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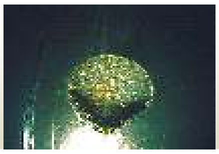

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FLAW CHARACTERISATION IN PHWR PRESSURE TUBES BY ULTRASONICS: EXPERIENCE DURING IAEA-CRP

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Introduction

A typical Indian Pressurized Heavy Water Reactor (PHWR) consists of a few hundred horizontally placed coolant channels. The coolant channel comprises of a Zr-2.5% Nb pressure tube encircled by a Zircaloy-4 calandria tube and four garter spring spacers (Zr-2.5 Nb-0.5 Cu), which prevent these two tubes coming in contact with each other during their service lives (Fig. 1). The pressure tube carries the nuclear fuel, high- temperature, high-pressure heavy water coolant and is subjected to fast neutron irradiation. The integrity of the pressure tube is central to the safety of PHWRs. To ensure this, they are periodically subjected to in-service inspection by Non-Destructive Examination (NDE) techniques. The International Atomic Energy Agency (IAEA) conducted a Coordinated Research Programme (CRP) 'Intercomparison of Techniques for Pressure Tube Inspection and Diagnostics' involving countries that operate heavy water reactors. The first phase of this CRP dealt with flaw characterization in pressure tubes by in-situ NDE techniques. This paper deals with our experience during NDE of pressure tube samples, which were circulated as part of this CRP. The results of these investigations and the analysis of test results are discussed.

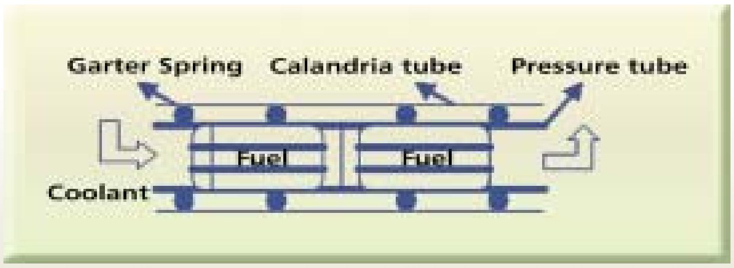


Fig. 1: Simplified sketch of coolant channel

Pressure Tube Degradation and its Life Management

The 540 MWe Indian PHWR [1] consists of 392 coolant channels. The pressure tube, 103.4mm ID, 4.3mm wall thickness, is approximately 6.3meter long. It operates at 300°C, 11 MPa internal pressure and is subjected to neutron flux of the order of 10^{13} n/cm^2/s. These conditions lead to degradations in the pressure tube with respect to i) dimensional changes as a result of irradiation creep and growth, which result in increase in its diameter and length, ii) deterioration in mechanical properties due to irradiation embrittlement, thereby reducing its flaw tolerance, iii) the growth of existing flaws, which were too small or 'insignificant' at the time of installation, and iv) initiation and growth of new flaws like fretting damage due to debris and fuel element bearing pads. The pressure tube material also undergoes corrosion in heavy water aqueous environment during service. This reaction releases hydrogen in the form of deuterium, a part of which gets absorbed in the pressure tube. The absorbed hydrogen can limit the life of a pressure tube due to degradation mechanisms such as Delayed Hydride Cracking (DHC), hydride blister formation and cracking and hydride embrittlement. It is a regulatory requirement to periodically subject pressure tubes to in-service inspection by employing Non-Destructive Examination techniques. In Indian PHWRs, these inspections are carried out by an automated tool called BARCIS (BARC Channel Inspection System). The BARCIS inspection head carries ultrasonic and eddy current sensors and involves four specific tasks: detection of flaw, if any, in the pressure tube, measurement of pressure tube wall thickness, measurement of gap between pressure tube and the calandria tube and location of garter spring spacers [2, 3]. In addition to BARCIS, there are several other indigenously developed diagnostics tools and analytical models to assess and predict the health of coolant channels in Indian PHWRs [4]. These life management tools provide valuable inputs to designers, plant operators and the regulatory authorities, on fitness-for-service assessment of pressure tubes.

Objective of IAEA-CRP

To foster international collaboration in the efficient and safe use of nuclear power, the IAEA conducted a Coordinated Research Programme (CRP) on Inter-comparison of Techniques for Heavy Water Reactor (HWR) Pressure Tube Inspection and Diagnostics. This CRP was carried out within the framework of the IAEA Department of Nuclear Energy's Technical Working Group on Advanced Technologies for HWRs (the TWG-HWR). The TWG-HWR is a group of experts nominated by their governments and designated by the Agency to provide advice and to support implementation of IAEA's Project on advanced technologies for HWRs. Seven laboratories from six countries including Argentina, Canada, China, India, Korea and Romania, participated in this CRP.

The primary objective of this CRP was to arrive at the most effective NDE techniques for pressure tube inspection. It is very crucial that the NDE techniques that are employed for this purpose are very reliable in detection of all significant flaws and very accurate to characterize them in terms of their geometry and nature. In order to assess the effectiveness of these techniques for their intended purpose, it is important that they are periodically subjected to 'blind tests' on pressure tube samples containing flaws of concern. This CRP gave the opportunity for the participating laboratories to prepare their own pressure tube samples containing flaws and carry out blind tests on pressure tube samples prepared by others. Because these were blind tests, the results of examination on pressure tube samples, can be directly correlated with the effectiveness of NDE techniques for detection and characterisation of flaws. A good detectability and accurate characterisation would strengthen the confidence in the technique(s) employed, while poor detectability and inaccurate characterisation would give a feedback to the laboratory, that the existing technique needs improvements or new techniques should be developed. The inter-comparison of NDE techniques based on the results of investigation of pressure tube samples highlights the most reliable and accurate NDE method (ultrasonic, eddy-current or a combination of both) and also a specific technique for that NDE method (time-of-flight monitoring, amplitude monitoring, C-scan image, etc.) for detection and characterization of various kinds of flaws encountered in pressure tubes. This information is useful for the heavy water reactor community to improve the tools being used for pressure tube inspection and diagnostics, by modifying the existing techniques or adapting new ones, so that the inspection is carried out in the most effective manner. The inter-comparison of NDE techniques also helps in identifying those areas where none of the existing techniques are reliable or effective to the desired level. It identifies areas of research for future collaboration in this field.

Conduct of IAEA-CRP on Pressure Tube Inspection and Diagnostics

The participating laboratories prepared pressure tube samples containing artificial flaws resembling real defects of concern. Details on these laboratories and their samples can be found in the report IAEA-TECDOC 1499 [5]. The flaws on the outside surface were hidden by a cover to facilitate blind testing. The CRP was conducted in a round-robin manner during which, the pressure tube sample moved from one laboratory to other. All samples had to be inspected from the inside surface, as in real conditions during in-service inspection. The samples after examination by participating laboratories, were returned to the originating laboratory, which determined the 'flaw truth' in its sample by destructive means or non-destructive means by using either a measuring microscope or a profilometry of replica. The originating laboratory analysed the sample inspection reports from investigating laboratories on its pressure tube sample and assessed their performance on flaw detection and sizing. The intercomparison of NDE techniques employed by investigating laboratories provided a very good platform to determine the most effective NDE technique(s) for detection and sizing of flaws in pressure tube. These findings are reported in IAEA-TECDOC-1499.

