

# BARC NEWSLETTER

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*FROM THE DIRECTOR ...*

## ENERGY FROM THORIUM : SOME PERSPECTIVES

Dear colleagues,

Importance of thorium in our programme is all too well known. Sustained work on all aspects of thorium utilisation has been carried out right from the beginning. Now it is time we give a renewed boost to this programme.

Work on the development of Advanced Heavy Water Reactor (AHWR), which utilises thorium efficiently, has already been taken up in BARC. AHWR is designed to get a large fraction of energy output from thorium. It also incorporates several advanced safety features, which characterise new innovative reactor designs worldwide. In addition, work on accelerator driven reactor systems which offer a good promise towards evolution of inherently safe nuclear power generating systems also merit our attention. Such systems also offer the promise of fissile material growth with our Th-U<sup>235</sup> cycle supplementing the fast reactors.



There are some other application areas of nuclear energy which may become important in the near future. These are :

- i. Systems to produce hydrogen or other hydrocarbon substitutes as a possible fuel for meeting transportation requirements.
- ii. Compact power packs (in the range of a few hundred kilowatts) for use in remote areas.
- iii. Desalination plants coupled with nuclear reactors (land based or barge mounted) for production of fresh water from sea water.

For such applications, especially the first two, high temperature reactors employing gaseous or advanced liquid metal alloy coolants would be necessary. It is worth noting that thorium, a matter of high priority for us, offers many special advantages in reactor designs for such applications.

Thorium based fuel cycle has a special advantage since it produces much lower volumes of higher actinides in the waste stream. Totally closed fuel cycles, where the actinides and long lived fission products are recycled, should be our long term strategy. Our current closed fuel cycle

is already a major advancement over once through fuel cycle adopted by some countries from an environmental impact stand point, since most of the long half life components in the form of plutonium or  $U^{233}$  get recycled. In addition, we already have a well developed capability for processing and immobilisation of high level radioactive waste – a capability possessed by only a few countries. Further, advancements in these areas would have to be continued.

Thus, our vast endowment of thorium, which we all recognise as a virtually inexhaustible energy source, also holds the promise of a quantum jump in safety, economics and eco-friendly characteristics of nuclear energy for sustainable development.

Towards thorium utilisation, several tasks need to be accomplished through a well defined plan of activities. A number of new technologies are required to be developed and demonstrated on an industrial scale and finally pursued on the basis of economic viability. While one of the primary objectives of research and development should be to improve the economics of nuclear energy systems to make them attractive compared to other contemporary energy systems, there is also a need to have an open mind while looking at a first of a kind system, since ultimately it is the performance in practice rather than on paper that would determine further evolution of any technology.

## REACTOR SYSTEMS

### *Advanced Heavy Water Reactor (AHWR)*

The design feasibility study of AHWR has already been completed. Under a 9<sup>th</sup> Plan project, engineering development as well as work for preparing a detailed project report is being carried out. It should be possible to take up construction work on AHWR on the basis of this project report. Scale up of efforts on irradiation of thorium and its reprocessing to produce  $U^{233}$  in sufficient quantities is necessary. Development of fuel cycle for Th- $U^{233}$  as well as Thorium – Plutonium fuel cycle to support thorium reactor operation has to take into account special challenges posed by thorium. Several component technologies that have already evolved in BARC could be effectively integrated to meet this objective.

### *High Temperature Reactor (HTR)*

HTR will be useful for non-electricity applications as well as for compact power packs. The HTR design and technology study should be completed in the first phase, giving due attention to heat transfer systems with heat pipes and liquid metal coolants and energy conversion systems like Sterling engine and thermionic emission. Power packs to be used in remote areas require designs which would enable continuous operation over long duration without need for refuelling. HTR Systems also open route to space power systems. This technology is, therefore, well worth concentrating on.

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## *Accelerators as neutron source*

Accelerators could well become effective contributors to nuclear power in the near future. Availability of accelerator driven non-fission neutron sources for driving sub-critical fission reactors could in principle revolutionise nuclear power by eliminating/minimising issues related to nuclear excursions, speeding up nuclear power capacity growth and transmutation of actinides and long lived fission product wastes. To realize such accelerators for generation of 1 to 2 GeV proton beams with tens of mA beam current, a dedicated programme is required to develop all the critical components, including ion sources, injectors, accelerator structures and the whole technology of handling the beam under severe space charge force. This is a major technology challenge which would also give a boost to basic research in nuclear physics in addition to nuclear power.

## *Source driven reactors*

Physics studies on the configurations of source driven reactors have been initiated and will have to be completed before design study of such a reactor is taken up. These studies should also include an evaluation of a possible version of AHWR core to locate neutron generation targets in the seed/booster zones to use spallation or fusion neutrons whenever the technology becomes available to produce them in right strengths.

## **FUEL AND FUEL CYCLE DEVELOPMENT**

### *AHWR fuel and fuel cycle*

The cost of reprocessing and special fuel fabrication could be reduced by adoption of high burn-up fuels. A programme is thus necessary to develop robust high burn-up fuels, with suitable fuel configuration to accommodate fission gases and minimise mechanical as well as chemical fuel-clad interaction. The cladding material should also be able to withstand coolant side corrosion. Thorium oxide is a difficult material for chemical reprocessing. Further,  $U^{232}$  daughter products which are hard gamma emitters accumulate over a period of time after the reprocessing step. Thus, ease of reprocessing and quick conversion to fuel element is an important objective of AHWR fuel cycle development. Co-precipitation, sol-gel and vibro-pack fuel are likely to be important elements of such a fuel cycle.

