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A GLOBAL EQUATION OF STATE FOR HIGH ENERGY DENSITY PHYSICS

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Introduction

High energy density physics deals with behavior of matter under extreme conditions of pressure and temperature. Several fields of research involve high energy density: astrophysics, geophysics, inertial confinement fusion (ICF), explosive and impact loading of materials, Z-pinch devices, etc. All of these fields involve one common feature: i.e., concentration of an intense source of energy in a small region at a fast rate. This leads to hydrodynamic phenomena involving rapid motion of materials due to large pressure gradients generated inside the system [see Box 1]. Fig.1 depicts some typical regimes of energy density vs energy that occur in some of the situations. The DARHT facility is for explosive driven hydrodynamic radiography. Saturn is a typical example of a large planet. NOVA and NIF are experimental facilities for laser-driven ICF, which attempt to reach the regimes closer to nuclear weapon tests. Energy in the ICF systems is liberated via fission and fusion nuclear processes.

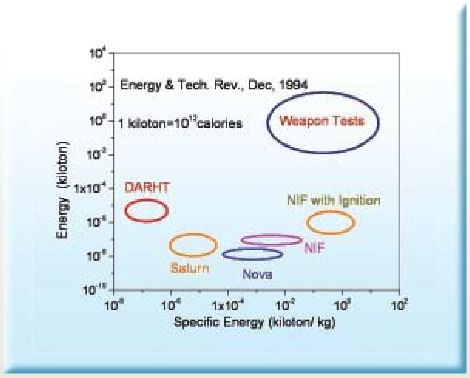


Fig. 1: Energy vs Energy Density

One of our aims at Theoretical Physics Division is to develop state-of-the-art capability for theoretical modeling

Box 1: Hydrodynamics

Compressible flow of materials is accompanied by density changes, which in turn affects the pressure-distribution in a self-consistent manner. The resulting hydrodynamic process is characterized by changes in four macroscopic variables: material velocity, density, pressure and internal energy. These four parameters are described by the hydrodynamic equations based on conservation laws of mass, momentum and energy and an equation of state (EOS), formally relating pressure, density and energy. At low pressures, material properties like yield stress, shear stress and plastic flow models are also needed.

Hydrodynamic phenomenon is also accompanied by energy transport mechanisms such as conduction, hot electron and radiation transport. This is so because at high temperature, atoms of the material not only acquire kinetic energy but also get internally excited or ionized. On de-excitation, they release photons. Thus, electrons and radiation transport energy in a moving and radiating fluid. The intricate coupling between hydrodynamics, electron conduction and radiative-transfer is crucial for modeling the ICF system.

Most often, the time scale of motion is much larger than that for rearrangement of electron configurations in atoms. Hence every local region of the system evolves through a series of (thermodynamic) equilibrium states. Thus we use the Local Thermodynamic Equilibrium (LTE) approximation, which makes it feasible to independently derive the EOS using equilibrium statistical mechanics.

and computational design of direct and indirect ICF systems. Together with experimental physics programs, our efforts could make a contribution towards R&D in thermonuclear fusion.

High pressure EOS

Equation of state (EOS) of materials is an inevitable ingredient of all hydrodynamic simulations. Fig. 2 describes the types of EOS theories used in different regions of temperature and density. Thus, up to about 1 eV temperature and below solid density (ρ_0) atoms are modeled as interacting soft spheres. This offers an improvement over the classical hard sphere or Van-der-Walls models. For densities slightly above ρ_0 , Gruneisen's model of solids, with experimentally determined parameters like Debye temperature (θ_D) and Gruneisen's constant (Γ), is found to be appropriate. Variation of these constants with density is usually accounted theoretically. Zero temperature isotherm at all densities is evaluated using electron band structure calculations; using the APW (Augmented Plane Wave) method. This involves all the details of crystal structures, their domain of stability, etc. However, at higher temperatures, the most common approach is based on density functional theories like Thomas-Fermi (TF) model with two important quantum corrections. The TF model is based on self-consistent calculation of electron potential and density inside an ion sphere. The first quantum correction accounts for the exchange effect, which requires two-electron wave function to be anti-symmetric with respect to interchange of electrons. The local free electron approximation used in the TF model is relaxed with the second correction, which introduces gradient terms in the energy functional. Saha's model and its generalization involving multiple levels of atomic ionization, are used in the low density and high temperature regions. Liquid metal perturbation theories are preferred in the higher temperature region near solid density. There is also a zone where none of the aforesaid theories are valid. The only approach here, is to interpolate the results computed in the surrounding regions. An extensive review of the various EOS models has been published from BARC [1].

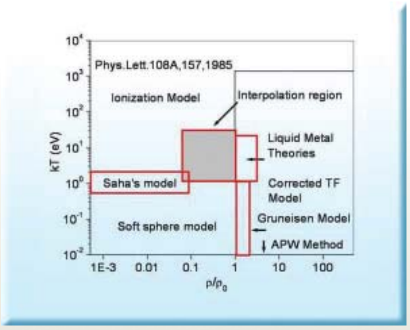


Fig. 2: EOS Models

The different approaches mentioned above are utilized for generating EOS data libraries, like the SESAME tables developed by LANL of USA. Experimental and theoretical information obtained from condensed matter physics on each material is continuously updated into these schemes, thereby making them quite accurate and reliable. The possibility of improving upon these theories exists as and when new developments take place.

Global EOS models

An alternate approach is to develop a global EOS model, which employs a few theoretical methods in the entire phase region. Generally, these methods contain several physical and thermodynamic parameters. This approach becomes applicable, if experimental values of the parameters are made use of. Hugoniot of materials derived from shockwave physics [see Box 2] and any other thermodynamic information, form the database, for evaluating the model. Global EOS models, with varying degrees of sophistication, have been developed by several groups. The Quotidian Equation of State (QEOS) developed at LLNL of USA is one such model [2].

The earlier formulation of QEOS model uses TF theory for electrons. As this does not predict chemical binding at solid density, a correction to the zero-temperature isotherm, called Barnes correction, is added to restore chemical binding. This requires experimental data on bulk modulus (B_0) at solid state density ρ_0. Contribution to pressure by ions is accounted using Cowan's model, which provides an interpolation between the Debye and ideal gas theories. Parameters like θ_D , Γ and melting temperature (T_m) are evaluated using semi-empirical fits in terms of atomic number (Z), mass number (A), etc.

Adding semi-empirical corrections, a second version of QEOS has also been developed by LLNL. The first correction, which involves two parameters, modifies the zero-temperature isotherm. These parameters are adjusted to get agreement with the measured relation between shock speed (U_S) and fluid speed (U_P). The second correction, which also involves two parameters, is used to account for a solid-solid phase transition.

At Theoretical Physics Division, we have developed a global EOS model, following the main ideas employed in QEOS. However, we introduced several improvements, so that it can generate wide-range tables, including the liquid-vapor phase region. We found that QEOS and its improved version were quite inadequate in this region. We first identified, that thermal contribution to pressure by ions and electrons needed improvements. For that, we introduced a scaling of melting temperature thereby adjusting it to the experimental value at solid density. We also incorporated the experimental value of low temperature electronic specific heat. In the liquid-gas regime, we used the Lennard-Jones soft sphere model, whose parameters were determined using cohesive energy (E_{COH}) and bulk modulus. These improvements allow us to predict the critical point parameters: ρ_c, p_c and T_c. Molecular liquids like D_2, undergo dissociation due to heating behind a shock wave. We have also developed a dissociation model for such systems.

Results and Discussion

With the improvements mentioned above, it is now possible to generate EOS libraries for metals, alloys and compounds over a wide range of parameters. Specifically, we have verified shock wave data of 25 materials, which are of direct relevance to high-pressure physics research. Moreover, near critical isotherms, isobaric expansion and shock unloading data also have been checked for several materials [3, 4]. For illustration, some of the typical results are discussed below.