Table 1: Flaws in IND1 pressure tube sample

Sr. NO.	Location and Orientation	Flaw Size*			Flaw type
		Length (mm)	Width (mm)	Depth (mm)	
1	OD ,Oblique at 45°	5.84	0.21	0.16	DHC
2	ID, equiaxed	2.50	2.3	1.15	smooth debris fret
3	OD, equiaxed	1.46	0.80	0.63	laminar flaw near OD
4	ID, axial	11.50	2.3	1.00	bearing pad fret
5	ID, axial	6.00	0.4	0.22	reference flaw
6	ID, circ.	6.00	0.3	0.21	reference flaw
7	OD, oblique at 20°	5.81	0.24	0.16	DHC
8	OD, equiaxed	1.92	1.27	3.67	laminar flaw near ID
9	ID, axial	2.00	1.0	1.10	sharp debris fret
10	OD, circ.	5.88	0.32	0.11	shallow DHC
11	OD, axial	5.85	0.28	0.13	reference flaw
12	OD, circ.	5.76	0.27	0.14	reference flaw
13	OD, circ.	11.96	0.39	0.23	DHC
14	OD, oblique at 20°	5.84	0.17	0.13	DHC
15	OD, equiaxed	1.62	1.15	2.14	Laminar flaw at mid-wall
16	OD, axial	5.80	0.24	0.068	shallow DHC
17	OD, axial	11.88	0.35	0.17	DHC

** In the above table, the flaw dimensions for OD flaws are found out by measuring microscope and for ID flaws by profilometry of replica*

Indian Pressure Tube Sample

The Indian pressure tube sample IND1 is 103.4mm ID, 4.3mm wall thickness and 500mm long. It contains a total of 17 flaws, including the reference flaws required for calibration of ultrasonic and eddy current examination. The reference flaws are made as per Canadian standard [6] and included axial and circumferential notches and flat bottom reflectors at different depths. In addition to these, the Indian pressure tube sample contains OD notches resembling axial, circumferential and oblique Delayed Hydride Cracking (DHC) and ID grooves resembling fretting damage due to debris and bearing pad. Table 1 gives the details of all the flaws in IND 1 sample.

Ultrasonic Testing Techniques for Pressure Tube Examination

The selection of NDE techniques for pressure tube examination was left open to the participating laboratory. The underlying condition was that the applied techniques should be useful during in-service inspection. The CRP witnessed two NDE methods for examination of pressure tube samples: ultrasonic and eddy current. In India only ultrasonic testing was used for examination of pressure tube samples.

Fig. 2: Inspection head for pressure tube examination

The inspection head carries six ultrasonic transducers: four for angle beam examination and the remaining two for normal beam examination. Fig. 2 shows the inspection head employed during pressure tube examination.

The angle beam transducers were arranged in two pairs (axial and circumferential) in which one transducer acted as transmitter and the other as receiver. They were placed on an inspection head such that, the ultrasonic beam from transmitter (T) reaches the receiver (R) after travelling a two skip distance in the pressure tube. One of the normal beam transducers was focused on OD while the other on ID of the pressure tube. The ultrasonic beam from four angle beams and one normal beam converged at one point in the pressure tube. The schematic arrangement of transducers for different scans is shown in Fig. 3.

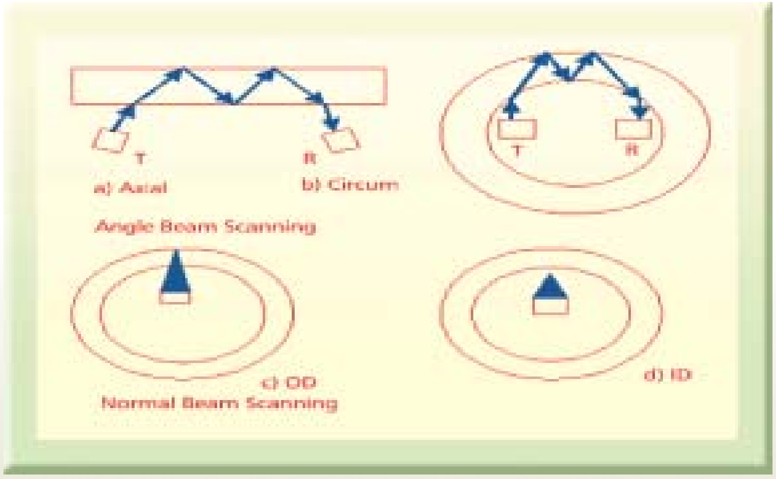


Fig. 3 : Angle and normal beam scans

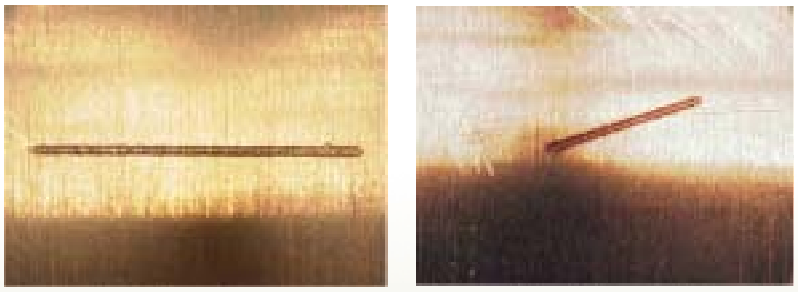
The ultrasonic transducers for angle beam are 10 MHz frequency, 10 mm diameter and 30 mm focal length. The normal beam OD focused transducer is 10 MHz frequency, 6 mm diameter and 25 mm focal length, while the one focused on ID is 20 MHz frequency, 6 mm diameter and 12 mm focal length. All the transducers are point focused. The ultrasonic technique for flaw detection included pulse-echo and pitch-catch scan using angle beam and pulse-echo scan using normal beam. The angle beam pitch-catch scan is very effective for detection of flaws not favorably oriented, like oblique and tilted flaws. With such an arrangement of transducers, any flaw in the pressure tube, irrespective of its orientation and location is detected in more than one scan. This ensures high degree of reliability in flaw detection. The length and width sizing of flaws was based on 6 dB drop technique, while the depth sizing was based on time-of-flight. Tip diffraction technique was used to get the diffracted signals from flaw tip in angle beam and normal beam scan. Depth of ID flaws was found by ID focused normal beam transducer, which monitors the shift in ID signal (surface profiling). The time-of-flight is measured with a resolution of 10 nanosecond (100 MHz digitizer) to get good accuracy in depth sizing. The data record included time-of-flight and amplitude plots and the B-scan images.

Pressure Tube Examination Set-up

The pressure tube samples are examined in a semi-automated set-up. The tube is held in fixtures and then filled with water from inside surface. The inspection head carrying ultrasonic transducers is driven by two stepper motors, one for axial and other for rotary motion. During examination, the data is collected by using angle beam pulse-echo axial and circumferential scan, angle beam pitch-catch axial and circumferential scan and normal beam pulse-echo scan. Any indication with an amplitude of 6 dB over noise in angle beam pulse-echo scan and/or resulting in amplitude drop of 5% or more in reference signal in normal beam pulse-echo and angle beam pitch-catch scan is evaluated. If the indication is suspected to be from a genuine flaw, then it is evaluated for length, width and depth. The depth is found out by both, angle beam pitch-catch and normal beam. Signals from scratches and dents created in the tube due to handling are only recorded and not evaluated in detail.

Pressure Tube Samples from Other Countries

All the participating laboratories, except one from Romania, contributed samples for round-robin analysis during this CRP. These samples contained flaws of varying nature and dimensions such as: DHC, debris fret, bearing pad fret, lap-type flaw and laminar flaw. The DHC flaws were simulated by fine EDM notches. Some of them had uniform depth along their length, while others had semi-elliptical profiles, typical of the real DHC (depth varying along the length, maximum



a) Axial and oblique notch resembling DHC

b) Debris fret on ID

c) Bearing pad fret on ID

Fig. 4 : Simulated flaws in pressure tube samples

depth at centre). The fretting damages on ID are simulated by grooves of varying complexities. The lap-type flaw was simulated by removing a thin slice of material from the OD surface. The laminar flaws were simulated by narrow flat bottom reflectors of varying depths, drilled from OD surface of the pressure tube. Fig. 4 shows the photographs of some of these flaws machined in pressure tube samples. Table 2 gives the consolidated idea about the dimensions of these flaws in the pressure tube samples, which were circulated as part of this CRP:

Table 3: India's performance on flaw detection

Sample	Originating Country	Total number of flaws	Flaws detected by India
ARG1	Argentina	20	20
CAN1	Canada	23	23
CAN2	Canada	12	12
CHI1	China	26	26
IND1	India	17	17
KOR1	Korea	12	12
ROM2	Romania	60	60
Total 7 samples		170	170

Table 2 : Dimensions of simulated flaws in pressure tube samples

Flaw Type	Simulated by	Length (mm)	Width (mm)	Depth (mm)
DHC	Fine notches	1 to 40	0.15 to 0.85	0.07 to 2.95
Debris Fret	Grooves on ID	1 to 4	1 to 3	0.8 to 1.5
Bearing Pad Fret	Axial ID Grooves	10 to 25	1 to 2	0.2 to 1.0
Lap-type Flaw	Rectangular Patch on OD	10 to 25	5	0.17 to 0.26
Laminar flaw	Flat bottom reflector drilled from OD	1 to 2	0.7 to 2	0.6 to 3.7

India's Performance during CRP

The Indian inspection team examined a total of seven pressure tube samples from different participating laboratories. These samples contained a total of 170 flaws. All the flaws, which are likely to be present in PHWR pressure tubes, were a part of these samples. The performance of Indian Inspection team on flaw detection is summarized in Table 3.

