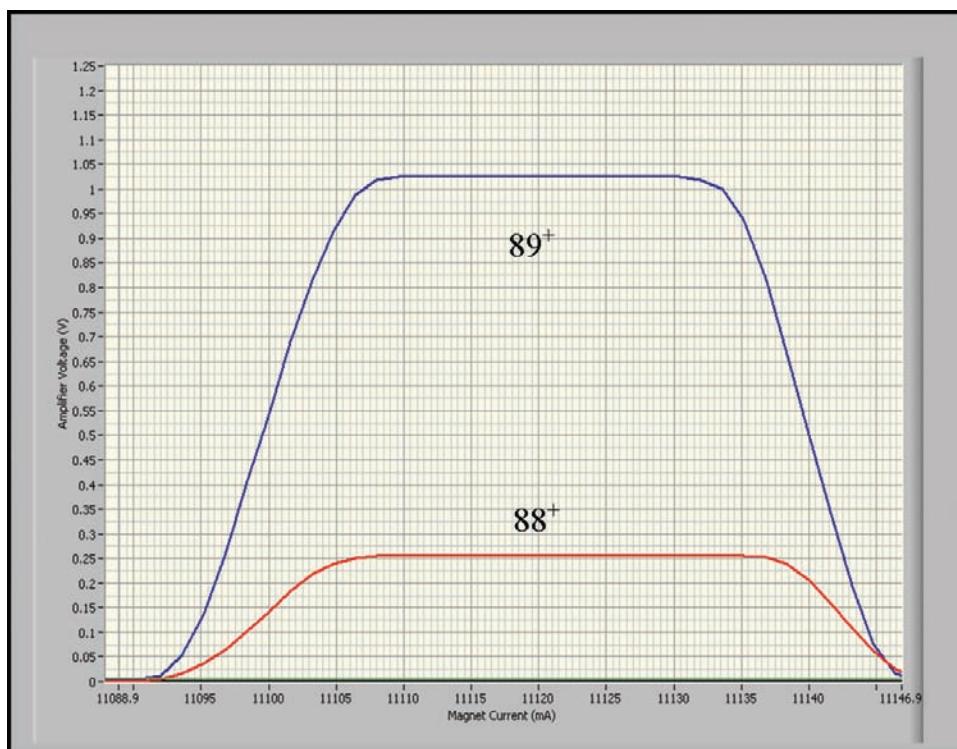


Fig. 5: Peak shapes for boron isotopes ^{10}B and ^{11}B corresponding to masses 88 and 89 for sodium borate ions

which corresponds to resolution of 150. The sensitivity was measured to be around 1 ion for 200 atoms of boron. The isotopic ratio data for natural boron standard (SRM 951) sample measured on ten filament assemblies is given in Table 2. The average ratio ($^{10}\text{B}/^{11}\text{B}$) obtained is 0.24914 with internal precision of about 0.02% and external precision of 0.04%. The calibration factor was

calculated using this measured ratio and true ratio (0.2473) which was further used to calculate the true ratios of the plant samples. Table 3 shows the isotopic ratio data for depleted plant sample.

For TIMS, the main limitation to obtain good precision is the fractionation i.e. variation of isotopic ratio with time due to change in relative evaporation

Table 2: Isotopic ratio data for Natural Boron sample

S. No.	Ratio ($88^+/89^+$) \pm Internal Precision (%)
1	0.24919 ± 0.01
2	0.24923 ± 0.011
3	0.24922 ± 0.007
4	0.24916 ± 0.023
5	0.24904 ± 0.007
6	0.24904 ± 0.017
7	0.24923 ± 0.012
8	0.24899 ± 0.007
9	0.24914 ± 0.04
10	0.24918 ± 0.005

Table 3: Isotopic ratio data for plant samples

Sample HWP, TAL	Ratio ($88^+/89^+$) \pm Internal Precision (%)
906	0.00736 ± 0.2
907	0.00737 ± 0.3
908	0.00657 ± 0.27
909	0.00694 ± 0.4
910	0.00680 ± 0.28
912	0.00461 ± 0.3
883	0.01444 ± 0.07
888	0.01496 ± 0.12
890	0.01141 ± 0.13

rates of isotopes with time [8]. Since in this case only two isotopes are present, the internal normalization is not possible. The only way to circumvent this problem is to maintain same conditions for every sample at every stage i.e. sample loading, filament heating profile and data acquisition time. During all these analysis every care was taken to reproduce these conditions for every sample.