Rankine-Hugoniot (RH) Curves

Experimental data in the high-pressure region are expressed in terms of RH curve or Hugoniot. This represents the locus of all pressure-volume states, that are attainable by a shock wave, starting from an initial state. Different experimental techniques are needed for exploring the high pressures region completely [see Box 2]. Fig. 3 shows experimental and theoretical Hugoniot for aluminum, which extends up to 10000 Mbar. There are significant errors in the data above 500 Mbar, which are available from nuclear tests. The reversal of Hugoniot at high pressure to lower side of density is due to thermal ionization. A shock wave of very high pressure raises temperature above 100 eV. Then, even K and L shell electrons are ionized due to shock heating. L shell ionization produces a second oscillation in the Hugoniot, which is masked in the figure due to experimental errors. TF theory cannot predict these oscillations, which are manifestations of electronic shell effects. Next, we consider uranium metal. Good agreement between experiments and theory extending

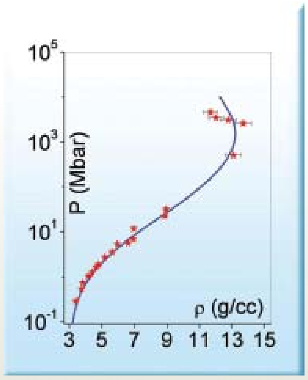
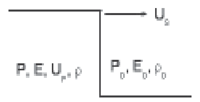


Fig. 3: Pressure-density Hugoniot of Al

Box 2: Shock Waves

Shock waves are generated whenever speed of a hydrodynamic wave depends on pressure. The crest of the wave travels faster than the trough thereby forming a shockwave front, which sharply separates the fluid with different physical states.

Density, pressure, fluid speed, and internal energy (ρ, P, U_P, E) of the shocked and undisturbed medium (denoted with subscript 0) are related via mass, momentum and energy conservation laws. These relations for compression defined as ρ / ρ_0, shock pressure and change in the internal energy are known as 'Rankine-Hugoniot' equations. In these equations, which have five unknowns, the variable U_S denotes the shock speed. Thus if any two variables are measured, the remaining three can be calculated. If the EOS in the form $P=P(\rho, E)$ is known, then these four equations can be solved in terms of one of the variables, say, fluid speed U_P. Thus experiment and theory can be compared, thereby testing high pressure EOS models of materials.



$$\rho / \rho_0 = U_S / (U_S - U_P)$$
$$P - P_0 = U_S \rho_0 U_P$$
$$E - E_0 = (P+P_0)(1/\rho_0 - 1/\rho)/2$$

There are different experimental techniques involving gas guns, explosive driven impact, lasers and even underground nuclear tests, for measuring shockwave parameters. In what is called the free surface method, the shock arrival times, and hence shock speed U_S, are measured using probes placed at pre-assigned locations. In addition, fluid velocity U_P is obtained from free-surface velocity: $U_{FS} \approx 2U_P$. But the more common method is to launch a shock wave into a composite target made of a standard material, with known shock properties, and the sample. Then, matching the shock impedance of the two, the Hugoniot of the sample can be determined in terms of that of the standard material. Unfortunately, all these experiments are once-through types, due to permanent damages caused to the system, by the strong shock waves.

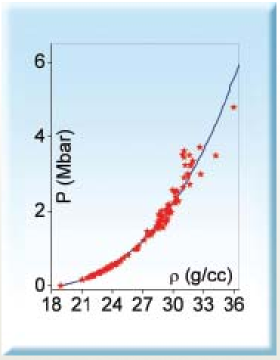


Fig. 4: Pressure-density Hugoniot of U

up to 5 Mbar is seen in Fig. 4. The scatter in the data above 3 Mbar is a feature of the explosive driven flyer methods.

Molecular Dissociation

Molecular systems, e.g. D_2, T_2, N_2, O_2, etc, undergo thermal dissociation due to shock heating. Dissociation, which depends strongly on temperature, generates two atoms per molecule. Therefore, more pressure than for the molecular fluid is required to compress the dissociated fluid. This effect is similar to that in aluminum, where thermal ionization is the underlying mechanism. Thus, the compression ratio (ρ/ρ_0) reduces for pressures beyond

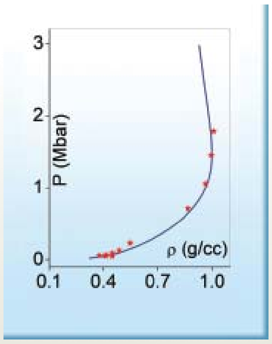


Fig. 5: Pressure-density Hugoniot of D_2

which significant dissociation occurs. Rounding off of the shock wave discontinuity is another consequence of dissociation. Experimental and theoretical Hugoniot of liquid D_2, extensively used for ICF experiments, is compared in Fig. 5.

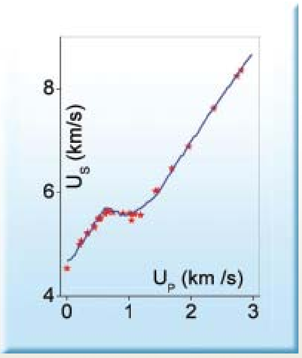


Fig. 6: Shock speed vs particle speed in Fe-Co alloy. Break in the curve is due to a structural phase transition

Solid-Solid Phase Transition

Many solids undergo transformation from one crystalline phase to another on the application of pressure. A practical application of this is the conversion of graphite into diamond. A change of phase shows a distinct break in the otherwise linear variation of U_S with U_P. The correction terms in the zero-temperature isotherm, mentioned earlier, are used to account for the transition. Fig. 6 shows the data pertaining to the transformation from BCC to FCC lattice in Fe-Co alloy.

Shock Unloading

When a shock wave breaks out at the free surface of a material, pressure reduces and free surface velocity (UF_S) increases, starting from the fluid speed (behind the shock). This is due to conversion of internal energy of compression into the kinetic energy of the expanding material. During unloading, the material decompresses and evolves through the low-density region. Depending on the shock pressure before unloading, material can pass through pure liquid, liquid-vapor or pure vapor regions. On attaining ambient pressure, free surface velocity rises to almost double the fluid velocity. The good agreement between theory and experiment for copper, shown in Fig. 7, validates our EOS model.

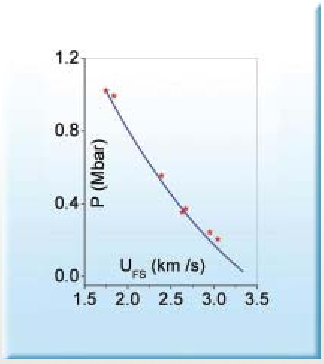


Fig. 7: Pressure variation vs free surface velocity in Cu

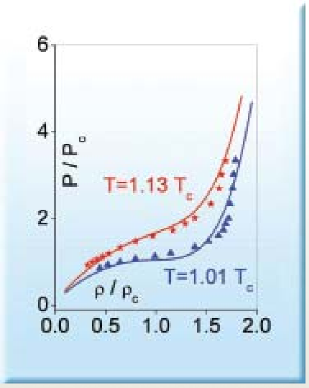


Fig. 8: Two Isotherms of Hg

Liquid-Vapour Region

Modeling the liquid-vapor phase transition is one of our main improvements. To check the accuracy of isotherms in the critical region, in Fig. 8, we compare theory and experiment for two near critical isotherms of mercury, one at $T=1.01\ T_C$ and another at $T=1.13\ T_C$. Our results agree quite well with experimental data. Fig. 9 shows a comparison of isobaric expansion data (at 1 kbar) for tantalum, i.e., variation of ρ vs T, through the liquid-vapor co-existence region. The data in the liquid region, as well as the discontinuous fall at about 7300 °K are correctly accounted. As a final test of our model, in Fig.10 we compare variation of enthalpy (W) of tantalum with T. This experiment is also performed along the same path of isobaric expansion at 1 kbar. Thus, the two data sets together provide a check on the variation of internal energy (E) against T.

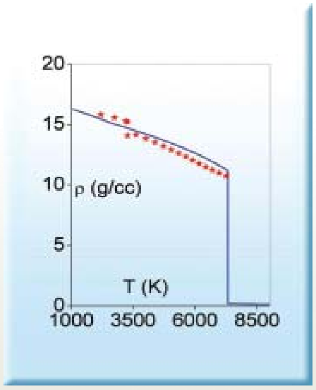


Fig. 9: Isobaric Expansion of Ta at 1 kbar. Break in the curve is due to a liquid-vapor transition

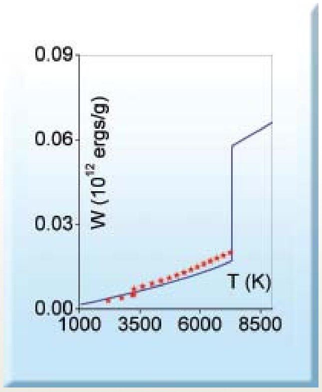


Fig. 10: Enthalpy vs T for Ta. Break in the curve is due to a liquid-vapor transition

Note:

Experimental data on Al is from Physics Letters referred to in Fig. 2; on Hg in Fig. 8 is from Physical Review 3, 354, 1971. Experimental data in the remaining figures are from proceedings of 'Shock Compression of Condensed Matter, 1997, pg.47.