The Indian inspection team detected all the flaws in all the pressure tube samples. Out of all the participating laboratories, only the Indian team could achieve 100% result on flaw detection.

With respect to the sizing, the accuracy of length sizing was very good for all the flaws, except the oblique ones. These flaws are required to be imaged in C-scan mode to get the true estimate of their length. The width of fretting damage and the lap type/laminar flaws was sized very accurately. For crack-like flaws simulated by very fine notches, the width was not reported. None of the NDE techniques employed during this CRP by various participating laboratories could give satisfactory results on width of fine notches. The accuracy of depth sizing for majority of flaws was very good.

Table 4 gives India's result on depth sizing of flaws in one of the pressure tube samples.

Table 4: Inspection results on a pressure tube sample

Flaw Type	Flaw Depth (mm)		
	True value	NDE estimate	Error (mm)
OD, DHC (Semi-elliptical)	2.40 (max.)	2.26	0.14
OD, DHC (Semi-elliptical)	1.56 (max.)	1.38	0.18
OD, DHC (Semi-elliptical)	2.95 (max.)	2.78	0.17
OD, DHC (Semi-elliptical)	0.81 (max.)	0.74	0.07
OD, DHC (Semi-elliptical)	2.05 (max.)	1.65	0.40
OD, DHC (Semi-elliptical)	1.45 (max.)	0.97	0.48
OD, DHC (Semi-elliptical)	2.05 (max.)	1.65	0.40
OD, DHC (Semi-elliptical)	1.45 (max.)	0.97	0.48
Equiaxed OD Dent	1.52	1.48	0.04
Equiaxed OD Dent	0.53	0.48	0.05
Equiaxed OD Dent	2.03	1.96	0.07
Equiaxed OD Dent	1.04	1.04	0.0
Bearing Pad Fret	1.94	2.26	0.32
Bearing Pad Fret	0.94	0.99	0.05
OD long shallow notch	0.15	0.12	0.03

The above Table indicates that the NDE estimate on depth is very accurate, except for three flaws. It is observed that other investigating laboratories also encountered error of this order for these flaws. This indicates that the true depth reported by the originating laboratory for these flaws may not be correct.

Table 5 consolidates India's performance on flaw sizing accuracy for all the flaws in all the pressure tube samples examined during this CRP. The flaws in these samples are grouped in to six categories: (i) OD shallow DHC, (ii) OD deep DHC, (iii) ID shallow DHC, (iv) OD oblique DHC, (v) shallow fretting damage and (vi) deep fretting damage. Not included in this Table are: (i) reference notches and flat bottom reflectors as per the Canadian Standard, (ii) lap type or laminar flaws, as their depth sizing is not of interest during in-service inspection,(iii) flaws, for which it is quite likely that the true values reported by the originating laboratory are incorrect and (iv) very deep DHC. The depth sizing accuracy for the above flaw types is expressed in terms of Root Mean Square (RMS) error. It is calculated as follows:

$$\text{RMS Error} = [\Sigma (x_{it} - x_{im})^2 / (n-2)]^{0.5}, \quad i = 1 \text{ to } n$$

x_{it} is the true flaw depth,
x_{im} is NDE estimate on flaw depth,
n is the number of flaws

Table 5 indicates that the accuracy of depth sizing for all the types of flaws in pressure tube samples was very good. For shallow ID and OD DHC, considering the difficulty associated with locating the flaw-tip, the accuracy achieved in their depth sizing was extremely good. The depth of oblique flaws was

Table 5: India's performance on flaw depth sizing

Flaw Type	Depth Range (mm)	Average Depth (mm)	RMS Error (mm)
OD shallow DHC	0.07 to 0.18	0.14	0.027
	0.23 to 0.31	0.27	0.041
OD deep DHC	0.38 to 0.81	0.65	0.113
ID shallow DHC	0.14 to 0.29	0.21	0.026
Oblique DHC	0.11 to 0.17	0.14	0.038
Shallow fretting damage on ID	0.21 to 0.25	0.24	0.045
Deep fretting damage on ID	0.78 to 1.51	1.10	0.075

also sized very well, considering their unfavorable orientation. The debris fret, shallow and deep, were sized most accurately, when seen in relation to the RMS error encountered in terms of percentage of true depth.

Fig. 5 shows the B-scan images for some of the flaws in pressure tube samples.

Fig. 5a shows the B-scan image for the DHC on OD (simulated by a fine notch). The corresponding A-scan at the flaw location is also shown. The image is collected by circumferential movement of a normal beam OD transducer. X-axis represents the time-of-flight and the Y-axis represents the transducer travel. The signal on the left is from pressure tube ID and the one on the right is from pressure tube OD. The semi-elliptical profile of the notch, which is typical of DHC, is clearly seen in the image. The time of-flight plot for this flaw is shown in Fig. 6a. From this plot, one can find the maximum shift in time-of-flight of the flaw tip signal, with respect to the reference signal (OD) and get the depth estimate. In the present case this shift is 0.408 microsecond and the calculated depth is 0.97 mm. Figure 5b shows the B-scan image for a bearing pad fret (simulated by ID groove). The image shows the change in surface profile of the ID signal at the flaw location. This image is collected by moving the ID focused normal beam transducer along the width of the flaw. The time of-flight plot for this flaw is shown in Fig. 6b. From this plot, one can find the maximum shift in time-of-flight of the reference signal (ID) at the flaw location and get the depth estimate. In the present case this shift is 0.354 microsecond and the calculated depth is 0.27 mm.

