An Effort towards Increasing the Life of Pressure Tube

Safety Evaluation of Indian Nuclear Power Plants post Fukushima incident

Radiation Technology Applications in Healthcare
Calandria Vault of Unit 3, Kakrapara 3, Gujarat
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Nuclear Fuel Complex (NFC) is engaged in the production of natural uranium oxide fuel bundles for pressurized heavy water reactors (PHWRs) enriched uranium fuel assemblies for boiling water reactors (BWR), reactor core structural, reactivity control mechanism and special material such as tantalum, niobium etc. It also produces all the reactor core assemblies and other critical components such as fuel cladding tubes, hexagonal wrapper tubes etc. made from special stainless steel for fast breeder reactors. NFC in addition produces high quality stainless steel tubes/pipes and titanium half alloy products for critical and strategic applications.

NFC has been producing fuel for all the NPPS in India, 2 BWRs at Tarapur and 18 other PHWRs with a total capacity of 470 MWe. Intense research and technology development has enabled NFC to master not only production of fuels assemblies from cake form to fuel bundles but also produce all allied components involving specialized material developed to meet the stringent quality requirement of the nuclear industry. NFC has produced more than 500,000 PHWR bundles since inception. Constant innovations in production methods and research has enabled NFC to produce fuel at competitive costs and also improved its production throughput over the years. NFC recently commissioned a Zirconium complex at Palayakayal in Tamil Nadu expanding its zirconium fabrication capacity.
An Effort towards Increasing the Life of Pressure Tube-by Nuclear Fuel Complex Hyderabad

Zr-2.5wt% Nb alloy is presently being used as a pressure tube material in pressurized heavy water reactors. In-reactor performance of the pressure tube is a function of the reactor environment as well as the material microstructure, texture and mechanical properties. The cold-worked Zr-2.5Nb pressure tubes during service in PHWR reactors undergo irradiation enhanced changes in shape. The dimensional instabilities (tube axial elongation, diametral creep, and creep sag) in pressure tubes are due to the irradiation creep and irradiation growth dictated by the microstructure and texture of the tubes. Thus the satisfactory performance and the life of the pressure tube depend mainly upon its dimensional stability in the reactor, which is a strong function of several metallurgical parameters. These parameters include the shape, the size and the size distribution of the grains, the distribution of various phases, dislocation density, and the crystallographic texture. These microstructural and textural features essentially depend on the manufacturing process of the alloy. Diametral expansion and wall reduction affect the creep rupture capability of the pressure tube. Based on Canadian data for PHWRs from in-reactor experiments, 5% diametral creep and ~10% wall thinning is considered to be a very conservative limit, with respect to creep rupture and creep ductility. The recently measured values for diametral creep in Zr-2.5% Nb pressure tubes, used in cold worked stress relieved condition (CWSR) from KAPS-2 and RAPS-2 PHWRs, indicated wide scatter and acceleration in the creep rate after initial period of operation. Maximum diametral creep rate up to 0.25% per Hot Operating Year (HOY) has been reported in L-08 channel of RAPS-2.

The fabrication of pressure tubes involves a large number of thermo-mechanical treatments, and the final microstructure thus developed determines the long-term and short-term properties of these tubes. It is important to understand the influence of each of these fabrication steps on microstructure and crystallographic texture in order to optimize the pressure tube fabrication flow sheet. There has been continuous effort toward improving the resistance to irradiation induced creep and growth through the modification of the microstructure of the pressure tube material. The conventional method of fabrication of these tubes involves hot extrusion followed by 25% cold drawing. Pressure Tubes in NFC are currently fabricated from Zr-2.5% Nb alloy, which involves hot extrusion of lower extrusion ratio and two-stage pilgering with an intermediate annealing treatment. To this effect a comprehensive program was initiated at NFC to fabricate pressure tube with different fabrication routes. Essentially two major type of pressure tube variety were attempted with respect to modification in metallurgical characteristics to achieve improved in-reactor creep performance.

A) Heat Treated Pressure Tube.

B) Modified Cold Worked Stress Relieved Pressure Tube with Radial forging.

A) **Heat Treated Pressure Tube:** In this case full scale pressure tubes were manufactured by successfully introducing solution heat treatment and an ageing treatment in the thermo mechanical fabrication flow sheet of Zr-2.5%Nb pressure tube to stabilize the two phase microstructure.