### *High Temperature Reactor fuel*

High temperature reactor fuels require very demanding capability. While many exotic fuel compositions are being proposed, fuel made of graphite coated particles is one of the suitable candidate for HTR. The process of manufacturing fuel elements of different design and geometry, (e.g. spherical compacts or prismatic fuel elements) have to be developed and proven in the fuel irradiation tests. Other ceramic fuel compositions for use in HTR also deserve careful attention to enable evolution of fuels capable of supporting a range of diverse high temperature applications.

### *Th- $U^{233}$ processing*

Implementation of Thorium fuel cycle requires extraction of  $U^{233}$  from the spent fuel and its reinsertion into the fuel cycle. Setting up of KAMINI reactor has demonstrated this capability on a small scale. Presently, thorium bundles are being irradiated in the power reactors. We now have to take up reprocessing of power reactor fuel to separate  $U^{233}$  and fabrication of fuel for AHWR using  $U^{233}$ . Considerable development work is involved in realising this capability as already highlighted earlier.

Partitioning of thorium, uranium and plutonium has been carried out on a pilot plant scale using fuel bundles irradiated in research reactors. This experience needs scaling up to process Thorium - Plutonium oxide fuel from AHWR.

### ***U<sup>233</sup> clean up***

A major hurdle of U<sup>233</sup> utilisation is the activity due to the daughter products of associated U<sup>232</sup> impurity. While some of the strategies spelt out earlier would enable bypassing this problem, there is a need to extract U<sup>232</sup> out of the fuel cycle to contain this problem over successive recycles. A laser based isotopic purification technique should thus be developed to clean-up U<sup>233</sup> and keep U<sup>232</sup> levels in the fuel cycle to manageable limits.

### ***Pyro-electro-refining technology***

Pyro-electro-refining is an important technology for realisation of total recycle of transuranics. Variants of this technology have been demonstrated for sodium bonded metallic fuel in Integral Fast Reactor and vibro-packed ceramic fuel in BOR-60 reactor. This is an important technology and should be developed and demonstrated on a scale of 10 to 20 kg batch size. This will facilitate transition from the oxide to the metal fuel option for Fast Reactors and also be useful for preparation of the feed for U<sup>233</sup> clean up.

### ***Partitioning of actinides and fission products***

It is well known that the thorium cycle produces several orders of magnitude lower transuranium actinides as compared to other fuel cycles. Further development of technologies for co-precipitation, sol-gel, vibro-pack fuel elements on one side, and partitioning of different actinides and fission products and clean up of U<sup>233</sup> on the other, should enable economic recycling of most of the long half life components which would otherwise appear in waste stream. With our strong capability to immobilise waste products which have only moderate half life, it should be possible to virtually eliminate issues connected with long lived radioactive wastes.

The recovery of long-lived transuranium actinides, and long lived fission products of value could make nuclear power even more eco-friendly and at the same time could improve economics in the long run through value addition. However, the question of increased volume of secondary waste also needs to be addressed. While use of specially engineered solvents provides one option, employment of selective photochemical methods show promise of achieving the same task with an actual reduction of waste volume. Development of both the techniques should be pursued.

### ***High temperature materials***

The in-core structure and reactor vessels for high temperature reactors, including compact power packs have to withstand operating conditions with temperature in the range of 600°C to 900°C. Special materials and alloys, capable of long periods of uninterrupted operation at high temperature and also those capable of withstanding high temperature steam need to be developed.

### ***Denatured zirconium***

Improvements in neutron economy could have considerable impact on the performance parameters of AHWR. One of the methods to improve neutron economy is to replace the natural zirconium alloy in the structural components and fuel cladding with Zr alloys from which Zr<sup>91</sup> isotope has been removed. A laser based separation process could be developed for economically removing the intermediate isotope of zirconium. The availability of such materials will also improve the fuel burn-up performance of new as well as existing PHWRs.

## ENERGY CONVERSION AND OTHER PROCESSES

### *Hydrogen related processes*

In the long run, hydrogen, which is a pollution free fuel, is likely to replace the fossil fuels in most energy related applications. In the interim, other hydrocarbon substitutes would perhaps become important for catering to the needs of transport sector. Nuclear reactors which could provide energy in bulk, in conjunction with several alternative processes, namely, thermo-chemical (by endothermic reaction), photo-chemical (by radiolysis) and electrochemical (by electrolysis) could provide effective alternative to fossil fuel for transport and other sectors in the long run. In the area of electrolysis, significant amount of work has already been done in BARC in terms of development of high pressure electrolyzers.

### *Desalination*

BARC is in the forefront of desalination technologies. Several models of desalination units based on multistage flash processes, reverse osmosis and other technologies have been developed. They need to be upscaled depending upon the needs of different geographical regions of the country. Under the 9<sup>th</sup> Plan, we are setting up a sea water desalination plant using nuclear heat to produce 6300m<sup>3</sup>/day of fresh water at Kalpakkam. Specially designed reactor systems, including barge mounted reactors, can be effectively integrated with desalination systems to utilise this capability for production of fresh water.

### SUMMARY

Indian Atomic Energy programme has come of age. The programme has successfully delivered a self-reliant capability for its first stage involving setting up of Pressurised Heavy Water Reactor systems and associated fuel cycle plants. We are now close to launching commercial Fast Breeder Reactor technology. It is time now for us to accelerate the development of the third stage which would take us closer to our ultimate objective of exploitation of our vast thorium resources to address our long term energy needs. On the basis of achievements so far, we can feel confident that this challenge would also be met.