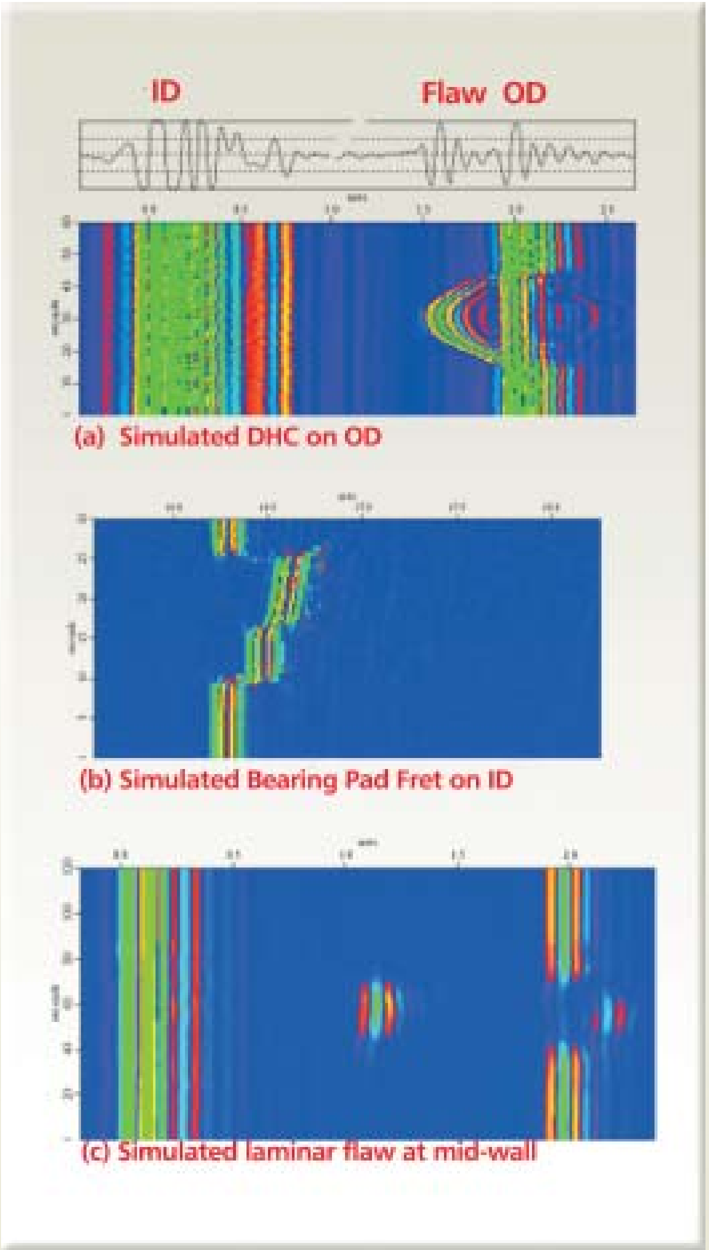


Fig. 5: B-scan images of simulated flaws in pressure tube samples

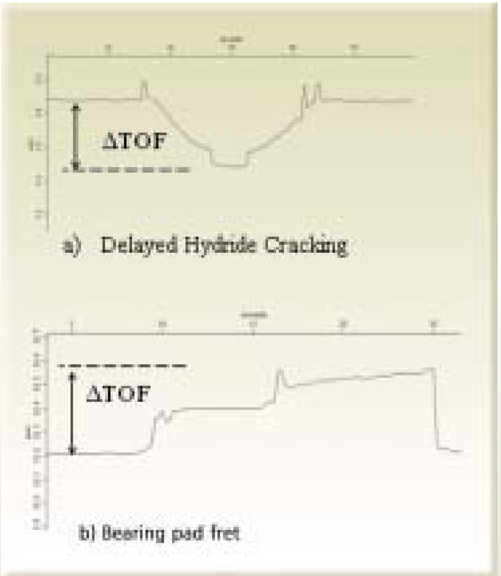


Fig. 6: Time-of-flight plots for simulated flaws in pressure tube

Fig. 5c shows the B-scan image for a laminar flaw, which is simulated by a flat bottom reflector. The flaw is at the mid-wall of the pressure tube. The image shows the signals from pressure tube ID and OD and an additional signal from the laminar flaw close to the centre of the pressure tube thickness. For these types of flaws, sizing of their through-thickness dimension is not important. They only need to be reliably detected and reported in terms of length, width and depth from scanning surface.

Analysis of Inspection Results

The Sample Inspection Reports submitted by investigating laboratories on Indian pressure tube sample were analyzed. The objective of this analysis was to assess the performance of investigating laboratories, but more importantly on the effectiveness of various NDE techniques for flaw detection and sizing. For flaw detection, this analysis was based on comparing the relative response that was observed from a particular flaw using various techniques. For example, in case of ultrasonic testing, the angle beam pulse-echo technique is based on the reflected signal, while the angle beam pitch-catch and normal beam is based on the drop in the amplitude of the transmitted and backwall signals, respectively. If the flaw gives higher amplitude of reflected signal in pulse-echo mode and a lesser amplitude drop of transmitted signal in pitch-catch mode, then pulse-echo technique is adjudged the 'Best'. Contrary to this, if the pulse-echo shows lesser response in terms of amplitude of the reflected signal and a pitch-catch or normal beam show better response in terms of drop in the amplitude of the transmitted or backwall signal, then they are adjudged as the 'Best' technique(s).

For flaw sizing, the analysis was based on comparing the true flaw dimensions with the ones estimated by NDE. The first step in this analysis is to find out the error encountered by individual laboratory during NDE sizing of length, width and depth for each flaw in pressure tube sample. The next step was to find the laboratory, which encountered the least error for these dimensions. Finally, the NDE technique employed by this laboratory for that particular dimension is identified. This analysis was carried out for all the flaws in Indian pressure tube sample. This analysis helped in identifying techniques, which worked consistently well for sizing flaw dimensions for different types of flaws in pressure tube sample.

The analysis of inspection results revealed that for axial and circumferential flaws the conventional pulse-echo technique in circumferential and axial direction is good enough. However, for the oblique flaws, the angle beam pitch-catch works much better. The lap-type or laminar flaws are best detected by normal beam scan. The same is also true for ID fretting damage. With respect to flaw sizing, it is observed that for the length, 6 dB or 20 dB drop technique using ultrasonic normal beam is the most suitable technique. The same is applicable for width of the flaw, if it is greater than the size of the ultrasonic beam. For fine crack-like flaws, none of the existing NDE techniques could give desired results. For depth sizing, time-of-flight measurement using normal beam and/or angle beam pitch-catch gave accurate results for OD flaws. ID flaws are best sized by time-of-flight measurement using high frequency normal beam ID focused transducer. A more detailed account of this analysis and the most effective NDE techniques for detection and sizing of various types of flaws can be found in the report IAEA-TECDOC-1499.

Conclusion

The structural integrity of pressure tube is of prime importance for the safe operation of heavy water reactors. Non-destructive examination during in-service inspection plays a crucial role in this regard by providing inputs in the form of flaw characteristics. It is of utmost importance that the inspection techniques employed during in-situ pressure tube examination reliably detect all the harmful flaws and characterize them very accurately. The IAEA-CRP on pressure tube inspection gave a very good opportunity to the participating laboratories to assess the effectiveness of various NDE techniques (both established and under development) by carrying out blind tests on the pressure tube samples. The intercomparison of these techniques based on the results of examination helped in identifying technique(s) most suited for detection and sizing of various types of flaws encountered in heavy water reactor pressure tubes.

India's performance on flaw detection and sizing during this CRP was excellent. The detection of all the flaws of various sizes, shapes and orientation in all the pressure tube samples was a significant achievement. Equally noteworthy was the accuracy achieved in depth sizing of these flaws by NDE. India's performance on flaw detection during this CRP, reflects the effectiveness of using ultrasonic testing techniques, especially new approaches like amplitude drop in angle beam pitch-catch and normal beam examination. A very good accuracy in depth sizing of flaws could be achieved due to the use of time-of-flight based measurements.

India also carried out detailed analysis of sample inspection reports on Indian pressure tube sample. The analysis led to the identification of most effective NDE techniques for detection and sizing of various types of flaws in heavy water reactor pressure tubes. This assessment is reported in IAEA-TECDOC-1499.

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FUEL ROD CLUSTER SIMULATORS (FRCS)

The Centre for Design & Manufacuture has successfully manufactured and delivered two FRCS as per design and drawings provided by RED, BARC.

The 19-element Fuel Rod Cluster Simulator (FRCS) represents one Fuel Channel of a 230 MWe PHWR. FRCS converts electrical power into equivalent thermal power to simulate power generation by nuclear reaction in a fuel channel. It consists of 19 – 6 meter-long heater elements (Fig.1), bundled together to form a cylindrical shape of 83 mm diameter with the help of six spacers.

Each heater element is a thin walled 16 mm diameter SS304L tube filled with Ceramic pellets with Copper leads brazed at either ends. At the Outlet end, the Copper lead is a 750mm long solid rod, with flexible braided Copper lead at its end, and at the Inlet end, the lead is a Copper tube 1250mm long, which in turn is brazed to the SS Tube Plate. (Fig.2). The Copper lead tubes are diverted to form a larger array to facilitate simultaneous brazing of all the 19 fuel rods. The brazed joints with Tube Plate forms the pressure boundary at the Inlet end. (Fig. 3).