Conclusions

The results presented above are just some of the illustrations. However, these show the utility of the global EOS model for hydrodynamic simulations. The model needs several experimental parameters: solid density (ρ_0), bulk modulus (B_0), cohesive energy (E_{COH}), electronic specific heat coefficient (β_0), melting temperature (T_M), and Debye temperature (θ_D). Critical point parameters are also well predicted by this model. The constants C and S in the relation, $U_S=C+S\,U_P$, are computed such that Hugoniot data is reproduced. For solids undergoing structural phase transition the EOS model needs, among other parameters, the full U_S - U_P curve.

Work is being pursued along several aspects, which need to be added or improved upon in the present EOS model:

An important addition needed is the treatment of porosity of materials. Most of the manufacturing techniques do not yield the exact theoretical density. Release of internal surface energy on shock loading of highly porous materials, is an important effect to be accounted for in simulations.

It is essential to replace some of the experimental parameters used in the models with results from first principle electron band structure calculations. This is particularly so for radioactive materials, for which experimentation is quite difficult. Further, it is customary now to use the results of such calculations for the entire zero-temperature isotherm for all materials.

The present treatment of solid-solid phase transitions in the model is semi-empirical. We need to incorporate explicit EOS of both phases as well as the kinetics of phase transformations.

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3. High pressure EOS of materials: A hand book, BARC/2005/R/002. M.K. Srivastava, Aditi Ray, G. Kondayya, S. Chaturvedi and S.V.G. Menon.
4. Improved EOS of metals in the liquid-vapour region laser & particle beams (under publication) Aditi Ray, M.K. Srivastava, Fig. 8: Two Isotherms of Hg G. Kondayya and S.V.G. Menon.

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UNDER-WATER DIMENSIONAL INSPECTION OF TAPS FUEL CHANNEL

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Introduction

The fuel channel forms an outer cover of the fuel assembly for the Boiling Water Reactor (BWR) of the Tarapur Atomic Power Station (TAPS), Tarapur. It is a Zircaloy-4 channel, with a square section of 113.5x113.5 mm, wall thickness of 1.5 mm and length of 4029 mm. Zircaloy channel being expensive is reused, after the removal of the spent fuel, provided, the changes in dimensions due to irradiation, are within limits. Any lateral growth of the channel, may obstruct the movement of the control rod, during shut down operation. Growth at the bottom end of the channel may be responsible for the leakage of coolant, which in turn, affects the heat-removal pattern, making it unpredictable.

The Centre for Design and Manufacture (CDM) has designed and developed a Channel Growth Measuring Device (CGMD), for measuring the outer dimension, wall thickness and bow of the fuel channel for BWR, TAPS. CGMD is a non-contact, remotely operated, underwater dimensional inspection device, based on ultrasonic immersion method. It consists of a column sub-assembly, upper roller guide sub-assembly, measuring head, focused ultrasonic immersion probes, multiplexing unit and an ultrasonic precision thickness gauge. Measurement is carried out in 12 m deep fuel pool at TAPS, since irradiated fuel channel is highly radioactive. Since the inclination of the channel during its up and down movement, does not affect the accuracy of measurement by CGMD, an overhead crane, instead of any sophisticated device, is used, to move the channel up and down, inside the measuring head during measurement. The measuring head is fixed on the column sub-assembly, which rests vertically inside the pool. The System is capable of taking readings on all four faces of the fuel channel with high accuracy. This paper highlights the principle, design, calibration and operation of CGMD, alongwith analysis of results, for six fuel channels.

Principle of Measurement

CGMD is based on the ultrasonic immersion method, for measuring the time-of-flight of ultrasound wave, in any given medium. Since the velocity of ultrasound at a given temperature is constant in a medium, time- of-flight is directly proportional, to the distance traveled by the ultrasound and thus Ultrasonic Thickness Gauge (UTG) is directly calibrated, in terms of thickness of material.

Outer Dimension (OD) Measurement

The measuring principle of CGMD can be explained with the help of Fig. 1. The fuel channel is immersed in water, for dimensional measurement, using four ultrasonic focused probes. Considering the fact that change in OD will be maximum at the middle of each face (because each corner has got high rigidity than its adjoining faces), probe is mounted at the center of each face, at a predetermined distance. In pulse echo mode, each probe acts as a transmitter as well as a receiver. Transmitted pulse gets reflected from water zircaloy interface and its time-of-flight for half of the distance, gives the water path (W_1, W_2, W_3 and W_4) between probe face and channel outer face. Knowing water paths, one can calculate the channel OD, using equation (1) or (2) given in Fig.1. Since the probe distance P_{13} or P_{24} is fixed and known, any variation in OD will change the water path and this can be easily detected by the UTG.

Wall Thickness Measurement

UTG with the facility for ‘first interface triggering, can eliminate the water path before channel face and with

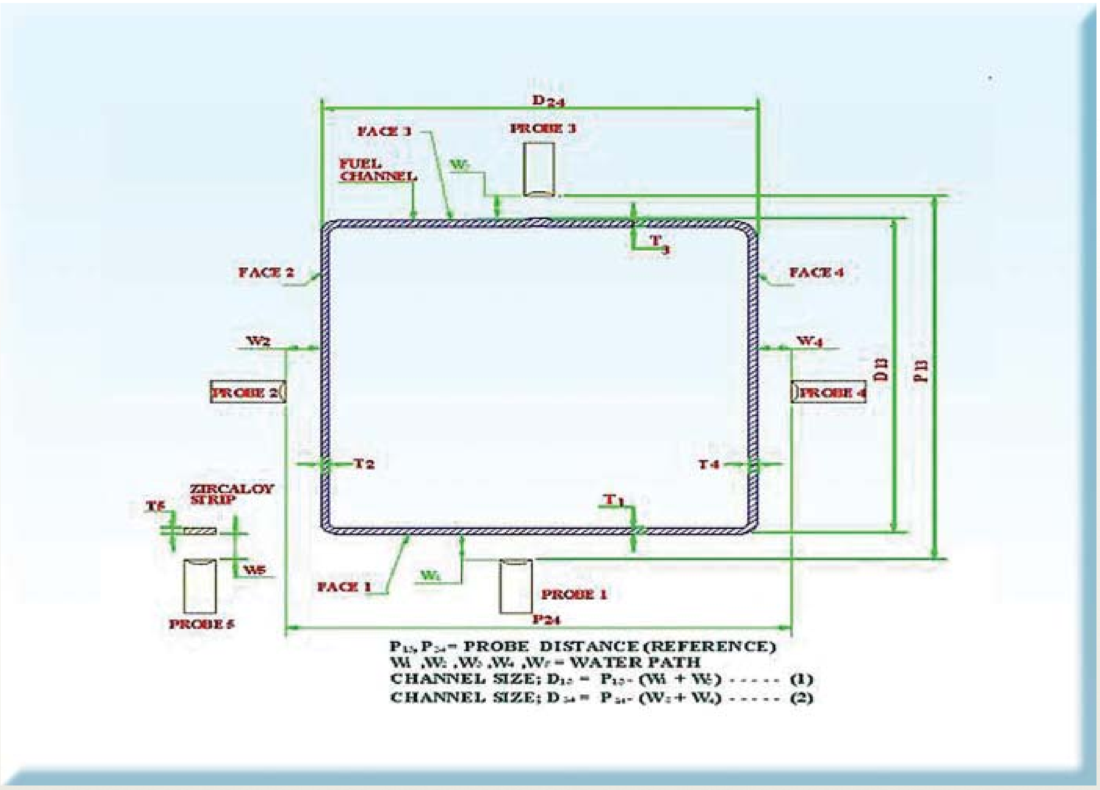


Fig. 1: Principle of channel growth measurement

proper velocity the input wall thickness of channel can be measured, by selecting either first interface and first back wall echo or first and second back wall echoes, from the channel. However, switching from water path measurement to wall thickness measurement, requires change of range, gain, damping and other parameters, suitable for measuring 1.5 mm thick zircaloy.