I have, in the foregoing sections, identified a number of development tasks. Many of these tasks would need inputs from core research areas which are also being pursued at BARC. Such synergy between applied and basic research which we are carrying out hand in hand is our strength.

This is a unique opportunity for us to move ahead based on our own ideas of development of technology to address our national objectives. While doing so, several attributes of thorium utilisation which may also be of interest to other countries are likely to be demonstrated.

Dear colleagues, I put forward this perspective before you. Our 9<sup>th</sup> Plan should be able to accommodate most of the objectives spelt out here. We should now channelise our specialised knowledge and expertise in realising these objectives through our own innovations. There is a challenge in it for most of us in the BARC community, and I am sure we would take up this challenge most effectively.

*Dr Anil Kakodkar*

## HEM-99 : EXPERTS' MEET ON HEPA FILTRATION SYSTEM STANDARDISATION AND INDIGENISATION

The stringent regulatory criteria for the releases of radiation from nuclear operations have led to an increasing demand on the quality of the HEPA (High Efficiency Particulate Air) filtration systems used by the nuclear industry. Although these demands are met within the Department of Atomic Energy (DAE) through Indian industries, there are critical areas where dependency on import still exists. With the onset of embargoes, it is felt necessary to draw out an indigenisation programme of the entire HEPA filtration systems. Towards this end, a two-day experts' meet on this topic sponsored by Board of Research in Nuclear Sciences (BRNS) and organised by Fuel Reprocessing & Nuclear Waste Management Group, BARC, was held at Multipurpose Hall, Training School Hostel, Anushaktinagar, Mumbai on Feb. 11-12, 1999. Ten working groups prepared draft reports prior to the meet on the state-of-the-art development and applications of HEPA filtration systems in DAE as well as in industry. These reports were deliberated upon during the meet.

The meet was inaugurated by Mr R.K. Garg, Ex-Chairman & Managing Director, Indian Rare Earths Ltd. and former Chairman, Environmental Safety Committee, Maharashtra Pollution Control Board, and presided over by Mr B.Bhattacharjee, Director, Chemical Engineering and Technology Group, BARC and Chairman, Nuclear Reactor and Fuel Cycle Committee, BRNS. There were two invited talks, one by Mr A.S. Lakshmanan, CMD, Senapathy Whiteley Ltd., Bangalore (a firm which has shown commitment in indigenisation of HEPA filter medium) and the other by Mr S. Krishnamony, Ex-Head, Health Physics Division, BARC.

*Mr R.K. Garg delivering the inaugural address. Others seated from left are Mr K.G. Gandhi, (Co-convenor), Mr K. Balu, Director, FR&NWMG, BARC, Mr G.J. Pandya (Convenor), Mr B. Bhattacharjee, Director, CE&TG, BARC, Mr M.P. Patil, Facility Director, BARCF, Kalpakkam & Ms Shylaja Harinarayana (Secretary)*



The meet provided an interactive forum for experts from different units of DAE as well as representatives of indigenous manufacturers of HEPA filtration systems and related components such as filter papers and fibres. Several aspects having bearing on their techno-economics, testing practices and standards and reliability were addressed in the meeting. The meeting was attended by representatives of about 22 private agencies which included manufacturers of filter related materials and suppliers of test equipment like aerosol generators and particle counters. Special mention may be made of the participation from the Bureau of Indian Standards, Central Glass and Ceramics Research Institute, Forest Research Institute, Khadi and Village Industries, Pollution Control Boards of Maharashtra and Gujarat.

The function of the HEPA filtration systems in conventional industries (such as pharmaceutical, chemical and semiconductor) is either to clean polluted air before it is released into the environment or to admit clean air with very low dust concentration into a process area. In the nuclear industry, they are used as an important engineering safeguard to prevent the potential release of airborne radioactive and non-radioactive particulates into the environment in normal operating as well as in accidental conditions. Apart from their high efficiency (99.97%) in removing particulate matter in the sub micron range, they offer very low flow resistance (i.e., a pressure drop of less than 25 mm wg at the rated air flow). The construction of these systems is quite elaborate and consists of various stages, beginning with the manufacture of micro fibres, filter paper, pleating of the paper to form filter packs, and manufacturing the mounting frames and related accessories. A standard HEPA filter has a face dimension of 610 x 610 mm and a depth of 292 mm having an air handling capacity of 1700 CMH.

In the nuclear industry, these filters are widely used in the entire fuel cycle from the stage of mining/milling to nuclear waste management operations. Several protocols with respect to the periodic replacement and disposal of the filter systems need to be strictly adhered

to in order to observe the cardinal principle of radiological protection expounded by ICRP, namely, 'as low as reasonably achievable' releases. Therefore, strict quality assurance measures are followed in the manufacture and testing of HEPA filters and associated systems to be used in nuclear facilities.

The presentations of the working groups dealt with in-depth details of the aspects mentioned above. A brief summary of these followed by the discussions generated during the meeting as well as specific recommendations are given below.