Conclusion

The basic evaluation of the instrument shows that the instrument is suitable for precise isotopic ratio measurements for Boron with a precision of 0.02% internal and 0.04% external. It can be used for other masses falling in the mass range of 1-200 amu. The sensitivity and peak shapes obtained are highly satisfactory for the analysis of Boron samples. Analysis time involved in measurement on one sample is 30- 35 minutes. Moreover, the provision of turret with 12 filament assemblies increases the throughput of the system and makes it more useful for the plant where the operator has to routinely analyze more number of samples.

Acknowledgement

Authors express their gratitude to Dr. S.Kailas, Director, Physics Group, BARC for his constant support and encouragement throughout this development. They also wish to acknowledge the colleagues from TPD, who have contributed untiringly to this development. They also wish to thank the team at HWP, Manuguru for their participation during the acceptance tests.

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Fire Prevention in Unitary Air conditioners

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Technical Services Division

Abstract

Several incidences of minor fire and a few incidences of major fire in the unitary Air Conditioners (AC) have been observed in BARC in the past. Technical Services Division (TSD), which is responsible for maintaining the ACs, has adopted multipronged approach to prevent recurrence of fire incidences. These approaches consist of using capacitors having highest level of safety protection, i.e., P2 protected as per IEC 60252-1-2001-02 standard with self healing properties, overpressure disconnection device and installing timer control device to avoid continuous running of ACs. Recently we have started installing fire extinguishing aerosol generator with thermo cord/thermal actuating sensor in unitary air conditioners. This article gives an overview of fire occurrences in ACs, their probable causes and technical solution for mitigation.

Introduction

Mechanical Maintenance Section, Technical Services Division is carrying out maintenance of large number of air conditioning, refrigeration and ventilation equipment spread over entire BARC premises. The various equipment such as unitary air conditioners (Window & Split air conditioners) Fan Coil Units, Water coolers, Deep-freezers, Chillers, Cold Rooms and vehicle air conditioners are being maintained on regular basis in order to enhance their reliability, increase their useful lives and reduce downtime & fire incidences.

Equipment Description

The four major components of the unitary AC are a hermetically sealed compressor, a condenser, a

capillary tube type throttling device, and an evaporator. Besides, fan motor, capacitors, relay, contactors, and thermostat, etc. also form part of air conditioner. Fig. 1 shows the different components of a unitary AC. The working of unitary equipment is based on Vapor Compression Cycle (VCC) as shown in Fig. 2. The desired degree of cooling is achieved by extracting heat from the space to be airconditioned and expelling the heat into the atmosphere. More than 99% of commercially available air conditioners in the market are based on vapour compression cycle in which refrigerant's properties are being utilized.