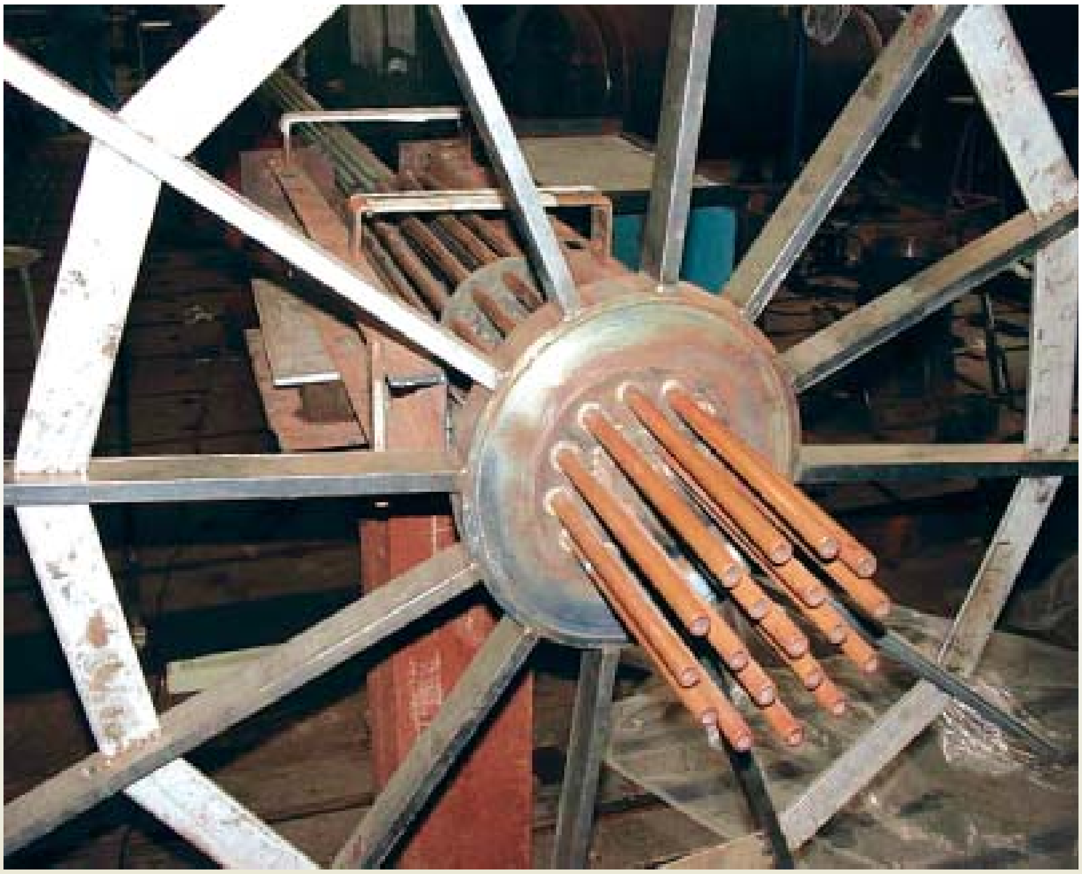

Fig.1: Fuel rod cluster ready for insertion into the channel

Fig 2: SS tube plate end of fuel rod cluster

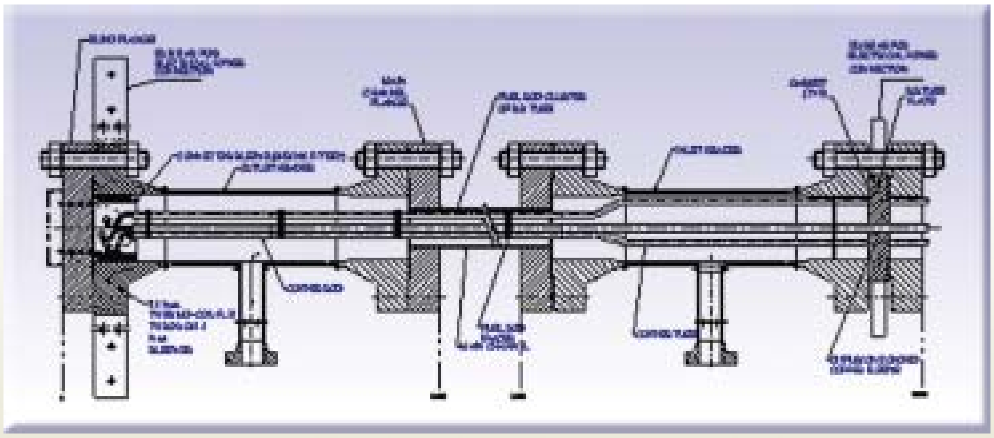

Fig. 3 : FRCS assembly drawing

Five of the fuel rods are instrumented, each carrying four thermocouples and another five thermocouples are attached to the five spacers. All the 25 thermocouples are extracted thro' the blind flange, at the Outlet end thro' brazed joints and these brazed joints form the second pressure boundary. The Heater Element section of the FRCS is housed in a Channel made up of 100 mm N.B. SS304L Tube with appropriate flanges at both ends and insulated by means of Ceramic sleeves. Both Inlet and Outlet Headers contain the Copper lead sections of the FRCS, with provision for electrical power connections in the form of bus-bars. (Figs. 2 & 3).

The individual components, channel and the entire FRCS assembly were subjected to the following tests:

Fuel Rods (S.S. / Copper)

(i) Helium Leak Test

(ii) Hydro-test (internal) – 90 kg/sq. cm

(iii) Hydro-test (external) – 175 kg/sq. cm
Channel With Headers :
Hydro-test - 240 kg/sq.cm
FRCS Full Assembly (Fig. 4) :
Hydro-test - 240 kg/sq. cm

A mock-up of the FRCS, with 1000 mm long Fuel Rods was initially fabricated to develop the various processes. This mock-up helped in developing the following processes:

(i) Fabrication of Fuel Rods, involving Copper to SS brazed joints. The Fuel Rods fabricated as per this process were also subjected to Helium Leak Test.

(ii) Development of Tube Plate with Copper bushes diffusion bonded in it. This new process facilitated Copper to Copper brazed joints between Fuel Rod and Copper bushes fixed in the 35 mm thick Tube Plate. Direct brazing of Copper end of Fuel Rod to SS tube plate was not found to be feasible.

Fig.4: FRCS channel assembly under hydro-testing

Fig:5 : Full FRCS assembly ready for despatch

Fig. 6: FRCS assembly being transported to Hall 7, BARC

Fig. 7: FRCS as delivered at Hall 7 site

Penetration of brazing upto 35 mm depth could be achieved using the new process.

(iii) Brazing process for joining Copper (Rods & Tubes) to SS (Fuel Rods Tubes) and Copper tube to Copper Sleeve diffusion bonded to SS tube plate, to withstand the given pressures.

(iv) Brazing process for simultaneous brazing of all the 19 fuel rods with appropriate brazing alloy was also developed.

(v) Installation of the Thermo-couples, involving appropriate brazed joints.

The two Fuel Rod Cluster Simulator assemblies were successfully completed, (Fig. 5), tested and delivered at RED's Hall-7 site.

For transporting the 9 Meter FRCS Assembly, survey was made to select suitable mode of transport at the designated site behind Hall 7, through a very narrow lane, the only access route available to the site. Finally, two trolleys (Fig. 6) (with rubber tyres as cushions), were attached below the FRCS Assembly and these were pulled using one fork lift, at front end and one fork lift at the rear end, to lift and shift the trolleys as required. Fig. 7 shows FRCS as delivered at Hall 7 site.

ANNOUNCEMENT

Forthcoming Symposium

International Symposium on Vacuum Science & Technology (IVS-2007)

The Indian Vacuum Society will be organising the above symposium at Mumbai, from November 28-30, 2007. It will provide an opportunity to researchers and technologists to review the current scenario, report results, share available expertise and consider future R&D in this area. A souvenir and an exhibition of vacuum related equipment would also be organised along with the symposium. The topics to be covered in the symposium would be as follows :

- Large vacuum systems
- Particle accelerators
- Space simulation systems
- Plasma fusion devices
- Vacuum technology : production of low, medium, high, ultra-high and extreme high vacuum, vacuum measurement
- Leak detection
- Vacuum metallurgy; vacuum evaporation, hard coatings and thin films
- Vacuum brazing, welding, melting and sintering.