Bow Measurement

The principle of bow measurement is explained in Fig. 2 showing measurements at three axial locations (planes N_1, N_2 and N_3). Change in water path (W_1, W'_1 etc.) may be attributed to the following three factors: change in outer dimension (D_1, D_2, D_3), bow (bending) and inclination of the channel with respect to the X-axis. Water path can give direct measure of bow, provided it is made independent of the other two parameters namely outer dimension and inclination of the channel. This can be done simply by plotting the profile of central points (C_1, C_2, C_3) between three points and bow may be calculated depending upon the following three conditions:

a) If $Y_1 = Y_2 = Y_3$, both inclination and bow are absent.

b) If $Y_1 < Y_2 < Y_3$ or $Y_1 > Y_2 > Y_3$ and C_1, C_2 and C_3 lie on a straight line, the channel is inclined inside the measuring head, however there is no bow.

c) If Y_2 is different from Y_1 or Y_3 and C_1, C_2, C_3 lie on a curved line, then the channel has bow equal to the curvature of this line.

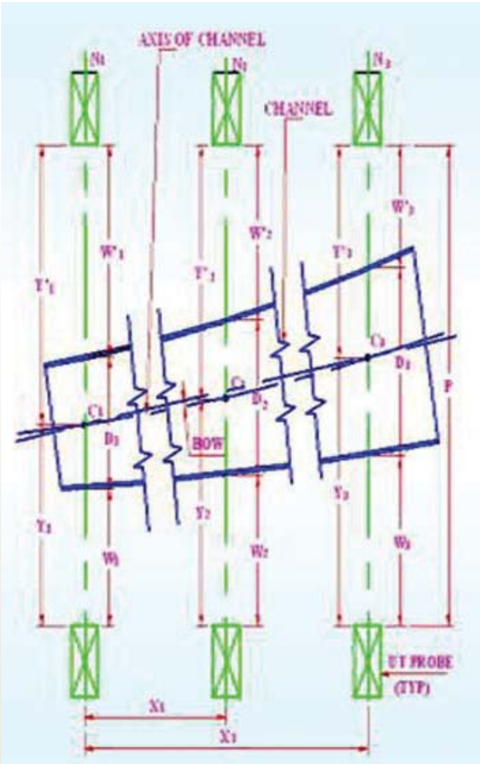


Fig. 2: Bow measurement by CGMD

Fig. 3: Calibration check using a small tank with measuring head

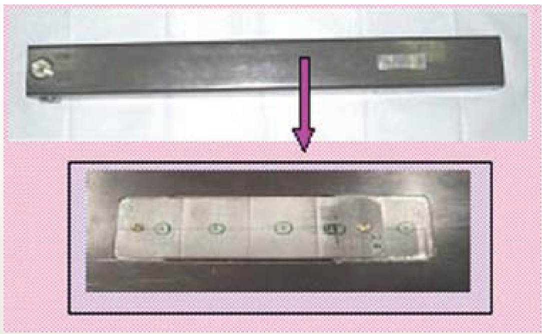


Fig. 4: Calibration sample and exploded view of step block

Calibration

Probe Zero and Material Velocity

Initially ultrasound velocity and probe zero were determined, using two-point calibration method, which requires thin and thick samples of the same material, having thickness within the measurement range. Calibration check was performed in a small tank using only measuring head, as shown in Fig. 3. To check the performance of the device, a calibration sample has been prepared in a cut piece of fuel channel, as shown in Fig. 4. It consists of a zircaloy strip of different steps, fixed on a cutout at the center of each face, of zircaloy channel cut piece. Thickness and outer dimension at each step have been determined precisely, using a screw gauge and a coordinate measuring machine respectively. Calibration results are given in Table 1 and Table 2.

Table 1: Calibration for OD measurement

Face	OD (D)	OD by UT (U)	Actual OD (A)	Error (A-U)
F_1-F_3	D_1	115.50	115.51	+0.01
	D_2	115.02	115.02	0.00
	D_3	114.45	114.44	-0.01
	D_4	113.99	113.96	-0.03
	D_5	112.70	112.67	-0.03
F_2-F_4	D_1	115.48	115.52	+0.04
	D_2	114.98	114.99	+0.01
	D_3	114.51	114.55	+0.04
	D_4	113.75	113.89	+0.14
	D_5	113.00	112.98	-0.02

Table 2: Calibration for thickness measurement

Face & Step	Thick-ness	Value by UT (U)	Actual Value (A)	Error (A-U)
F_1 S_1	T_1	1.50	1.50	0.00
	T_2	1.26	1.20	-0.06
	T_3	1.01	1.00	-0.01
F_2 S_2	T_1	1.24	1.22	-0.02
	T_2	1.00	0.98	-0.02
	T_3	0.76	0.75	-0.01
F_3 S_3	T_1	1.51	1.46	-0.05
	T_2	1.26	1.21	-0.05
	T_3	0.99	0.95	-0.04
F_4 S_4	T_1	1.25	1.25	-0.00
	T_2	1.00	0.99	-0.01
	T_3	0.75	0.75	0.00

In ultrasonic thickness gauging, a number of instrument parameters such as : delay, range, gain, mode, pulse energy, gate, threshold, probe zero, velocity, frequency etc. have to be optimized, for getting accurate reading. This is time consuming, as one has to switch over a number of times, between thickness and water path measurement. Therefore, all parameters required for water path and zircaloy thickness measurement are stored in separate files, which can be recalled by the activation of a single button. This makes measuring very simple and fast.

Velocity Correction

Normally, temperature of water in fuel pool is around 40^0 C, whereas calibration is done outside the pool at ambient temperature; hence it becomes necessary to incorporate velocity correction for the change in temperature. Velocity of ultrasound was calculated in water as well as in zircaloy, at two different temperatures: one representing the ambient (30^0C) and another representing the pool temperature (40^0C). With the increase in temperature, the ultrasound velocity increases faster in water, whereas, it decreases slowly in zircaloy material. Considering ambient temperature as reference, the values of wall thickness and water path at 40^0C, change only by 2 microns and 6 microns respectively, if velocities at 40^0C, are used as input for measurement (Tables 3 and 4). However in large pool, temperature may differ from point to point, therefore provision was made for online velocity correction without measuring the temperature. The additional probe and 1.5 mm thick zircaloy strip were mounted, facing each other, on the measuring head as shown in Fig. 1. With the predetermined values of strip thickness and water path, velocity of ultrasound in zircaloy and water, can be determined at any temperature, prevailing at the time of measurement, near the measuring probes.

Table 3: Water path measurement at different temperatures with velocity correction

Water Temp (^{0}C)	Velocity sound in water mm/µsec	Water Path (mm)			
		W_1	W_2	W_3	W_4
30 (Ambient)	1.5176	20.924	20.865	20.928	20.940
40 (Pool)	1.5387	20.921	20.867	20.931	20.934

Table 4: Wall thickness measurement with temperature compensation

Water Temp (^{0}C)	Velocity sound in Zircaloy mm/µsec	Channel Wall Thickness (mm)			
		T_1	T_2	T_3	T_4
30 (Ambient)	4.8444	1.565	1.515	1.504	1.567
40 (Pool)	4.8268	1.565	1.513	1.505	1.556

System Description and Inspection Procedure

The main components of CGMD are: column sub-assembly, upper roller guide assembly, measuring head, ultrasonic focused immersion probes along with waterproof cables, multiplexing unit and ultrasonic thickness gauge (Fig. 5).

The Column sub-assembly is a box structure, of size 236 x 200 x 6000 mm, fabricated by using two channels. The upper roller guide assembly and measuring heads

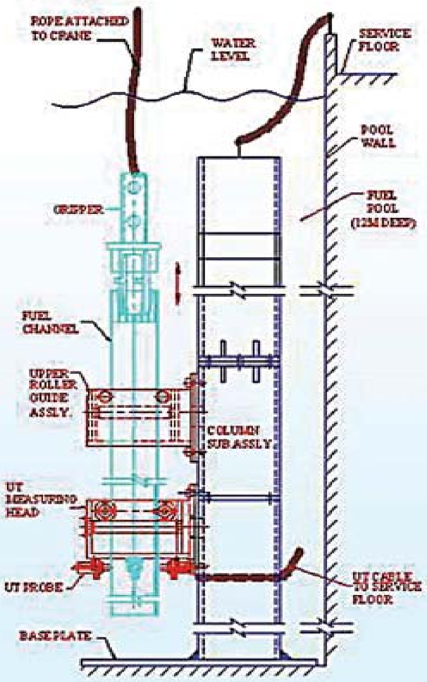


Fig. 5: Measurement set up for CGMD

are fixed at a distance of 900 mm and 1800 mm respectively, from the top surface. A base plate of size 600 x 600 x 18 mm is welded off center at the bottom, so that, column can stand vertically on its own, without any additional support. The column sub-assembly is completely immersed and rests at the bottom of 12 m deep pool. All the probe holders containing UT probes are fixed on the bottom side of the measuring head, to protect them from any damage, due to the up and down movements of the channel. Waterproof cables connected to transducers are routed through the opposite side of the column, up to the service floor. These cables are connected to UTG through a multiplexing unit, with the facility to manually activate, any one out of the four probes. Column sub-assembly is tied up with firm support, available on the service floor with the help of rope, to prevent any accidental toppling.