#### **INDIGENISATION OF HEPA FILTER MEDIA**

The filter medium used in a HEPA filter is a continuous sheet of paper of around 30 m length and 572 mm width. The thickness of the paper is around 0.4 mm. The sub-micron fibres of the filter paper are in random distribution and orientation. The particles in an air stream follow a tortuous path while passing through the paper and get trapped by interception, inertial and diffusion mechanisms. Theoretical as well as practical observations indicates 0.3 micron size particles as the most penetrating through such a fibrous filter medium and hence the filter media are generally evaluated for removal efficiency against this size. The filtration velocity across the HEPA filter medium is as low as around 2.5 cms/sec with an airflow resistance of less than 25 mm wg. In addition to providing the desired filtration properties, the filter medium requires to possess some special physical properties regarding tensile and folding strength, water repellancy, etc. Around 2.25 kg of filter medium is required for assembly of a standard 1700 CMH HEPA filter. The annual requirement for HEPA filter media is around 10 tonnes for nuclear industry that is presently met by imports.

HEPA filter media can be processed using proper combination of fibres such as cellulose, asbestos, glass, ceramic, other man-made fibres, etc. The most commonly used filter medium all over the world is composed of borosilicate type micro glass fibres, the fibre diameter ranging from 0.5 to 0.75 microns. Very small quantities (less than 8%) of certain additives are also present to impart strength and water repellancy.

In the early seventies, filter media made out of certain locally available asbestos fibres mixed with a small proportion of either cellulose fibre or the imported micro glass fibre had been extensively used by Waste Management Division, BARC in the manufacture of HEPA filters for use in nuclear facilities of DAE. Indigenisation of such a filter medium involves :

- a) Development of technology for production of sub micron fibres, and
- b) Development of technology for processing filter media from these fibres.

Glass fibres available in India, generally used as insulation materials, are above 5 micron diameter. Only a very few firms are manufacturing submicron glass fibres required for HEPA filters all over the world. Efforts have recently been initiated through Central Glass and Ceramic Research Institute (CGCRI), Calcutta, to develop the sophisticated technology based on flame blown process required for manufacture of ceramic and glass fibres in the sub micron size range. The technology of Mill Scale Processing of HEPA filter medium using imported microglass fibre has already been developed by Waste Management Division, BARC in collaboration with Forest Research Institute, Dehradun. HEPA filters assembled out of this filter medium were successfully used in all nuclear plants and facilities of DAE in mid seventies.

Efforts have been renewed at BARC for processing asbestos filter media by blending with ceramic fibres. This work has been taken up in close association with a firm having facilities for mill scale processing of filter media and a firm having handmade processing facilities. Results from initial laboratory scale studies are encouraging.

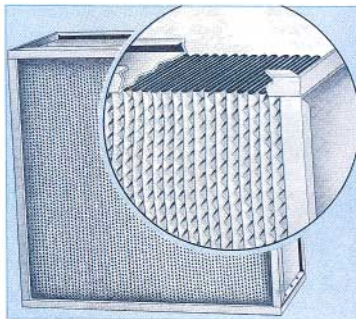
As was evident from the discussions during HEM-99, there is an urgent need to realise indigenous production of HEPA filter media from indigenously produced micro fibres. Encouraging progress has already been achieved in this direction through joint efforts/interaction among FR&NWMG, BARC, Forest Research Institute, Dehradun, CGCRI, Calcutta and some private industries in the field

of fibre and paper manufacturing. The participating experts from BARC/DAE felt that the indigenous development of the filter paper and the media could be achieved within a year.

#### STANDARDISATION OF SPECIFICATION FOR HEPA FILTERS FOR NUCLEAR APPLICATIONS

The necessity of evolving common specifications for HEPA filters was felt essential over the years to ensure that:

- Only quality filters are procured and used in the nuclear industry and to avoid use of filters with varied specifications for similar uses.
- Only locally available raw materials are used as far as possible.
- The local manufacturers meet the specific requirements for the nuclear industry.



*A typical HEPA filter with an enlarged view showing the details of construction*

Draft specifications for HEPA filters for use in nuclear facilities, prepared by a working group of experts, were discussed at the Experts' Meet, HEM-99. The salient features of the recommended specifications include use of adequate and time-tested raw materials, reliable performance and qualification tests and well laid inspection programme.

With regard to evaluation of removal efficiency for submicron aerosols, different test



methods have been developed and followed by different countries. In the test method developed and followed by BARC over the years, a hetero-disperse Di-Octyl Phthalate (DOP) test aerosol is employed with a size selective particle counter for measurement of aerosol concentrations in the air streams. This method is presently being followed by most of the local HEPA filter manufacturers. Further, in the nuclear industry HEPA filter systems are used as once-through systems, unlike the recirculatory systems of clean air delivery. Hence the level of testing is more stringent and involves individual testing of each filter, quantifying the penetration of aerosol through the filter and precisely differentiating filters with even small variations in penetration. This needs a well designed filter test rig. Therefore, the recommended specifications demand prior approval of such a test method and test rig facility used by the manufacturer.

In addition to the strict control on the quality of the HEPA filter medium, it is also essential that only time-tested materials of construction are used for the filter frame, separator, sealant, gaskets etc. Based on past experience, specifications have been recommended which give details of such materials for the purpose of formulating common specifications for nuclear facilities. However, use of alternate materials can be reviewed, after evaluation of their suitability for nuclear industry. Two categories of HEPA filters, using the same materials for assembly, have been specified.

a) *Category-1* filters for use in normal ventilation exhaust applications of nuclear facilities that do not involve high temperature and humidity under normal or accident conditions and for majority of the applications ensuring use of specified materials of construction. For this category of filters, two non-destructive qualification tests i.e. core tightness test and resistance to rough handling test, on random samples, have been included in the recommended specifications, in addition to performance testing of individual filter unit. All the materials of construction, especially the HEPA filter medium, have been specified in detail.

b) *Category-2* filters are for specific operational requirements of some users wherein the specifications may include, in addition to the above requirements, certain type tests on randomly selected filters to ensure the ability of these filters to withstand the extreme conditions that might arise during normal and anticipated operational occurrences. For these filters three destructive qualification tests, on random samples viz., tests for resistance to moisture and over pressure, resistance to heated air and spot flame resistance, have been added.