For further details one may contact :
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For regular updates, one may check the website http://www.ivsnet.org

DAE-BRNS INTERNATIONAL SYMPOSIUM ON MATERIALS CHEMISTRY (ISMC-06)

The International Symposium on Materials Chemistry (ISMC-06) held during December 4-8, 2006 was sponsored by DAE-BRNS and supported by the MRSI-Mumbai chapter. The five day symposium was attended by delegates from home and abroad. Out of a total of 220 delegates, 18 were from Europe, USA and Japan. Through 35 invited talks and 140 poster presentations, several important research areas of materials chemistry in conventional and nuclear fields were covered in the symposium. Thermochemistry, structural chemistry, surface chemistry, hydrogen energy generation and storage, catalysis, nanoscience, computational chemistry, etc. were some of the topics.

The symposium was inaugurated by Dr. Anil Kakodkar, Chairman, AEC & Secretary, DAE. The chief guest, Professor C.N.R. Rao, Linus Pauling Research Professor and Honorary President of the JNCASR, Bangalore, delivered the keynote address presenting detailed account of the new directions in the chemical design of materials and the emerging research areas in materials chemistry. During the symposium, the delegates working in diverse fields, presented their work as well as views about the current trends of research in material science, thereby benefiting both the scholars as well as the experts in different fields. The participants were enlightened during the evening lectures delivered by prominent personalities

Inaugural session of the International Symposium on Materials Chemistry, ISMC-06

Prof. C.N. R. Rao in conversation with Chairman AEC and Director BARC

in science and technology; Dr. S. Banerjee, Director, BARC spoke on the use of advanced nuclear reactors for hydrogen generation. Dr. V. C. Sahni, Director, RRCAT spoke on Indian Synchrotron Radiation Source (INDUS-II) and its potential applications for materials investigations. Another evening talk dealing with Nano-materials was presented by Dr. Kulshreshtha.

There were invited talks dealing with different aspects of nuclear materials. Dr. V. Venugopal, Director, RC&I Group, BARC presented high temperature thermochemistry of nuclear materials, Dr. Vasudeva Rao, Director CG, IGCAR, presented the process chemistry of the synthesis of boron metal. Dr. V.N. Vaidya, Raja Ramanna Fellow of DAE, talked on the sol-gel process for ceramic nuclear fuel, Dr. T. Gnanasekaran, Head Liquid Metal & Structural Chemistry Division, IGCAR talked on the development of chemical sensors for FBR technology. Professor Adolf Mikula and Professor H. Ipser both from University of Vienna, Austria, presented thermodynamic property measurements and modeling, respectively, for liquid alloys of technological importance. The areas of computational material chemistry of superconductors, nanolayered phases and organometallic sandwiched complexes were covered in the three talks respectively presented by Professor Arun Bansil from Northeastern University, Boston Massachusetts Professor Rajiv Ahuja; from Condensed Matter Theory Group, Uppsala University, Sweden; Professor Julius Jellinek from Argonne National Laboratory, Illinois, USA. In the areas of electronic, electrical and magnetic materials for devices there were presentations by Dr. J.V. Yakhmi, Assoc. Dir. PG, BARC, Lahceene Ouahab CNRS director of research, Rennes Cedex, France, Dr. Glen R. Kowach, The City College of New York, Professor Hiroshi Mizuseki, Tokyo University and Dr. M. Maglione, ICMCB-CNRS, Bordeaux University, France. Professor Frank van Veggel talked on photonic materials; Professor Helmut Papp, University of Leipzig talked on acid-base catalyzed process, Professor Eric W. Kaler, University of Delaware, Newark, talked on interfacial chemistry of wormlike micelles; Professor Tilman Butz, University of Leipzig talked on

Dr. Anil Kakodkar, Chairman, AEC presenting memento to the chief guest, Professor C. N. R. Rao

possible penetration paths of sunscreen embedded titania nano particles into vital skin-tissue; Professor Olivier Joubert, Institut Materiaux de Jean Rouxel, Nantes Cedex, France, talked on new families of oxide ion conductors for fuel cell application; Dr. Juergen Koehler, Max-Planck Institute, Germany, talked on transition metal anions and their bonding implications in intermetallic compounds; Professor W. Kaim, University of Stuttgart, Germany, talked on unique coordination chemistry of TCNX liganded system and Professor O.N. Srivastava, BHU talked on the new trends in hydrogen storage material research. Besides these, there were talks by different experts from national institutes such as IIT, NCL and some Indian Universities. Some of our colleagues from Chemistry Division presented their work in this forum. Younger colleagues conducted repertoire sessions for the posters presented in the symposium.

The delegates got an opportunity to interact with material and equipment suppliers who provided them with details of the latest equipment useful in the field of materials research. Some of the young scientists were awarded for their excellent research work and its presentation. The mutual benefits to the participants were echoed in the feedback received during the valedictory session. The symposium helped in working out a number of collaborative programmes with universities through the DAE-BRNS scheme.

TROMBAY SYMPOSIUM ON DESALINATION AND WATER REUSE (TSDWR-07) : A REPORT

The Board of Research in Nuclear Sciences (BRNS) in collaboration with the Indian Desalination Association (InDA) organised a three-day Trombay Symposium on Desalination and Water Reuse (TSDWR-07) from February 7-9, 2007 at Mumbai (India). The forum provided an interface, wherein policy makers, users, suppliers, technical experts and researchers together deliberated on various issues concerning technical and executional aspects of water management schemes to formulate strategies and identify problem areas for further research and development. The International Journal on Nuclear Desalination (IJND) will publish relevant papers presented in the symposium.

The topics covered in the symposium included:

- Water Scenario in India and Current Status
- Impact of Climate Change on Water Resources
- Sea water Desalination Technologies
- Brackish water Desalination Technologies
- Waste Water Treatment, Water Recovery and Reuse
- Nuclear Desalination
- Innovative Desalination Technologies
- Water Purification Technologies
- Integrated Water Resource Management
- Rain Water Harvesting
- Safe Drinking Water in Rural and Remote Areas
- Research & Development Scenario
- Water Quality Assurance & Monitoring.

Dr. R. Chidambaram, Principal Scientific Adviser to the Government of India and Homi Bhabha Professor inaugurated the symposium. He said that energy security and water security are critical issues in India's

On the dais from left to right are : Dr. S. Prabhakar, Organising Secretary, TSDWR-07, Mr D.S. Shukla, Director, Chemical Engg. & Tech. Group, BARC, Dr Anil Kakodkar, Chairman, AEC & Secretary, DAE, Dr R. Chidambaram, Principal Scientific Adviser to the Government of India & DAE Homi Bhabha Professor, Dr S. Banerjee, Director, BARC, Dr. P.K. Tewari, Head, Desalination Division, BARC and Mr D. Goswami, Desalination Division

development. He outlined the efforts made by his office to bring together different agencies working in the field of desalination and water purification technologies. He referred to isotope hydrology being applied to address the problem of water scarcity in Gaucher area of Uttarakhand and the need for long term research and development studies in the field of advanced membrane development including nano tube embedded membrane for desalination and water purification.

Dr Anil Kakodkar, Chairman, Atomic Energy Commission, highlighted the increasing demand for water due to changing lifestyles and increasing population. He referred to the barge-mounted desalination unit developed by BARC which is useful for supplying safe drinking water along the coastal region. There is a strong need for involving local NGOs to use the desalination and water purification technologies for common good of people.

Dr S. Banerjee, Director, BARC, said that BARC has been in the forefront in this field including design, development and deployment of desalination and water purification plants, both for domestic and industrial water applications. The experience acquired over the years has indicated that there are still some areas where technologies have to be upgraded or some innovations are required.

Dr P.K. Tewari, President, Indian Desalination Association (InDA) and Chairman, Organising Committee welcomed the participants from India and abroad. He mentioned that promotion of desalination, water reuse and water purification technologies is one of the main objectives of Indian Desalination Association. InDA has more than 175 life members and 20 corporate members. Dr. S. Prabhakar, Secretary, Organising Committee proposed the vote of thanks.