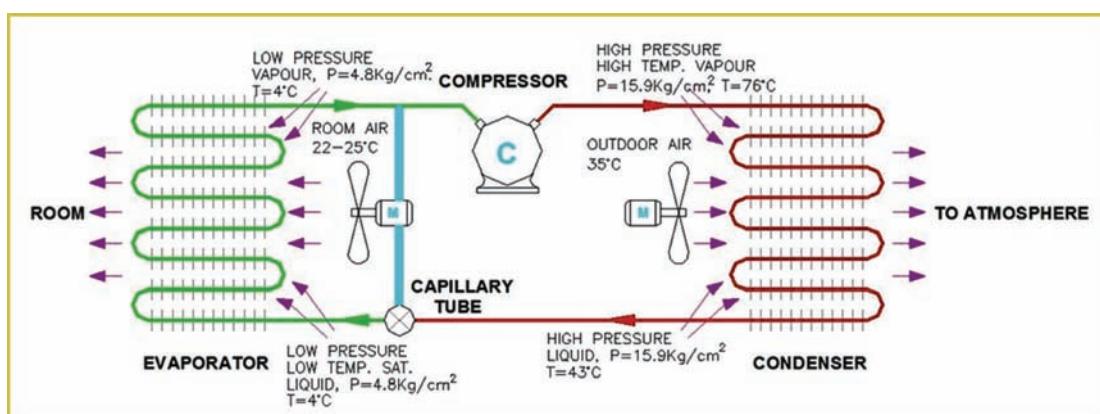


Fig. 1: Schematic Representation of a Unitary AC

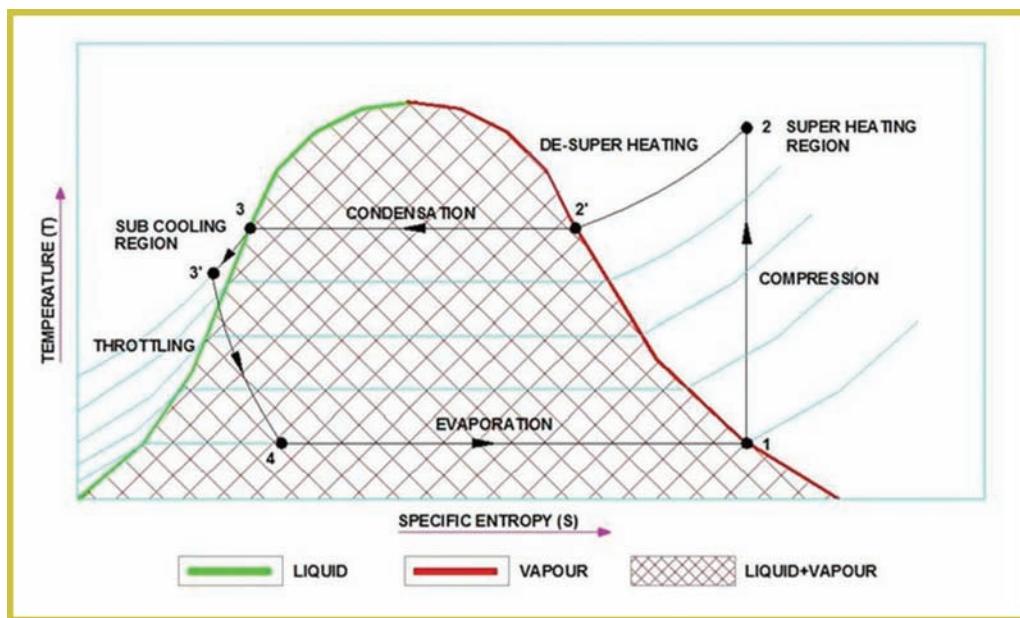


Fig. 2: Vapor Compression Cycle

Over a period of time spanning more than two decades, we came across maintenance of various makes and models of air conditioners. Earlier ACs were considered as industrial products and they were bulkier. For example, about 25 years back, a typical 1.5TR window air conditioner weighed in the range of 82 to 85 kg. In the recent times however, there is stiff competition in the market which has forced the designers to optimize the designs. Thus, the trend now is to use nonmetallic components wherever possible and to cutdown the design margins so as to reduce thickness and size of different components and parts. As a result, the weight of a typical 1.5 TR rating AC is only about 60 Kg.

Fire Incidences

Based upon the statistical record of AC related fire occurrences in BARC in 8 to 10 years in the recent past, numerous cases of burning smell, electrical spark or smoke coming out from air conditioners get reported to TSD during each year. Such cases are more frequent during monsoon as the air is generally wet and there could be moisture ingress into the unit. In majority of the cases, as a corrective measure, the occupant(s) of the room themselves

switched the power supply off and reported the incident to TSD for further corrective action. Because of the prompt action of the occupant, there were no significant loss of user's documents and assets. However, six major fire incidences occurred due to unitary air conditioners and four incidents of these caused significant loss of user's documents and assets besides destruction of office stationery, furniture and room interior. These places are:

- a) Old Training School.
- b) VIP canteen dining hall at 14th floor Training School Hostel.
- c) Training School Hostel, Room no. 808.
- d) RCnD building, Room no. 109.
- e) Purnima building, Room no. 11-S.