All the inspection work was carried out at TAPS-2, during its shut down period for refueling. However, prior to taking up the actual work, calibration check was performed for which only the measuring head along with calibration sample, was immersed in a SS drum filled with water. After confirming the readings on the calibration sample, mock up was done on fresh channel to simulate actual testing conditions.

Based on the amount of radiation exposure, channels were identified and inspection was carried out one by one. The first fuel bundle was removed from the channel using gripers and then the channel was inserted in the upper roller guide assembly, with the help of a crane. Meanwhile, velocity of ultrasound in water and zircaloy at the pool temperature were calculated using probe number 5. While the channel was being lowered down, probe one was switched on and water path measurement file was activated. The moment this channel touched the ultrasonic beam, the UTG started flashing the readings for water path, indicating that, channel lower edge was in front of the center of the probe. The channel was further lowered down by 10 mm (approximately) and a zero marking was placed on the rope carrying the channel, corresponding to some fixed point on the crane. At this point, water path measurement was carried out, using all the four probes, activating them one by one. Similarly, after selecting the file for thickness measurement, channel thickness of all the four faces was determined. Before taking any reading, velocity correction was done, to compensate the temperature effect. Readings were taken at ten axial locations, at an interval of 150 mm each, thus covering entire critical position of the bottom end of the channel. Measurement technique being non-contact, simple and user-friendly, 80 readings per channel were obtained, in just 25 to 30 minutes. Out of the six channels inspected, the one with exposure of 19,000 MWD/T (Mega Watt Day per Ton) could be inserted in the measuring head, with slight difficulties. However, channels with exposures of 40,800 MWD/T, 60,000 MWD/T and 61,000 MWD/T could not be inserted, as channel growth was more than the opening, available in the upper guide assembly. After inspection, channels were re-assembled with their respective fuel bundles and kept back in their original locations inside the pool. As all the operations were carried out under water, utmost care was exercised to avoid any sort of accident.

Analysis and Result

The Microsoft Excel program was used, for tabulating the wall thickness and water path readings for each channel, as it is very helpful in calculating the OD, using a specific formula and also for plotting graphs. Bar graph in Fig. 6 gives the outer dimensions of channel, across each pair of opposite faces, at each axial location. Relation between channel growth and exposure is seen from the graph in Fig. 7, which is a plot between radiation exposure and maximum OD, obtained by CGMD, for each of the six channels. Fig. 7 indicates that, higher the exposure, higher the growth. Table 5 gives bow calculation for face 1 and 3 of Channel No. NFC-684, with exposure of 19017 MWD/T. Since the bottom edge is prone to damage during operation, as well as during assembly and removal of the fuel bundle, the first reading near the bottom edge at axial location N_1, has not been considered for bow calculation. The maximum and minimum value of Y co-ordinates for longitudinal axis are 63.83 mm and 63.20 mm respectively, therefore channel is straight within

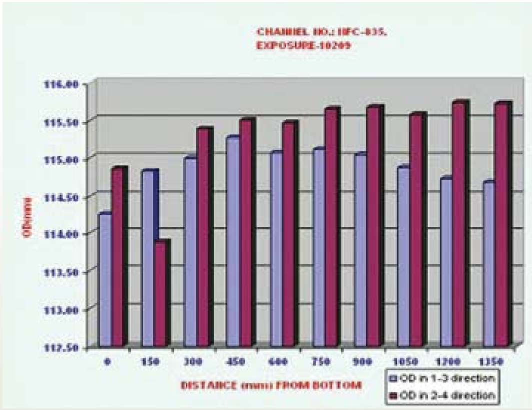


Fig. 6: OD of TAPS fuel channel by UT

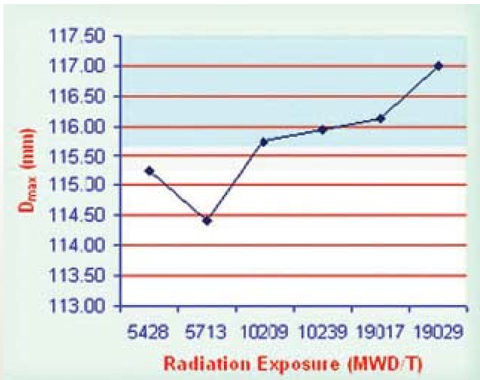


Fig. 7: Channel growth versus exposure

0.63 mm between planes N_2 and N_{10}. Since Y+Y' = probe distance (constant), value of either Y or Y' can be used, for plotting the central line profile.

A careful analysis of the results, reveals the following vital information:

a) The minimum and maximum values of wall thickness are 1.44 mm and 1.55 mm respectively, for one channel. In case of another channel, minimum and maximum values of wall thickness are 1.52 mm and 1.60 mm respectively. Similarly minimum and maximum values for OD are 113.73 mm and 114.42 mm respectively for a channel and 114.01mm and 117.00 mm for another channel.

Table 5: Calculation for bow measurement for face 1 and 2

Channel Details	Axial Location	Distance from bottom	Water Path		Channel Size D_{13}	D_{13}*1/2	Co-ordinate of longitudinal axis		Probe distance P=Y+Y'
		mm	W_1 mm	W_3 mm	mm	mm	Y	Y'	
Channel No.- NFC-684 Bundle No. MC 563 Channel Exposure – 19017 (MWD/T)	N_1	*0*	*6.07*	*5.31*	*114.02*	*57.010*	*63.08*	*62.32*	*125.40*
	N_2	150	6.16	3.90	115.34	57.670	63.83	61.57	125.40
	N_3	300	6.21	4.12	115.07	57.535	63.75	61.66	125.40
	N_4	450	5.96	4.24	115.20	57.600	63.56	61.84	125.40
	N_5	600	5.93	4.12	115.35	57.675	63.61	61.80	125.40
	N_6	750	5.70	4.31	115.39	57.695	63.40	62.01	125.40
	N_7	900	5.44	4.45	115.51	57.755	63.20	62.21	125.40
	N_8	1050	5.66	4.17	115.57	57.785	63.45	61.96	125.40
	N_9	1200	5.39	4.39	115.62	57.810	63.20	62.20	125.40
	N_{10}	1350	5.68	4.19	115.53	57.765	63.45	61.96	125.40

Note: Co-ordinate of central line $Y=D_{13}*1/2+W_1$, $Y'=D_{13}*1/2+W_3$, Probe Distance =P

Result: Longitudinal axis of fuel channel is straight within 0.63mm (63.83-63.20)

b) Maximum OD for each channel is across $Face_{24}$, whereas minimum OD is across $Face_{13}$. All channels, minimum OD zone is within from the bottom, whereas, maximum OD zone is at almost 1000 mm from the bottom.

c) Mostly, with the increase in exposure, channel outer dimension increases and growth takes place only in one transverse direction, without having any bearing on the wall thickness.

d) Up to radiation exposure 19000 MWD/T, bow in channel is negligible.

Future Scope

Though the present system has taken care of most of the crucial requirements of fuel channel inspection, there is still a lot of scope for improvement. To overcome the problems faced during inspection of fuel channel, following modifications would be required, in the future upgraded version of CGMD:

a) Provision for inspecting channel with higher OD and bow.

b) Provision for integrating computer with UTG, for immediate data transfer and calculations using Microsoft Excel Program.

Conclusion

Dimensional inspection by CGMD is very simple, fast and accurate. Irradiated fuel channel can be inspected by CGMD, as it uses non-contact, ultrasonic immersion technique. Without measuring the temperature, online velocity correction is possible which takes care of any change in the temperature. It is possible to know the wall thickness, growth and bow of fuel channel. Analysis of data obtained from the inspection of bottom portion of the six fuel channels, establishes a quantitative relation, between exposure and channel growth.

"ACCIDENT PREVENTION AND PROMOTION OF OCCUPATIONAL HEALTH AND SAFETY": 26 TH COURSE

The 26th course on "Accident Prevention and Promotion of Occupational Health and Safety" was conducted by the Industrial Hygiene and Safety Section of the Radiation Safety Systems Division, BARC, during September 11-22, 2006. The course comprised 23 technical lectures on varied topics of health, safety and environment, presentation of case studies and demonstrations on industrial hygiene surveillance, fire fighting and first aid. A technical visit to the Central Labour Institute, Sion, was also included in the training programme.