Though the above specifications have been recommended for adoption by various indentors of the Department, a review from time to time is considered necessary.

The forum of experts during discussions in the Meet stressed on the importance of evolving such uniform specifications for other industrial applications also. Other important aspects identified for further considerations were:

- a) Establishing an acceptable dust holding capacity test for HEPA filters,
- b) Qualification of HEPA filters for resistance to aerodynamic shock for specific nuclear plants,
- c) Evolution of an Indian Standard for HEPA filters and
- d) Economising the use of HEPA filters, by implementing better pre-cleaning techniques.

#### **STANDARDISATION OF HEPA FILTER BANKS & MOUNTING FRAMES FOR NUCLEAR FACILITIES**

For best performance results of filtration systems, it is essential that the HEPA filters, manufactured, tested and accepted for use with utmost quality control, are installed in well designed filter banks. It has been often experienced that HEPA filter banks, though installed with pre-tested and qualified filters, do not achieve compatible bank efficiency due to deficiencies in the filter mounting frame, embedments, masonry structure, entry doors etc., which constitute the filter chamber as a whole of a filtration system. All these components are mainly of static nature and leak

tightness can be achieved with concerted efforts.

Various designs of filter mounting frames exist in nuclear installations, apart from those in



*Typical filter mounting frame in a filter house*



*HEPA filters installed in filter mounting frame*

non-nuclear industries. A working group of HEM-99 went through all the existing designs of such frames from the point of standardisation. Based on the feed back

received from various sites and based on interaction and discussions during the HEM-99 Meet, some standardisation process has commenced to provide guidelines for the designer. Some salient points that are being deliberated towards this end are:

- a) The filter chamber/housing for a small bank can be made of metal and large bank can be of R.C.C construction.
- b) The embedment parts which are required for developing/fixing the filter frames in R.C.C. chamber should be designed such that atleast one continuous limb/leg goes deep inside the concrete to ensure adhesion/integrity and provide long contact path to ensure leak tightness.
- c) Prefilters should be considered if the dust concentration is more than  $1 \text{ mg/m}^3$  of air.
- d) HEPA filters can be arranged in  $4 \times 4$  or  $3 \times 4$  configuration.
- e) The filters can be installed either in the upstream or downstream side based on application.
- f) The upstream and downstream plenums should be designed in such a way that almost all the filters in the bank are utilized fully.
- g) In order to save man-rem, quick release arrangement for replacement of filters should be adopted for filter change operations.
- h) Filter frame members should be designed in such a way that the deflection in the total length of major member is not more than 0.1% of total length at maximum pressure drop across the filters (normally 250 mm pressure differential at maximum dust loading is taken for calculating deflection).
- i) Considering clause-h above, that member for the frame should be selected which has got maximum section modulus. "T" section can be considered for filter frame fabrication.
- j) The filters should be changed when the pressure drop across the filters is about three to four times the initial value.

Some designs of interest have been worked out for further considerations. During discussions in the forum, the need to evolve uniform/standard specifications for filter frames

and filter banks for each of the identified specific requirements in DAE was stressed upon.

#### **PERFORMANCE DEMANDS ON HEPA FILTERS IN NUCLEAR FACILITIES**

The design of reactor building ventilation systems in nuclear power plants (NPPs) and research reactors in the country provide for separate air clean-up systems for normal operation of the plants and for accident conditions. Following an incident/accident involving release of radioactivity, the air clean-up system for normal operation is immediately and automatically taken out of service and the emergency air clean-up systems are brought into service, at predetermined stages, either manually or automatically depending upon their assigned role in the event management. Air flow through emergency air clean-up systems are generally less in comparison with air flow through normal air clean-up systems. But the estimated air temperature, humidity, aerosol concentration and radiation field at the inlet of HEPA filters of emergency clean-up systems are much higher in comparison to that experienced by filters in normal air clean-up systems. While only HEPA filters are used in the exhaust ventilation of normal air clean-up systems, the emergency air clean-up systems normally consist of activated charcoal adsorbent filters in series with HEPA filters to trap all the particulate and radioiodine load envisaged under the accident conditions.

In Fuel Reprocessing Plants (FRPs), once-through ventilation systems consisting of HEPA filter banks, on supply as well as exhaust sides, are engineered to trap any radioactive particulates escaping from the process systems during normal operation, upset conditions or accident conditions. Air clean-up systems consisting of HEPA filters and associated exhaust fans are to be kept operational with supply flow cutoff/reduced in the event of a fire in highly radioactive areas to ensure sub-atmospheric pressure in the affected plant areas to obviate hazards associated with ground level release of radioactivity.

The main differences in the design criteria for ventilation air clean-up systems of FRPs and

NPPs are that

- a) The ventilation systems of FRPs handle very large volumes of air in comparison to that of NPPs and
- b) The HEPA filter banks for use in normal operation and in accident conditions are the same in FRPs, while these systems are different in NPPs.