As already mentioned, all the reported events are thoroughly documented. Subsequently, the events are thoroughly discussed and analyzed at various levels including local safety committee and unit level safety committee of respective groups and finally at Conventional and Fire Safety Review Committee (CFSRC). An important aspect of investigation is to arrive at the root cause of the incident and to work out technical solution for prevention of fire incidents in future. The solutions also aim at minimizing damage and loss, if fire were to actually occur.

Causes of AC Fire Incidents

Based on the analysed results and feedback of various safety committees and experience of TSD engineers, it can be stated that the initiation of fire in window and split air conditioners was due to one or more of the following factors:

Poor Workmanship of Electrical Wiring and Loose Connection: Owing to stiff competition in the Indian consumer market, it is suspected though difficult to establish that the measures enforced by manufacturers to reduce manufacturing cost might affect the quality of components and materials including wire, clips and joints. Also, sometimes the workmanship could be poor, i.e., soldering/crimping of lugs may not be properly done, screws might not be fitted properly leaving loose connection, etc.

Thermostat malfunctioning: Sometimes the thermostat does not work properly and fails to cut-off the machine which results in continuous running of compressor and finally may lead to fire.

Failure of capacitors: Most of the commercially available air conditioners are provided with non-metallic or metallic capacitor without explosion proof features. It is observed that over a period of time, the dielectric material of the capacitor deteriorates whereby dielectric loss might increase. This would cause overheating and chances of bursting increases which ultimately may lead to fire.

Continuous running of air conditioners: Unitary ACs are generally designed to work intermittently, typically with duty cycle of 12 hours, unless specifically ordered. However, due to under estimation of heat load, too low temperature setting of thermostat of the machine, and bad usage practices e.g. operating ACs with doors/ windows kept open, continuous running of ACs might happen. As these ACs are not designed for continuous operation beyond 12 hours, the components may get overheated leading to bursting and ultimately leading to initiation of fire.

Failure of transformer in control circuit (PCB): Overheating of transformer provided in the control circuit of air conditioner may lead to its burning, resulting in initiation of fire.

Addition/alteration in air conditioners: The various components in commercially available air conditioners are designed for their optimum operation and utilization. Any addition/alteration in original design might affect the performance of the unit drastically, if proper fitting is either not ensured or replacements recommended by the original manufacturers are not done. Sometimes due to increase in system resistance the condenser cooling gets affected and may lead to high pressure built up in the system which may lead to failure of components and sometimes may lead to fire.

Corrective Measures taken by TSD

Based on our experience over a period of time the following corrective actions have been taken by TSD to reduce fire incidences in unitary air conditioners:

- a) TSD is carrying out bi-monthly maintenance for window and split air conditioners to keep the equipment in healthy condition.
- b) During maintenance, healthiness of each component is checked and if found faulty, it is replaced with new one.
- c) Since last six to seven years, TSD is replacing old non-metallic capacitors with metallic bellows type explosion-proof capacitors, only of a reputed make. In case of overheating, bellows expand as a result of which the power supply is automatically disconnected.
- d) More recently, capacitors having highest level of safety features as per IEC 60252-1-2001-02 standard, i.e. P2 protected with self healing properties and overpressure disconnection device, are being installed in the AC units. This will further increase reliability of capacitor and in turn reduces chances of failure and resulting fire.
- e) As it is widely known, unitary air conditioners are not designed for continuous operation for more than 12 hours and their extended operation should

be avoided. Hence, TSD has conceived a timer controlled device, comprising of MCB (Miniature Circuit Breaker), contactor, timer, plug and socket, as shown in Fig. 3. These components are assembled in a metallic box and power supply is given to air conditioner through this device. In case of round the clock occupancy of laboratories where operation beyond 12 hours might occur, each machine is fitted with timer so that the machine is automatically started and stopped as per pre-set duty cycle.

f) Aerosol based fire extinguishing device is also being installed on trial basis in AC units. In a number of tests carried out at TSD workshop, the capability of the device in initiation of fire extinguishing has been established. The aerosol extinguishes fire by inhibiting the chain reaction in combustion on molecular level. It removes the flame free radicals and extinguishes fire without depleting oxygen. The temperature set-point for initiation of aerosol extinguisher is verified to be typically 172°C with thermocord and 300°C without thermocord. The aerosol extinguisher is environment friendly and it does not cause any harm to living beings or humans.