The technical sessions included invited talks, oral presentations and poster papers. A preprint volume of the proceedings and a souvenir was brought out. The technical papers cover a wide range of topics from water resource management to different aspects of desalination and water purification. A technical exhibition of products, instruments and equipment relevant to desalination, water recovery and recycle including water purification technologies was also organised. The Symposium had an excellent response from the water community. There were about 300 delegates including participants from abroad. In all, about 70 papers were accepted for presentation and grouped into nine technical sessions with each one of them having invited talks from eminent experts in the field, alongwith oral and poster presentations spread over three days.

The speakers emphasised the need to keep pace with rapid growth in economy and aspirations of growing population for good quality water including safe drinking water. Also the issue relating to site-specific strategies for upgradation of technologies and innovations was addressed. The strategies discussed involved a combination of methodologies such as rain-water harvesting, water purification technologies, sea-water and brackish water desalination, waste-water treatment and reuse leading to distribution of fresh water at affordable cost. The symposium brought together desalination technologists and water management experts from government sector, industries, research and development organisations and academia from within the country and abroad to share their experiences with the end objective of availing water at affordable cost.

61ST BRNS-IANCAS NATIONAL WORKSHOP ON "RADIOCHEMISTRY AND ITS APPLICATIONS TO MULTIPLE AREAS": A REPORT

The 61st BRNS-IANCAS National Workshop was conducted for 15 days at SVKM's Mithibai College, Vile Parle, Mumbai, during October 28 to November 11, 2006, on "Radiochemistry and its applications to multiple areas". Dr R.B. Grover, Director, Knowledge Management Group inaugurated the workshop and delivered the keynote address on "Role of Nuclear Energy in India's Energy Mix". Dr V.K. Manchanda, President, IANCAS briefed the audience on the activities of the association, in promoting Nuclear Science and Dr Y. Babu, Coordinator of the workshop, outlined the programme of the workshop. Mr Balwant Rai Sheth was the Guest of Honour at the function which was presided over by Dr K.V. Mangaonkar, Principal, Mithibai College. Prof. Z.R. Turel, Coordinator of the workshop from Mithibai college welcomed the guests and the participants, from various universities and colleges all over the country. Dr (Ms) Pawar, Head, Chemistry Department gave a vote of thanks.

There were 37 participants in the workshop and 15 of them of were from outside Mumbai. In all eighteen lectures were delivered by experts and seven experiments were arranged by IANCAS. Some advanced lectures on topics such as: Nuclear fission, fusion, fuel reprocessing, waste management, food irradiation, nuclear reactors, accelerators, man-made elements, radiopharmaceuticals, isotope dilution analysis, activation analysis etc, were delivered at the workshop.

Dr V. Venugopal, Director, RC & I Group presided over the valedictory function, at which Dr Anil Morarka, Managing Director, Mira Chemicals was the Guest of Honour. Dr K.L. Ramakumar, Vice-President, IANCAS and Dr Mangaonkar addressed the audience.

On the dais at the inaugural function from right to left are Dr. Y.Babu, Shri Balwantrai Sheth, Dr.R.B.Grover, Dr.K.V. Mangaonkar, Dr. V.K.Manchanda, Dr. A.A.Pawar and Prof. Z.R.Turel

REPORT ON THE "DISCUSSION MEET ON ROLE OF ELECTROCHEMISTRY IN BIOSENSORS, NANOMATERIALS, FUEL CELLS AND IONIC LIQUIDS" (DM-BNFL-2006)

A two-day discussion meet on the "Role of Electrochemistry in Biosensors, Nanomaterials, Fuel cells and Ionic Liquids" (DM-BNFL-2006) was organised by the Indian Society for ElectroAnalytical Chemistry (ISEAC) and the Board of Research in Nuclear Sciences (BRNS), DAE, Mumbai during September 24 – 25, 2006. The discussion meet was organized as part of the Golden Jubilee year celebrations of BARC, at the Multipurpose Hall, Training School Hostel, Anushaktinagar, Mumbai. The opening ceremony of the discussion meet was held on September 23, 2006. During the opening ceremony, Dr S.K. Aggarwal, President, ISEAC and Chairman of the Organising Committee welcomed all the delegates and highlighted the activities of ISEAC, since its inception in October 2003. Mr. N.Gopinath, Secretary, ISEAC and Convener, DM-BNFL-2006, gave a brief summary and the importance of the topics covered in the discussion meet. Mr. Manoj K. Sharma, Secretary, DM-BNFL-2006 proposed the vote of thanks. As part of the opening ceremony, Dr. Juan M. Feliu, President of the International Society of Electrochemistry (ISE) from Spain briefly described the activities of ISE. He also formally

On the dais from left to right during the Panel Discussion on the Role of Electrochemistry in Biosensors are: Dr Chee-Seng Toh (Singapore), Dr Marek Trojanowicz (Poland), Prof. Jean Louis Marty (France), Dr S.F.D'Souza (Associate Director, Biomedical Group, BARC), Dr S.J.Higgins (UK) and Dr (Ms) Ritu Kataky (UK)

On the dais from left to right during the panel discussion on Role of Electrochemistry in Nanomaterials are: Dr R.M.G.Rajapakse (Sri Lanka), Dr Marek Trojanowicz (Poland), Dr K.C. Pillai (Chennai, India), Dr Francesco Paolucci (Italy), Dr J.V. Yakhmi (Associate Director, Physics Group, BARC) and Dr Bozidar Ogorevc (Slovenia)

released a volume containing manuscripts of the invited talks and contributed papers, which were presented during DM-BNFL-2006 and gave a plenary lecture on "Surface Characterization of Platinum Nanoparticles and Electrocatalytic Reactivity".

About one hundred participants including 11 overseas speakers participated in this discussion meet. There were 16 invited lectures and 15 contributed papers (presented as posters) during the discussion meet grouped under four technical sessions. There were panel discussions on Biosensors and Nanomaterials which were moderated by Dr S.F.D'Souza, Associate Director, Bio-Medical Group and by Dr. J.V. Yakhmi, Associate Director, Physics Group (S) at BARC, respectively. Posters were displayed throughout the discussion meet. Invited speakers from overseas included Dr S.J. Higgins and Dr (Ms) Ritu Kataky (U.K.), Dr J.L.Marty (France), Dr Chee-Seng Toh (Singapore), Dr Marek Trojanowicz (Poland), Dr. Bozidar Ogorevc (Slovenia), Dr Francesco Paolucci (Italy), Dr R.M.G. Rajapakse (Srilanka), Dr (Ms) Carita Kvarnstrom (Finland). The speakers from India included Dr K.C. Pillai (Chennai), Dr R.N. Basu (CGCRI, Kolkata), Dr Julio B. Fernandes (Goa University), Professor S.S. Sekhon (Guru Nanak Dev University, Amritsar) and Dr (Mrs.) S.R. Bharadwaj (Chemistry Division, BARC, Mumbai).

The valedictory function was held on Monday, September 25, 2006. During the function, some of the delegates presented their impressions about the discussion meet and expressed their satisfaction over the high quality of technical discussions during the meet. Dr. S.K. Aggarwal, President, ISEAC thanked all the delegates from India and abroad, as well as all the sponsors, for their keen interest during the deliberations of the discussion meet. He also announced the venue and dates of the Third ISEAC International Conference on Electro Analytical Chemistry and Allied Topics (ELAC-2007) to be held at Shilonbagh, Shimla during March 10-15, 2007. He requested all the delegates to check the ISEAC website (www.iseac.org), for regular updates on ELAC-2007.

BHEL SIGNS MoU WITH BARC FOR TECHNICAL CONSULTANCY ON DESALINATION

The Bharat Heavy Electricals Limited (BHEL) recently signed a Memorandum of Understanding (MoU) with the Bhabha Atomic Research Centre (BARC) for technical consultancy on desalination.

Desalination Division (BARC) has been engaged in research, development and deployment of desalination and water purification technologies, for a wide range of water-related applications. It includes seawater Reverse Osmosis (RO) plant for coastal areas, brackish water RO plant in villages for providing safe drinking water, Multi-Stage Flash (MSF) plant for seawater desalination using low grade steam, Low Temperature Evaporation (LTE) Plant using waste heat for seawater desalination, waste water treatment and reuse plants for effluents. The Desalination Division has proven expertise in desalination technologies, because of its operating plants in thermal desalination and Reverse Osmosis. It provides guidance and consultancy to different agencies in this regard.