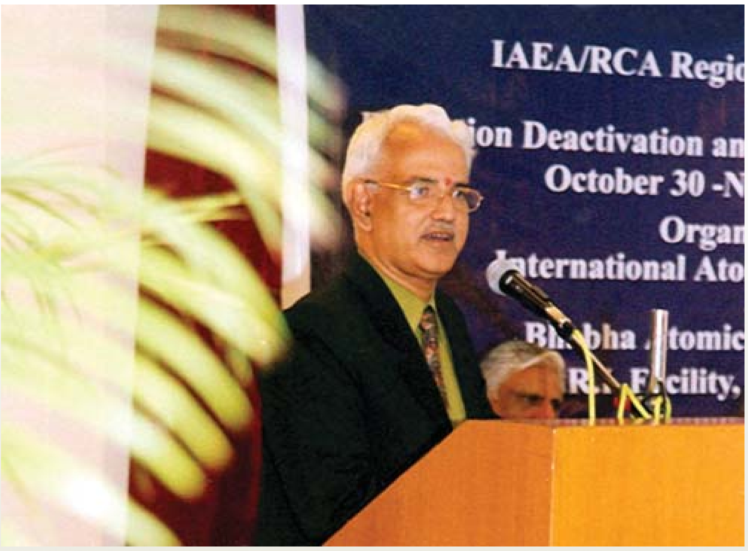
Dr L.M. Gantayet, Chairman, DSRC (WMP) and Head L&PTD, BARC releasing the Training Manual at the Inaugural Function

During the welcome address Dr D.N. Sharma, Head, Radiation Safety Systems Division, summed up the background of the course and highlighted the course contents. The course was inaugurated by Dr L.M. Gantayet, Chairman, DSRC (WMP) and Head, Laser and Plasma Technology Division, BARC, who stressed the importance of incorporating safety during the conceptual and design stages. He suggested that an exclusive session should be devoted, to the presentation of case studies by the participants, which was subsequently implemented in the course.

Mr H.S. Kushwaha, Director, HS&E Group and Chairman, BARC Safety Council delivering the valedictory address

During the valedictory function on September 22, 2006, Mr H.S. Kushwaha, Director, Health, Safety and Environment Group and Chairman, BARC Safety Council gave away the Certificates to the participants. In his valedictory address, he hoped that the participants would try to put the knowledge gained during the programme into practice, when they resumed work. Mr Kushwaha also distributed prizes to the winners of Safety Poster Contest 2006, held on the National Safety Day, this year.

REPORT ON IAEA/RCA REGIONAL TRAINING COURSE ON RADIATION DEACTIVATION AND STERILIZATION OF BIOHAZARDS



Dr K. Raghuraman, Head, Int. Studies Division & RCA National Representative, DAE at the Inaugural function of the IAEA Regional Training Course on Radiation Deactivation and Sterilisation of Biohazards -SHRI Facility, Vadodara

A one week IAEA/RCA Regional Training Course on "Radiation Deactivation and Sterilization of Biohazards," was held at the Sludge Hygienisation Research Irradiator (SHRI) Facility, Vadodara from October 30 to November 3, 2006. A total of thirteen participants from Bangladesh, India, Indonesia, Malaysia, Myanmar, Philippines, Sri Lanka, Thailand and Vietnam attended the training course. Dr Sunil Sabharwal, Head, RTDS was the course coordinator. The training program was inaugurated by Dr K. Raghuraman, Head, International Studies Division, DAE & National Coordinator RCA India, on 30th October 2006. Dr Raghuraman during his inaugural address, highlighted the key role played by India, in formulating the RCA programme since its inception. He said that the problems associated with biological hazards are of concern to all human beings and opined that, radiation technologists can provide solutions to some of these problems, in a cost effective manner as demonstrated by the SHRI facility. He hoped that the discussions at the training course would be useful to the participants, in developing technologies suitable for their countries.

The training course consisted of lectures on source and control of biohazards by radiation technology, dose setting procedures for radiation deactivation, EB and X-ray facilities for control of biohazards, radiation deactivation of postal mail, screening of cargo containers for biohazards, radiation hygienisation of sewage sludge and quality assurance in radiation processing. These lectures were delivered by Dr Arun Sharma, Head, Food Technology Division, BARC, Mr M.R. Shah, RTDS, BARC and IAEA experts Mr Gino Massaro from Belgium and Dr Iwona Kaluska from Poland. The training program also included technical visit to two radiation facilities, namely, SHRI- Facility where gamma radiation is being used for deactivation of pathogens present in municipal sewage sludge and to Universal Isomed Ltd., Vadodara,

Dr V. Venugopal, Director, Radiochemistry & Isotope Group, BARC along with the participants at the Valedictory function of the IAEA Regional Training Course on Radiation Deactivation and Sterilisation of Biohazards -SHRI Facility, Vadodara

a radiation sterilization plant in Gujarat, for sterilization of medical products. A visit to agricultural fields near Godhra was also arranged wherein the participants could see the use of irradiated sludge on a large scale on a grape farm, with encouraging results.

The concluding session of the training course was chaired by Dr V. Venugopal, Director, Radiochemistry & Isotope Group, wherein a discussion was held on future orientation and priorities of electron beam facilities, for material development and environmental remediation, in developing countries. Dr Venugopal said that radiation technology could offer advanced solutions to selective environmental problems, caused due to increased urbanization and enhanced industrial activities, as was evident from development of processes for the treatment of flue gases, textile waste water treatment and sludge hygienisation. He opined that, in future, radiation technology would play an important role in mitigating these problems as it could be effectively utilised on a large scale, with minimum controls and in a cost-effective manner. Dr V. Venugopal also gave away certificates to the participants, during the valedictory function.

BARC TRANSFERS TECHNOLOGY OF DIGITAL MEDICAL IMAGING SYSTEM (DMIS)

The technology of Digital Medical Imaging System (DMIS) developed by the Laser & Neutron Physics Section (L&NPS), Physics Group was transferred to M/s. Nucleotech Medical System International Ltd., Navi Mumbai, on November 16, 2006.

DMIS is an advanced film-less X-ray imaging system, with four functions viz. Fluoroscopy, Radiography, Digital Subtraction Angiography and Offline study in a single multipurpose unit. It offers reduced patient dose of the order of 1 to 2 as compared to conventional radiography units. It mainly consists of high frequency X-ray generator, coupled to the X-ray Image Intensifier Tube, to convert input X-ray signal to optical output signal, which in turn is coupled to CCD through special optics. It is a PC- based system with user friendly software, having important image processing and operator friendly features, as required by radiologists and X-ray technicians. A dedicated database management facility, caters to easy storage and retrieval of patient data. The first system designed and developed by BARC, has been in use at BARC hospital, for the last one year.

The Technology Transfer & Collaboration Division co-ordinated all activities related to the transfer of this technology i.e. preparation of technical brochure, advertisement of the technology for its transfer, preparation of agreement for transfer of technology, guiding the working group in making the technology transfer document and finally the agreement signing formalities.

At the conclusion of the technology transfer agreement signing ceremony. Seen from (left to right): Dr Amar Sinha, L&NPS, Mr A.M. Patankar, Head, TT&CD, Mr B.K. Pathak, Head, TTS, TT&CD, Dr (Ms) L. J. Dhareshwar, Head, L&NPS, Mr B.N. Karkera, Director R&D, Nucleotech MSI Ltd., Dr S. Kailas, Associate Director, (N), Physics Group, Dr R.B. Grover, Director, KMG, Mr Amaltash Saxena, CEO & MD Nucleotech MSI Ltd, Ms Suman Saxena, Director, Nucleotech MSI Ltd., Ms Preeti K Pal, TT&CD, Dr A. Chaubey, Head, Radiology Unit, BARC Hospital, Mr P S Sarkar, L&NPS, Ms Smita Mule, TT&CD

NATIONAL FIRE SERVICE WEEK AT BARC

In commemoration of the fire fighters, who lost their lives in the huge fire at the Mumbai Port Trust in 1944, the National Fire Service Day is observed every year, on the 14th April.

Several programmes were oganised by the Fire Sevices Section, BARC, during the Fire Service Week from April 14-20, 2006, to create awareness about fire safety, among BARC employees.