Fig. 3: Timer Control Device

Fig. 4 shows a collection of photographs taken during simulated testing of the aerosol based fire extinguisher.

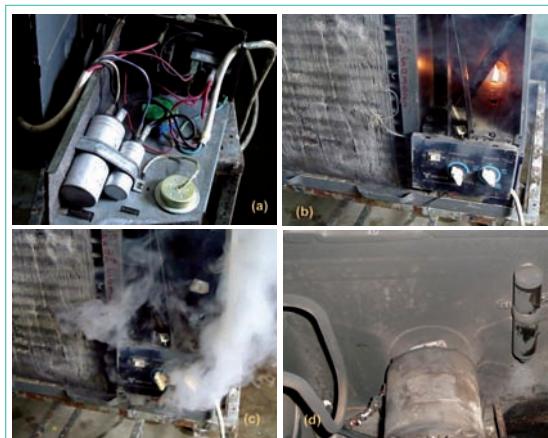


Fig. 4: (a) Aerosol based Fire Extinguisher with Thermocord installed in the junction box of a window AC; (b) Artificial initiation of fire in junction box; (c) Actuation of Aerosol based Fire extinguisher; (d) After fire has been extinguished by actuation of aerosol based fire extinguisher.

Concluding Remarks

Based upon the analyses of reports of incidences of fire related to unitary air conditioners and the corrective actions taken by TSD, measures such as use of timer for automatic disconnection of power supply to AC, use of aerosol based fire extinguisher for critical areas, and use of P2 protected capacitors having highest level of safety features with self healing properties and overpressure disconnection can be taken. Also, while servicing it must be ensured that no alteration or addition is done so as to affect the performance in an adverse manner. Users should avoid unattended operation of air conditioning equipment and the fire load such as curtain and combustible stationery should not be kept in the vicinity of unitary air conditioners. The practice of wooden paneling, which is often done to improve aesthetics, should be discouraged. Instead, aluminium compressed panels, which are available in wooden textures, are recommended to be used.

National Technology Day 2013: a Report

Every year May 11 is celebrated as National Technology Day across the country by scientific, educational and industrial establishments to commemorate the technological breakthrough achieved by the Department of Atomic Energy, with a series of controlled underground nuclear tests carried out at Pokharan, Rajasthan, in 1998. Bhabha Atomic Research Centre has been celebrating National Technology Day annually highlighting its R&D achievements in the field of Nuclear Technologies and their Applications. This year, to commemorate the occasion, the theme 'Agriculture and Food Security' was highlighted to showcase R&D achievements of nuclear technology in the field of agriculture and food sciences.

A function was organized in the Central Complex Auditorium, BARC, on May 10. Shri Ashish Bahuguna, Secretary, Agriculture and Cooperation, Ministry of Agriculture, Government of India, was the Chief Guest on the occasion. Sustained R&D efforts of three generations of scientists in BARC in the field of crop improvement and food preservation have created a visible impact on the national agriculture and food security scene. A highlight of the occasion was a special exhibition on the theme 'Agriculture & Food Security', jointly organized by Bio-

medical Group and Scientific Information Resource Division, Knowledge Management Group, BARC, highlighting the advances made by BARC in the



Dr R. K. Sinha, Chairman, AEC presenting a memento to the
Chief Guest



Shri Ashish Bahuguna, Secretary, Agriculture and Cooperation, Ministry of Agriculture, GOI From L to R: Shri Sekhar Basu, Director, BARC, Chief Guest, Shri Ashish Bahuguna and Dr. R.K. Sinha, Chairman, AEC releasing Booklets and Brochure on Agriculture & Food Security



Shri P.K. Mishra, Secretary, DOPT at the exhibition

Bhabha Science & Technology Awardees gave presentations of their award winning R&D work.