Performance demands on the HEPA filters in all the other ventilation systems of the reactor, that is in spent fuel storage building, service building, main control room, etc. are similar to those filters installed in either normal air clean-up systems or in emergency air clean-up systems of reactor building. Also, performance demands on HEPA filters used in ventilation systems of fuel reprocessing plants are not significantly different from those filters incorporated in the emergency air clean-up systems of reactor buildings of NPPs. Materials of construction of HEPA filters for use in FRPs, however, have to be suitably selected to face occasional air streams containing fumes of nitric acid. The two sets of HEPA filter specifications, as categorised, standardised and followed by most users of the Department, would generally suffice for all the requirements in nuclear applications including NPPs and FRPs.

It was a general expert opinion expressed at the meeting that though the design of the standard 1700 CMH HEPA filter is convenient from consideration of mounting, handling and packing of used filters, it may be worthwhile to develop a filter of the same shape and size with larger air handling capacity and to suit the volume reduction by compaction so as to minimise the number of filters to be used and to facilitate easy disposal. In view of the safety principle of ALARA to further reduce activity releases to the environment, upgradation of HEPA specification in respect of collection efficiency from the present value, i.e. 99.97% for submicron particles, has also been suggested. It is also felt important to develop appropriate shop testing methods to assess dust-holding capacity of filters under simulated plant conditions instead of certain existing accelerated test methods. Development of type test to establish minimum differential pressure with-standing capability of HEPA filter,

development of high strength HEPA filters, as have been developed in Germany, for use in systems like primary containment controlled discharge (PCCD) of PHWRs, necessity of evaluation and qualification of all raw materials used in HEPA filter assembly for radiation resistance are some of the other suggested works for future in case of nuclear grade HEPA filters.

#### **OPERATING EXPERIENCE ON HEPA FILTERS AND HEPA FILTER INSTALLATIONS**

A variety of experiences, gathered over the years in respect of not only operating HEPA filtration systems but also in the various stages of design, preparation of specifications, fabrication and installation were presented. These included quality assurance plan, inspection, handling and storage of filters, operating experiences in nuclear installations, disposal of used filters, etc. Some of the failures of filter banks due to human errors in handling and installing of filters, arising due to inadequate training of manpower, failure of components like gaskets and sealant, failure of instrumentation, etc. were brought forth with suggestions to avoid such events in future.

The necessity of performing *in situ* leak tests of filtration systems before commissioning the systems, during operation at regular intervals and at each replacement has been recommended to ensure the integrity and continued performance of filtration systems. The *in situ* test method presently followed in DAE and the adequacy of the test method based on experiences were presented, which resulted in a lively discussion in the forum with regard to size of test aerosol for *in situ* testing purposes. The importance of improvisation in identified areas like graded specifications, quality assurance programme, optimisation of number of filters and layout of filter banks, sequence/procedure of installation and removal of filters, manpower training for these specialised jobs, etc. were stressed during the Meet.

#### **REGION-WISE HEPA FILTER TESTING STATION - TECHNO-ECONOMIC FEASIBILITY STUDY**

It is quintessential to ensure that the HEPA filters, found acceptable in shop testing, are in good shape through the various stages of handling and transport. Therefore, it becomes necessary to have another inspection stage to ensure that before installation in the filter banks, the filters are of desired quality. Idea of region-wise HEPA filter testing station has emerged out of this concept. A Working Group under HEM-99, after considering various aspects related to techno-economic feasibility on this has recommended to develop and establish a "Test House" for HEPA filters and HEPA filtration systems as a "Regional Filter Testing Station". Such a station, managed by experts/engineers capable of providing consultancy and training, can be equipped with all test facilities for HEPA filters and raw materials used in their assembly.

The proposed filter testing station can also play the role of an R&D establishment, a training centre for personnel associated with HEPA filtration systems and an agency for qualifying HEPA filter manufacturers and certification of assembly and testing procedures and technical manpower of such manufacturers. This regional testing station can be considered as a class one "Test House" and can be recognised by safety bodies like AERB as a competent agency to train and provide certification. This station is envisaged as the first stage to evolve a "National Test House" catering to other areas like defence, space and other industries.

Initially such a station can be set up at BARC, Mumbai, where presently Waste Management Division has its air cleaning services facilities. The estimated cost is Rs 5 million for setting up such a station. Decision to set up more stations will emerge out of experience. The services and related developmental activities can be seen to generate enough revenue in future for this regional testing station to sustain on its own.

In addition to the regional testing stations, it is also felt necessary that all the sites of

HEPA filter installations of nuclear facilities are equipped with a test rig for evaluation of collection efficiency and pressure drop of standard 1700 SCMH capacity HEPA filters. It is also suggested that each major site should hold a stock of atleast one additional charge of filters at a time to obviate possibilities of rejection of some filters during the stage of testing.

The draft report on setting up such HEPA filter testing stations generated good dialogue which helped in evolving general consensus about the constructive role that such a facility can play towards achieving higher levels of quality assurance in HEPA filter manufacture and performance evaluation of filter media, filter assembly and other hardware of HEPA filtration system. It can provide expert services for training and qualifying/certifying of personnel involved. Recommendations that such a facility can serve as a consulting agency for carrying out performance audit of HEPA filtration systems for regulatory bodies like AERB and other statutory authorities in the field of environmental protection i.e.State and Central pollution control boards and also as a R&D facility on HEPA systems were well appreciated by participants. There were suggestions that the facility in due course can be evolved to offer expert services to the IAEA for training personnel from developing countries in the area of design, upkeep and performance evaluation of HEPA filtration system and components.