BHEL, the leading power plant manufacturer in India, is interested in design and manufacture of desalination plants. It has approached BARC for obtaining technical consultancy on desalination. BARC and BHEL under this MoU would work together for specific studies, consultancy and joint working for large-scale deployment of desalination technology. Project execution would be the responsibility of BHEL.

भा.प.अ. केंद्र के वैज्ञानिकों को सम्मान

BARC SCIENTISTS HONOURED

Dr. P.K. Tewari,

डॉ पी.के.तिवारी, निर्लवणीकरण प्रभाग, भाभा परमाणु अनुसंधान केंद्र को निर्लवणीकरण एवं जल शुद्धिकरण के क्षेत्र में योगदान देने के लिए सीबीआइपी - जवाहरलाल नेहरू जन्म शतवर्षीय अनुसंधान पुरस्कार प्रदान किया गया। यह पुरस्कार इन्हें फरवरी 13, 2007 को सी बी आइ पी द्वारा आयोजित आर एन्ड डी की छठी अन्तर्राष्ट्रीय उद्घाटन सभा के दौरान दिया गया था। डॉ तिवारी भारतीय निर्लवणीकरण समुदाय के अध्यक्ष एवं अन्तर्राष्ट्रीय निर्लवणीकरण समुदाय के निदेशक मंडल में भी हैं। ये अन्तर्राष्ट्रीय परमाणु ऊर्जा अभिकरण (आइएनडीएजी) के अन्तर्राष्ट्रीय नाभिकीय निर्लवणीकरण सलाहकार वर्ग के सचिव हैं। डॉ तिवारी नाभिकीय निर्लवणीकरण की अन्तर्राष्ट्रीय पत्रिका के संपादकीय एवं तकनीकी समिति के सह-सचिव भी हैं।

Dr. P.K. Tewari, Head, Desalination Division, BARC has been conferred with CBIP-Jawaharlal Nehru Birth Centenary Research Award for his contribution to the research and development in the field of Desalination & Water Purification in the country. The award was presented during the Inaugural Function of the Sixth International R&D Conference on 13th February 2007 organised by Central Board of Irrigation and Power. Dr. Tewari is President of Indian Desalination Association and on the Board of Directors of International Desalination Association. He is Chairman of International Nuclear Desalination Advisory Group (INDAG) of International Atomic Energy Agency (IAEA). Dr. Tewari is Co-chairman of Editorial & Technical Committee of International Journal of Nuclear Desalination.

Dr. A. K. Tyagi

डॉ ए.के. त्यागी, अध्यक्ष, ठोस अवस्था रसायनिकी अनुभाग, रसायनिकी प्रभाग को फरवरी 14-17, 2007 के दौरान एम.एस.विश्वविद्यालय, वडोदरा में आयोजित, एनयूसीएआर-2007 (NUCAR-2007) इन्डियन एसोसियेशन ऑफ न्युक्लियर केमिस्टस एन्ड एलाइड सांइटिस्टस (IANCAS) की द्विवर्षीय सभा के दौरान आइएएनसीएएस-डॉ तरुण दत्ता मेमोरियल पुरस्कार प्रदान किया गया। यह पुरस्कार इन्हें नाभिकीय पदार्थ अर्थात विकसित भारी पानी रियक्टरों का थोरिया आधारित ईंधन(AHWR), (भापअ केंद्र के डब्ल्यू एमडी के सहयोग से) नए ग्लास का विकास (AHWR), निष्क्रय मेट्रिक्स ईंधन, एवं विकिरण प्रतिरोधी पदार्थ के क्षेत्र में महत्वपूर्ण योगदान को मान्यता देने के लिए प्रदान किया गया। इसके अतिरिक्त डॉ त्यागी ने प्रौद्योगिकी-संबंधी नैनो-सिरामिक्स पर, ऊष्मीय फैलाव का तदनुकूल व्यवहार, फ्लुओराइड ठोस अवस्था रसायनिकी पर महत्वपूर्ण काम किया है। अंतर्राष्ट्रीय पत्रिकाओं में कई प्रकाशन इनके श्रेय में हैं। इन्होंने अन्य कई प्रतिष्ठापूर्ण पुरस्कार भी प्राप्त किए हैं। आप मुंबई विश्वविद्यालय एवं होमी भाभा नैशनल इन्सटिट्यूट (HBNI) के एक मान्यतापूर्ण पी.एचडी मार्गदर्शक भी हैं।

"Dr. A. K. Tyagi, Head, Solid State Chemistry Section, Chemistry Division, has been conferred with IANCAS-Dr. Tarun Datta Memorial Award by Indian Association of Nuclear Chemists and Allied Scientists (IANCAS) during its biennial conference NUCAR-2007 at M. S. University, Vadodara (14-17 Feb. 2007). This award was conferred on him in recognition of his significant contributions in the field of Nuclear Materials viz. thoria based fuels for Advanced Heavy Water Reactors (AHWR), development of new glasses for AHWR waste (in collaboration with WMD, BARC), Inert Matrix Fuels, and Radiation Resistant Materials. In addition, Dr. Tyagi has done considerable work on technologically important nano-ceramics; Framework solids with tailored thermal expansion behavior, rare-earth based inorganic fluorides and Solid State Chemistry under non-ambient conditions etc. He has to his credit a large number of publications in international journals. He is a recipient of several other prestigious awards also. He is a recognized Ph.D. guide of Mumbai University and Homi Bhabha National Institute (HBNI).

Dr Dipak K. Palit

डॉ दीपक के. पलित विकिरण एवं फोटो रसायनिकी प्रभाग, भाभा परमाणु अनुसंधान केंद्र को वर्ष 2006-2007 में अल्ट्राफास्ट स्पेक्ट्रोस्कोपी एवं फोटो एन्ड रेडियेशन केमिस्ट्री के क्षेत्र में विशेष योगदान देने के लिए भारतीय वैज्ञानिक अकादमी भारत, (एफ.ए.एससी.) के सदस्य एवं राष्ट्रीय वैज्ञानिक अकादमी भारत, (एफ.एन.ए.एससी.) के सदस्य भी निर्वाचित किए गए हैं।

डॉ पलित ने वर्ष 1982 में प्रशिक्षण केंद्र की रसायनिक शाखा के छब्बीसवें वर्ग के द्वारा भाभा परमाणु अनुसंधान केंद्र में कार्यारंभ किया। इन्होंनें डीएई होमी भाभा साइन्स एन्ड टेक्नॉलोजी पुरस्कार (2002), केमिक्ल रिसर्च सोसाइटी आफ इन्डिया से ब्रॉन्ज़ मेडल (2001), एवं इन्डियन केमिक्ल सोसाइटी से येधनपली मेमोरियल अवार्ड (1999) प्राप्त किए हैं । इन दिनों ये विकिरण एवं फोटो रसायनिकी प्रभाग, भाभा परमाणु अनुसंधान केंद्र के विकिरण एवं द्रुतगामी रसायनिकी अनुभाग की अध्यक्षता कर रहे हैं।

Dr Dipak K. Palit of Radiation and Photochemistry Division, BARC, has been elected the Fellow of Indian Academy of Sciences, India (F.A.Sc.) and also the Fellow of National Academy of Sciences, India (F.N.A.Sc.) in 2006-2007 for his significant contribution in the field of 'Ultrafast Spectroscopy and Photo & Radiation Chemistry'. Dr Palit joined BARC through 26th Batch Training School in Chemistry discipline in 1982. He is also the recipient of Homi Bhabha Science & Technology Award (2002) of DAE, Bronze Medal (2001) of Chemical Research Society of India, and Rev. Fr. L.M. Yeddanapalli Memorial Award (1999) of the Indian Chemical Society. Presently, he is working as the Head of Radiation & Ultrafast Chemistry Section of Radiation & Photochemistry Division, BARC.

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