There were several visitors to the exhibition, which was open for all upto 14th June, 2013. Shri P.K. Mishra, Secretary, Department of Personnel & Training, Government of India, Shri Atul Chaturvedi, Chairman, PFSB, Government of India and Shri Parkash Singh Badal, Chief Minister, Punjab were some of the dignitaries who visited the exhibition.

field of nuclear agriculture and food preservation. The exhibition was inaugurated by Shri Ashish Bahuguna. Dr. R.K. Sinha, Chairman, AEC & Secretary, DAE, presided over the function. Director, BARC, Shri Sekhar Basu, welcomed the Chief Guest, Dr. R.K. Sinha, Chairman, AEC and Secretary, DAE, other dignitaries, and the participants in the audience. As a part of the outreach program of BARC, information booklets and brochures were also released by the Chief Guest during the inaugural session of the programme.

Dr. K.B. Sainis, Director, Bio-medical Group, gave the vote of thanks. In the afternoon, DAE Homi



Shri Sekhar Basu, Director, BARC with Shri Parkash Singh Badal, Chief Minister, Punjab at the exhibition

Theme Meeting on “Indigenous Development of Silicon Photomultiplier (SiPM)”

A BRNS sponsored one day Theme Meeting on ‘Indigenous development of silicon photomultiplier (SiPM)’ was organized by Electronics Division on May 08, 2013 at Multipurpose Hall, Training School Hostel, Anushaktinagar. The aim of this meeting was to bring together the Users, Developers and Industry working on the development of SiPM, silicon strip sensors and related electronic instrumentation on one platform so as to synergize developments being done by various groups in this area. Members from DAE institutes, academic Institutes and from silicon industries such as BEL, Bangalore and SITAR, Bangalore participated in this meeting.

Dr S Kailas, Director Physics Group was the Chief Guest for the meeting. Dr T S Anathkrishnan, Head, ED presented the welcome address. Shri C K Pithawa, Director E&I Group presented the overview of the Theme Meeting. The meeting was convened by Dr Anita Topkar, ED. In his address, Dr S Kailas brought out the need for indigenous development and a collaborative R&D effort for the development of SiPM and silicon strip sensors to meet the requirements for various international and national experimental facilities for physics research.

A national level picture of R&D effort in the area of ‘SiPM and silicon strip sensors and related instrumentation development’ emerged through the presentations and discussions in this meeting. It was concluded that silicon strip sensors and SiPMs in various forms are required for various international experimental facilities (LHC, FAIR, SPIRAL2) and for various programs in India. Considering the wide range of applications of SiPM, Electronics Division, BARC has taken the initiative to develop SiPM indigenously and has made good progress in fabricating prototype SiPMs. In the panel discussion it was told that BARC would make the next version of SiPM designed as per the specifications required by various users. Considering technological advances, Electronics Division is also working on development of large area silicon detectors on 6" wafers which will be useful for the detectors for the future upgrades of various facilities. Participants of this meeting expressed their interest to put a collaborative R&D effort for indigenous development of SiPM and silicon strip sensors for various experiments.



On the dais (from Left to Right): Shri C. K. Pithawa (Dir, E&IG), Dr. S. Kailas (Dir, PG) and Dr. Anita Topkar (ED) at the inaugural function of the meeting

BARC Transfers Technology for Mass Multiplication Medium for Biofungicide *Trichoderma* spp.

Excess utilization of chemical insecticides has reduced fertility of soil, caused pollution of water and given rise to resistant pest varieties. To counter ill effects of chemicals on environment, bio-pesticides are being used on large scale. One such bio-pesticide is fungus- *Trichoderma*. Currently, sorghum or bajra grains are used for commercial production of *Trichoderma* spp. However their high cost and unavailability is limiting their use. Nuclear

Agriculture and Biotechnology Division, BARC has developed an alternate and cheaper medium for mass multiplication of fungus *Trichoderma* using agriculture waste.

The technology was transferred to M/s Pravara Agro Biotech, Ahmednagar on 1st May, 2013. The Company is engaged in the commercial production of *Trichoderma* based bio-pesticides since a decade and this technology transfer will help them to strengthen *Trichoderma* mass multiplication further.



From left to right: Dr. S. A. Memane, Shri Sunil Memane, Shri G. Gadekar from Pravara Agro Biotech, Ahmednagar, and Dr. N. Khalap, Dr. S. P. Kale, Head, TT&CD and Dr. S. T. Mehetre, NA&BTD.



The pond at BARC

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