#### **PARTICLE COUNTING SYSTEM RELATED TO EFFICIENCY TESTING OF HEPA FILTERS AND INSTALLATIONS**

The efficiency testing of a HEPA filter media, HEPA filters and HEPA filter banks/ installations involves detecting and quantifying the very small penetration fraction of a given test aerosol, lying around the most penetrating size (0.1 - 0.3 micron), through the filter material, filter element or the filtration system. The test methods developed and followed in BARC employ a size selective optical single particle counter (OPC) for detection of the penetrating particles. Such instruments are

presently imported by the HEPA filter manufacturers and users for carrying out the efficiency testing. Considering the difficulties of import due to restrictions, of late, and the inevitability of OPCs for HEPA filter testing, it has become imperative to go for its indigenous development.

OPC is based on the principle of detection of light scattered by the particles, which strongly depends on the particle size for a given wavelength. The angular distribution of the scattered light is determined using Mie scattering theory. The source of light used for the particle counter may be white light for detecting sizes larger than 0.3 micron, or monochromatic and coherent laser beam if the detection size is to be lowered down to 0.1 micron. The latter being highly intense, improves the signal to noise ratio, permits a larger light sensing zone and simplifies the optical arrangements required. The source light is focussed onto a view volume through which airborne particles pass in a direction perpendicular to the light beam. The amount of light scattered by each particle is seen by a photosensitive detector, commonly photodiodes, and converted to an electrical signal. Pulse height discrimination techniques are used to direct the signal to the proper size channel in a multi-channel analyser where the total counts are accumulated. The amplitude of the electrical pulse generated is a function of the particle size.

An optimum design of the OPC involves making a proper choice of the scattering angle. Although the forward direction provides stronger signals and is less sensitive to refractive index of the particles to be detected, it necessitates special care to reduce background noise, which is minimum at an angle of 90 deg. An intermediate angle represents the best compromise. Also, loss of particle counts which can occur due to particles being detected in coincidence or due to electronic dead-time of the analyser has to be minimised for better accuracy. The former situation necessarily requires aerosol dilution. Care has to be exercised in maintaining a perfectly streamlined aerosol flow by means of a clean sheath air, choosing an appropriate view volume based on the flow rate and upper limit of the concentrations to be measured and designing

the focusing and collecting lens arrangements. Based on the above considerations, the optimum specifications for the particle counter to be designed are as follows:

Particle size range	: 0.3 - 0.5 micron in 4-5 size intervals
Concentration range	: < 100 particles/cc
Coincidence error	: Not more than 5 %
Flow rate	: 0.1 CFM
Light source	: Laser diodes (630 nm, 10mW)
Viewing angle	: Forward acute angle
Detection system	: Photodiodes
Counting electronics	: Based on pulse height Analysis
Calibration	: Using DOP particles/sebacate (condensation) aerosols

To summarise, the development of the OPC involves specialised expertise in design calculations and calibration, laser source procurement/mounting and optical alignment and design and development of the detection and electronic systems. Expertise pertaining to all the above mentioned areas, available in-house in DAE, coupled with the manufacturing support provided by an external private agency can result in the indigenous development of this instrument.

The state-of-the-art in the field in the country with respect to laser based particle counters and challenge aerosol generation, as revealed through the discussions in the forum of the Meet, has progressed enough to become self sufficient through conclusive stage development effort.

#### **METHODOLOGY FOR ESTIMATION OF FISSION PRODUCT BEHAVIOUR UNDER VARIOUS CONDITIONS FOR NUCLEAR POWER PLANTS**

A realistic and accurate assessment of the particulate loading on filtration system of Nuclear Power Plants (NPPs) under normal operating conditions, postulated Design Basis Accident (DBA) conditions and largely hypothetical, but very relevant, severe accident conditions (more so after the Chernobyl accident) has been the subject of analytical and

experimental work worldwide to address various issues governing nuclear safety and related regulatory practices. With regard to Indian PHWRs, a finite amount of such data exist but a concerted effort is required to evolve a detailed methodology for an accurate assessment of the envisaged loading on filtration systems as exists in other countries.

A methodology for estimation of fission product behaviour under various conditions for NPPs was presented at the meet. This involves assessment of source term for normal operation and DBA conditions of NPPs, with reference to Indian PHWRs. A review/summary of the particulate data pertaining to various areas of the nuclear fuel cycle has also been presented. While, it was felt that assessment with respect to the above conditions is fairly well reported, assessment with respect to fission product behaviour under severe accident conditions, involving extensive core damage and loss of certain engineered safety features (ESFs) needs to be addressed in more detail.

The current methodology used worldwide to assess the fission product behaviour under severe accident conditions involves development and application of mechanistic codes/models to specific plants under specified conditions for selected accident scenarios. These models treat the fission product release during the fuel melting process, the behaviour and transport of fission product and aerosols in the reactor core, PHT and containment, effects of ESFs and calculate the release to the environment. A measure of the generality of the present methodology for applicability to various reactor types has been established. Although this assessment is reported to be most developed for LWRs, the broad framework holds valid for Indian PHWRs also and needs to be well defined for better estimates.