Dr S. Banerjee, Director, BARC, was offered a pin flag on the 17th of April, 2006 to kickstart the fund raising campaign in BARC. Dr Banerjee emphasized the need for fire safety awareness and appreciated the role of the Fire Services Section during the deluge on July 26, 2005 and the subsequent flooding incident at Trombay and rescue operation from Purnima building. Mr D.S.Shukla, Director, Chemical Engineering and Tehnology Group,

Dr S. Banerjee, Director, BARC, at the fund raising campaign function organised during the fire service week 2006, when he was offered the pin flag by Mr A.K. Tandle, CFO, BARC

Director, Fire and Emergency Services, Maharashtra, Chief Fire Officer, Mumbai Fire Brigade, Chief Fire Officer, BARC and the winning team of BARC in the Tactical Medley Drill along with the Trophy.

Officers taking keen interest in the exhibition of fire safety equipment displayed at RLG Complex

BARC, congratulated the winners of various competitions and members of the Fire Services Section, for their active participation.

At Radiological Laboratories, BARC, a live demonstration of fire safety and an exhibition were arranged on the 19th of April 2006. Mr A.K. Tandle, Chief Fire Officer, BARC, spoke about the significance of the Fire Safety Week. Dr Venugopal, Director, RC&IG, addressed the audience. Mr H.S. Kamat, Director, NFG, inaugurated the Fire Safety Equipment Exhibition and he also appreciated the safety measures and quick resonse of the Fire Services Section, BARC. Fire fighting and rescue demonstrations were held after the inauguration. Information card on "Electrical safety, House Keeping and Fire Safety" were distributed among the audience.

On behalf of BARC, Mr A.K. Tandle attended the inauguration ceremony of the Fire Service Week at Raj Bhavan, where His Excellency S.M. Krishna, Governor of Maharashtra, inaugurated the fire services personnel welfare fund raising campaign. Two teams from BARC Fire Services Section, participated in the Tactical Medley Drill Competition, organised by the Government of Maharashtra, at Civil Defence Headqurters, on the 16th of April, 2006. Team B from Fire Services Section, BARC, was awarded the third prize. Mr M.B. Kalushte and Mr S.J. Ghadshi both Firemen from FSS, BARC, received the second and third prizes respectively, in the individual ladder drill competition.

Funds collected during the fund raising campaign, were deposited in the office of the Fire Advisor to the Government of Maharashtra for fire service welfare activities.

DAE-BRNS INDIAN PARTICLE ACCELERATOR CONFERENCE (INPAC-2006): A REPORT

The Indian Particle Accelerator conference (InPAC-2006), sponsored by the Board of Research in Nuclear Sciences, DAE, was held at BARC/TIFR, Mumbai during November 1-4, 2006. The conference was organized as part of the BARC Golden Jubilee Year celebrations. InPAC-2006 was the third in the conference series on this topic. The earlier two conferences were held at the Raja Ramanna Centre for Advanced Technology, Indore (InPAC-2003) and at the Variable Energy Cyclotron Centre, Kolkata (InPAC-2005).

The main objective of this conference was to discuss the new developments related to various aspects of accelerator physics, accelerator technology and accelerator-based applications. It provided a forum to scientists and engineers working in this field, to discuss and develop expertise in the design and development of frontier technologies, in particle accelerators. About 250 scientists and engineers, both from India and abroad, participated in the conference.

Dr. R.K. Choudhury, Head, Nuclear Physics Division, BARC and Chairman, Organising Committee gave the introductory remarks, where he emphasized the importance of this conference for the growth and development of accelerator technology in India. Dr S. Banerjee, Director, BARC welcomed the participants. He remarked that accelerator development was one of the thrust areas of DAE with several applications in many interdisciplinary fields. He also enumerated the large number of fundamental discoveries that continue to be made using the energetic particle beams from accelerators. The conference was inaugurated by Prof. S.S. Kapoor, Senior INSA Scientist and Ex-DAE Homi Bhabha Professor. He noted that due to our growing achievements in accelerator technologies over the last several years, the international community is now looking upto India, for participation in international mega projects. Dr P. Singh, Convenor of the conference proposed the vote of thanks.

Dr S.S. Kapoor, Senior INSA Scientist and Ex-DAE Homi Bhabha Chair Professor delivering the inaugural address at InPAC-2006.

Particle Accelerators have been a major research tool in making new fundamental discoveries in physical sciences. Apart from basic science studies, accelerators are also finding enhanced use, in industrial and medical applications. New technological developments are underway, that will lead to the use of accelerators for nuclear energy generation and waste incineration. The conference covered the key areas in accelerator technologies in the following categories; 1) Proton and Heavy Ion Accelerators, 2) Electron Accelerators, 3) Synchrotron Radiation Sources and FEL, 4) Beam Dynamics and Optics, 5) Sources for Stable and Unstable Ion Beams, 6) Beam Diagnostics, Control and Instrumentation, 7) Magnet Design and Technology, 8) Power Supplies, 9) Radio frequency and Microwave Technology, 10) Vacuum Technology, 11) Cryogenic

Technology, 12) Radiation safety Issues in Accelerators, 13) Target Development and Secondary particle Production, 14) Medical, Industrial and other Applications of Accelerators and 15) Novel Acceleration Techniques.

The conference program included invited talks and contributed papers. Speakers from India as well as abroad delivered talks and contributed to the success of the conference. In addition to the 44 invited talks, 155 papers were presented during the conference. One of the highlights of the conference was the oral presentation of 10 best papers selected for this purpose. Five oral and six poster papers were selected for prizes. The contributions were presented by young scientists.

Another aspect of the conference was presentations on the up-to-date status of various accelerator installations in India and abroad. In addition to this, the invited talks on 'International Linear Collider' (Shekhar Mishra, Fermi Labs, USA), 'Recent Progress of Laser Driven Plasma-Based Accelerators' (Kazuhisa Nakajima, KEK, Japan), 'Recent Developments in Cyclotrons for Medical Applications' (Yves Jongen, Belgium), 'LINAC4: the Future Injector of the CERN Complex of Proton Accelerators' (R. Garoby, CERN, Switzerland), 'High Intensity Developments at the Legnaro National Laboratories' (A. Palmieri, Legnaro, Italy), 'Recent RFQ Development' (A. Schempp, IAP, Frankfurt, Germany), ' Status of the International FAIR Project' (Hans H. Gutbrod, GSI, Germany), 'Theoretical Aspects of Design and Development of RFQ LINAC' (A.P. Durkin, MRTI, Moscow, Russia), were well received.

The conference proceedings were published in advance, to facilitate discussions on different topics, covered during the conference.

Forthcoming Symposium

Fifteenth National Symposium on Environment (NSE-15)

Under the aegis of DAE/BRNS, the Dept. of Physics, Bharathiar University, in collaboration with Kudankulam Nuclear Power Project, NPCIL, has organised the above symposium, from June 5-7, 2007,at the Department of Physics, Bharathiar University, Coimbatore. The focal theme of the symposium is "Mitigation of Pollutants for Clean Environment." The symposium would cover the following topics:

- Technologies for clean environment
- Environmental radioactivity
- Monitoring and modeling of pollutants and their transport
- Mitigation strategies for pollutants
- Regulation aspects and environment
- Environmental awareness, education and other related areas.

Papers are invited on the focal theme of the symposium and other environment-related issues. The length of the paper (including an abstract of 200 words, tables, figures and references) should not exceed six pages (A4 size). Two hard copies of the paper as also the soft copy to be sent to:

Mr V.D. Puranik
Chairman, Technical Programme Committee (NSE-15) &
Head, Environmental Assessment Division, BARC
Trombay, Mumbai 400 085
Ph.: 022-2559 5415
Fax: 022-2550 5151
E-mail:puranik@barc.gov.in

Important Dates:

Submission of paper	:	Feb 15, 2007
Acceptance of paper	:	March 31, 2007
Submission of registration forms	:	April 15, 2007
Payment of registration/ accommodation fee	:	April 15, 2007

For accommodation, financial assistance, registration etc. please contact:

Prof. S. Selvasekarapandian
Convener
Symposium Organising Committee, NSE-15
Department of Physics
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NATIONAL SYMPOSIUM ON SCIENCE & TECHNOLOGY OF GLASSES / GLASS - CERAMICS (NSGC-06): A REPORT

A two-day National Symposium on Science & Technology of Glasses/Glass-ceramics (NSGC-06) with special emphasis on applications in laser, radioactive waste management and sealing, was held during Sept. 15-16, 2006 at the Multipurpose Hall, Training School Hostel/ guest house, Anushaktinagar, Mumbai. It was held under the aegis of Materials Research Society of India (MRSI) Mumbai-Chapter, in association with BARC. Dr Anil Kakodkar, Chairman Atomic Energy Commission and Secretary Department of Atomic Energy inaugurated the symposium and Dr H. S. Maiti, Director, CGCRI, Kolkata delivered the Key note address. In his inaugural address Dr Kakodkar appreciated the idea of this meeting which had direct relevance to DAE programme. He briefly mentioned about the growth of glass and ceramics activities in DAE and stressed the need for developing suitable matrices for containment of radioactive waste, in the context of Indian reactors. He also released a compilation of extended abstracts. Dr Maiti spoke about with the historical background of glass and the importance of research in this area. Dr V. C. Sahni, Director, Raja Ramanna Centre for Advanced Technology, Indore and Director, Physics Group, BARC , welcomed the delegates and invited speakers. He also brought out some important facts about glass science and its growth. Convener, Dr Kothiyal, Head, Glass and Ceramics Technology section, TP&PED and Secretary MRSI, Mumbai Chapter presented brief account of the activities of MRSI Mumbai Chapter and an introduction to NSGC-06. Dr Kothiyal mentioned that the Materials Research Society of India is an interdisciplinary professional body, which is dedicated to accelerated growth of indigenous research and development in the area of materials science and engineering and their applications. Prof. Ajit Kulkarni, IIT/Bombay and Co –Convener NSGC-06, proposed the vote of thanks.