Studies carried out for Indian PHWRs have also addressed the scenarios pertaining to DBAs. For severe accident conditions of Indian PHWRs, it has been concluded that uncertainties with respect to accident phenomenology and system response need to be addressed in detail. Also, mechanistic analysis of fission product retention in PHT and

assessment of containment failure modes needs to be addressed further.

#### **INNOVATIONS IN HEPA FILTER DESIGNS FROM ENVIRONMENTAL AND TECHNO-ECONOMIC CONSIDERATIONS**

Back-end aspects of the filtration systems such as various sources of generation of used HEPA filter wastes in nuclear facilities, the present practices followed for disposal of these HEPA filter wastes etc. were reviewed during the meet. Measures such as volume reduction, by compaction, of these HEPA filter wastes for future to minimise the disposal space required were suggested. A novel compacting technique, causing 1:5 volume reduction was presented in detail.

Present filter frame designs do not ensure easy separation of the filter pack from the frame and contaminate the frame. A change in the design configuration of the existing HEPA filters for easily detaching the filter pack from the housing has also been suggested to enable ease of compaction with a better ratio. The design suggests use of polythene sheets between the sealant and the filter casing frame members for this purpose. This design reduces the chances of airborne contamination and ensures much less decontamination of the frame. The economic gain in disposal cost also works out to be higher with this improved design.

#### **CONCLUDING REMARKS**

At the concluding session, the need to initiate processes leading to formulation of relevant National Standards was expressed. Enthused by the opportunity of face to face interactive dialogue that this Meet provided, some of the industry participants suggested that an Air Cleaning/Filtration Society of India be founded. On majority of the participants expressing their desire to become founder members, it was agreed to initiate appropriate actions towards founding such a Society.

In conclusion, the meet served as a purposeful maiden effort in bringing out and highlighting the various aspects of the topics that are directly related and important to

environmental and public safety, hitherto not addressed in depth. The encouragement provided by BRNS to the organisers of the Meet and assurance of continued support was highly appreciated by the Convenor.

(G.J.Pandya),  
*Associate Director (Engineering)*  
*Nuclear Recycle Projects Programme*



#### **WORKSHOP/TRAINING PROGRAMME ON APPLICATION OF NAA IN FORENSIC ANALYSIS**

A week long Workshop/Training Programme on 'Application of NAA in Forensic Analysis' organised jointly by the NAA Unit of CFSL, Hyderabad (BPR&D) and Analytical Chemistry Division, BARC, was held at BARC, Mumbai during February, 8-12, 1999.

The primary objective of this Workshop/Training programme was to expose the Forensic Scientists to recent advances in the use of Neutron Activation Analysis and other complementary analytical techniques for elemental analysis, which has proved to be of immense value in forensic investigations. The programme consisted of series of lectures, hand-on practicals as well as demonstrations in Radiochemical and Instrumental Neutron Activation Analysis with associated gamma ray spectrometry. Related techniques like Atomic Absorption Spectrometry (AAS), Anodic Stripping Voltammetry (ASV), EDXRF, DCP & ICP - AES, etc. were also covered in lectures. The experiments emphasised the applications of NAA and other complementary analytical techniques i.e. AAS, ASV to real life case samples of forensic interest i.e., in the field of ballistics, toxicology, source correspondence to decide commonness of origin or otherwise, narcotics, white collar crimes, suspected electrocution cases, documents, etc.

Thirteen forensic scientists from different Central/State forensic science laboratories in the

country and two scientists from BARC attended the course as trainees.

Mr B.B. Nanda, IPS, Director General, Bureau of Police Research & Development, Ministry of Home Affairs, Govt. of India, New Delhi inaugurated the Workshop/Training Programme on 8<sup>th</sup> February, 1999, by stating the objective and utility of the course. Delivering the Inaugural Address, Mr Nanda emphasised the potential application of Neutron Activation Analysis (a highly sensitive nuclear technique) in Crime Investigation. He stressed that the awareness should percolate down to *thana* level constable, so that the collection of clue material may be done properly by the field investigating officers.

Dr V.K. Mehrotra, Director, Central Forensic Science Laboratory, Hyderabad, formally welcomed the participants after pointing out the importance and relevance of the course for the forensic scientists. Dr P.K. Mathur, Head, Analytical Chemistry Division, BARC in his Introductory Address gave a brief account of salient activities of the NAA Unit at BARC since the inception. Dr J.P. Mittal, Director, Chemistry Group, BARC rendered the Presidential Address giving

an overview on the role of nuclear analytical chemistry in its application for the benefit of public. Dr N. Chattopadhyay, Deputy Director and Dr A.K. Basu, Sr. Scientific Officer of the NAA Unit of CFSL, Hyderabad (at ACD, BARC) were the Course Director and Coordinator respectively, of the programme. Overall the programme was thought provoking and the lively discussions were highly appreciated by the participants.

On the final day i.e. 12<sup>th</sup> February, 1999, after group discussion and feed back from participants, Dr N. Chattopadhyay, Deputy Director (NAA Unit) presented the certificates to the participants.

*Inauguration of the Workshop/Training Programme on 'Application of NAA in Forensic Analysis' (L to R) Dr N. Chattopadhyay, Deputy Director, NAA Unit CFSL, Hyderabad at ACD; Dr V.K. Mehrotra, Director, CFSL, Hyderabad; Mr B.B. Nanda, IPS, Director General, Bureau of Police Research & Development, MHA, New Delhi; Dr J.P. Mittal, Director, Chemistry Group; and Dr P.K. Mathur, Head, ACD*



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