Glass and glass-ceramics have become essential materials for modern technology. Apart from their traditional uses, they are important for a variety of applications in the areas of optical communication, laser host, innovative architecture, matrices for radioactive waste immobilization, encapsulation/sealing, energy conservation, bio-medical, safety gadgets, automobile, space and marine technology etc. They have a unique combination of various physical and chemical properties such as transparency, chemical inertness, thermal stability, corrosion resistance, electrical insulation, long durability, biocompatibility etc. Glass-ceramics form a class of materials with much improved characteristics as compared to glasses.

Glass is a highly disordered state of matter, which is called amorphous. It has no long-range order, that is, unlike crystals there is no regularity in the arrangement of its molecular constituents on a scale larger than few times the size of these groups. For example, the average distance between silicon atoms in vitreous silica commonly known as sand, is about 3.6 A° . This means there is no order between these atoms at distances more than 10 A° . Traditional glasses have been made by fusion of inorganic materials such as silica sand, sodium and calcium carbonates, feldspars, borates and phosphates. However, today we have many glasses, electronically conducting glasses, non -oxide and fluoride glasses, exotic varieties such as polymer glasses, splat-cooled (very high cooling rate) metallic glasses.

There were in all nine sessions including the Inaugural and concluding sessions in this two-day meeting.

Dr Anil Kakodkar, Chairman, Atomic Energy Commission and Secretary DAE, is releasing the Extended Abstract Book. Others from left are: Prof. A.K. Kulkarni, Dr H.S. Maiti, Dr V.C. Sahni and Dr G.P. Kothiyal

Following aspects of glasses and glass-ceramics were discussed by 19 eminent scientists from various institutions (BARC, DRDO, ISRO, CGCRI, IACS, BHU, IIT's, / Universities, Industries etc) from India and abroad, as invited speakers and 72 contributed poster papers:

- Physics/ Chemistry and Engineering
- Laser applications-materials, properties, devices
- Radiation resistance shielding /optics
- Radioactive waste management-materials, properties, long term behaviour
- Encapsulation/sealing – materials, properties, interface behaviour
- Glass fibers and applications
- Synthesis/production- techniques, new methods/ issues
- Devices and related instrumentation
- Industrial perspective in the Indian context

The contributed papers were categorized in four groups: (i) Synthesis and Characterization (GGSC), (ii) Laser and Optical Applications (GGLO), (iii) Radiation Shielding and radioactive Waste (RSRW) and (iv) Devices and Instrumentation (GGDI). Number of papers in these categories were 35, 10, 10 and 17 respectively. Four best posters were evaluated by an expert panel of four scientists/ engineers with Prof. Lionel Montagne of France as Chairman.

A book of Extended Abstracts was brought out as compendium of the proceedings. This meeting provided a forum to the materials science community working particularly on glasses and glass-ceramics, for sharing their knowledge and experience in recent developments and innovations and some emerging challenges in these fields. There were 197 registered participants from various National Institutions/ Universities/ Colleges and industrial houses including three from abroad. Fifty two participants were research scholars.

Delegates and Invitees at the inaugural function

Prof. L. Montagne presented the Best poster awards to four research groups in the concluding session. Secretary Mr V. K. Shrikhande proposed a vote of thanks to all those who helped directly or indirectly in the success of the symposium.

भा.प.अ. केंद्र के वैज्ञानिकों को सम्मान
BARC SCIENTISTS HONOURED

Dr (Ms) Goswami, M.

Mr Arjun Sarkar

Dr G.P. Kothiyal

डॉ (श्रीमती) मधुमिता गोस्वामी, तकनीकी भौतिकी एवं प्रोटोटाइप इंजीनियरी प्रभाग (टीपी एंड पीईडी) ने सितंबर 15-16, 2006 के दौरान बहुप्रयोजन हॉल, भापअ केंद्र के प्रशिक्षण केंद्र के अतिथि ग्रह, अणुशक्ति नगर , मुंबई में ग्लास/ग्लास सिरामिक्स (NSGC-06) के विज्ञान एवं तकनीक की राष्ट्रीय परिचर्चा में प्रिपरेशन एन्ड करेक्टरैज़ेशन ऑफ बीएओ-ज़ेडएनओ-एसआइओ$_2$ (BaO-ZnO-SiO_2) नामक शोध पत्र की प्रस्तुति पर सर्वश्रेष्ठ पुरस्कार प्राप्त किया। इस शोधपत्र के सह लेखक श्री अर्जुन सरकार, टीपी एंड पीईडी, भापअ केंद्र; डॉ जी पी कटियाल, टीपी एंड पीईडी, भापअ केंद्र भी थे।

Dr (Ms) Madhumita Goswami of Technical Physics & Prototype Engineering Division (TP&PED), received the Best Poster paper Award for the paper entitled "Preparation and characterisation of BaO-ZnO-SiO2 glass-ceramics for possible use in SOFC", presented in the National Symposium on the Science and Technology of Glass/Glass-Ceramics (NSGC-06), during September 15-16, 2006, held in Multipurpose Hall, BARC Training School Guest House, Anushakti Nagar, Mumbai. Coauthors of the papers were: Mr Arjun Sarkar, TP&PED, BARC; Dr G.P. Kothiyal, TP&PED, BARC.

Dr V. Venugopalan

डॉ वी. वेणुगोपालन, जल एवं वाष्प रसायन प्रभाग, भापअ केंद्र सुविधाएं, कल्पाकम को एल्ज़्वियर के द्वारा प्रकाशित अंतर्राष्ट्रीय वॉटर एसोसियेशन की एक प्रतिष्ठापूर्ण पत्रिका " वॉटर रिसर्च " का सह-संपादक नियुक्त किया गया हैं। शुरू में इन्हें तीन वर्ष की अवधि के लिए नियुक्त किया गया है। डॉ वेणुगोपालन, समुद्री जीव विज्ञान विशेषज्ञ, ने कोचीन यूनिवर्सिटी ऑफ साइन्स एन्ड टेक्नालोजी से उच्च स्नातक एवं नैशनल इन्सटिट्यूट ऑफ ओश्नोग्राफी (गौवा) से स्नातक की पदवी प्राप्त की है। इन्होंने वर्ष 1989 में जल एवं वाष्प रसायन प्रभाग, कल्पाकम में कार्यारंभ किया।

आप (डब्ल्यूएससीडी) जैव प्रदूशन एवं जैवेफिल्म प्रक्रिया अनुभाग के अध्यक्ष हैं। समुद्री एवं ताजा जल का परिस्थिति विज्ञान, पावर प्लांट कूलिंग वाटर सर्किट्स में समुद्री जीव का क्षय आपकी रुचि क्षेत्र में शामिल है।

Dr V. Venugopalan, Water and Steam Chemistry Division, BARC Facilities, Kalpakkam has been appointed Associate Editor of 'Water Research' a prestigious journal of the International Water Association, published by Elsevier. The appointment is initially for a period of three years. Dr Venugopalan specialised in marine biology with a post graduate degree from Cochin University of Science and Technology and a doctorate from the National Institute of Oceanography (Goa). He joined Water and Steam Chemistry Division, Kalpakkam in 1989. Currently he is heading the Biofouling and Biofilm Processes Section of WSCD. His areas of interest include marine and fresh water ecology and marine biodeterioration in power plant cooling water circuits.

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