It is observed in the case of cold worked pressure tube that the diametral creep strain rate is not linear with time and scatter band increases with years of operation. This situation may lead to loss of predictability near the end of service of pressure tube. In Zr 2.5 wt% Nb a two phase (α+β) alloy, at high temperature, due to thermal diffusion, Nb from the super saturated α-Zr grains moves to β-Zr grains, leading to the decomposition of the β phase and formation of β-Nb phase. Nb content in the α-Zr grains reduces gradually. As the creep resistance of Zr 2.5 wt% Nb pressure tube is attributed to the concentration of Nb in α-Zr grains, the phenomena will lead to enhancement in diametral
creep rate. Since the decomposition of β phase in Zr 2.5 wt% Nb tube would become larger with increasing operational life of the reactor, the diametral creep rate is expected to become enhanced until equilibrium microstructure is reached. Since the β phase is already in decomposed state in HT pressure tube, the creep enhancement observed in CW pressure tubes is not expected. Manufacturing of Heat treated pressure tube required optimization of parameters like solutionizing temperature, cooling rate during water quenching for solution heat treatment, aging temperature and aging time.

A flow sheet for fabrication of heat treated Zr-2.5Nb pressure tube has been shown in fig 1. Zr-2.5 Nb alloy ingots of 350mm diameter were produced in consumable vacuum arc melting furnace. Quadruple melting was carried out to reduce the impurity elements (mainly interstitials such as hydrogen, chlorine and phosphorus). In order to break the cast structure, these ingots were extruded to billets of 230 mm diameter size. Hollow machined billets were subsequently water quenched to achieve compositional and microstructural homogeneity. The quenched billets were soaked at 800°C for 1 hr followed by extrusion with an extrusion ratio of 9.4:1. The secondary electron micrograph images obtained from the longitudinal and transverse section in SEM is shown in Fig 2a,b. During the extrusion process, the α grains become elongated in the axial direction of the tube and thin in the radial direction. The longitudinal section exhibited α phase of lamellar morphology aligned along the extrusion direction. Transverse section exhibited α lamellae, whose width and thickness were not same. The average length, width and thickness of α lamellae were in the range of 15-20μm, 1-2.5μm and 0.3-0.5μm respectively. Beta phase was present as thin wafer between two α lamellae having average thickness of 0.02-0.05 μm. TEM micrograph of the longitudinal section revealed further finer details of microstructure (Fig. 2c). The α lamellae were found to consist of dynamically recrystallized α grains stacked in the extrusion direction. The hot extruded blank of Zr-2.5 Nb alloy was further subjected to cold deformation of 41% by pilgering. The heat treatment conditions were determined after establishing the β/β+α transus temperature for Zr-2.5%Nb alloy. On the basis of the quenching dilatometer studies, heat treatment conditions viz; soaking temperature of 883°C and soaking time of 30 Mins followed by water quenching were selected. Quenching was performed after heating in a horizontal furnace. The SEM and TEM micrographs of the quenched sample are shown in figure 3. From
SEM micrograph the primary $\alpha$ volume fraction was found in the range of 20-25%. Tubes subjected to quenching treatment were further cold worked to the extent of 23% by pilgering. The objective of this cold deformation process was to achieve the final dimension of the tube of acceptable quality. These tubes were finally given ageing treatment at two different temperatures (540°C and 515°C) for duration of 24 hrs. Cold deformation of martensitic microstructure resulted in considerable increase in the dislocation density and dislocation substructure.

TEM micrograph revealed the presence of such defect structure (Fig. 4). These defects acted as nucleation sites for precipitation of $\beta$Nb from the supersaturated martensitic phase during ageing process. Ageing treatment was given below monotectoid temperature (610°C) to obtain fine $\beta$ precipitates having composition close to equilibrium along with retained primary $\alpha$. Two different ageing temperatures (540°C and 515°C) below the recrystallization temperature were used in the present trials after the 2nd pilgering operation (See Fig 1). The microstructures are presented in fig. 5 and 6. Some of the salient observations from these microstructures are:

(a) no recrystallization of the microstructure at 515°C as well as 540°C
(b) Fully recovered structure at 540°C for 24h whereas only partial recovery (60 to 70%) at 515°C for 24h
(c) complete tempering of martensite at 540°C, while partial tempering of the same at 515°C
(d) in the case of sample aged at 515°C for 24h, small $\beta$ precipitates (size less than 15nm) were observed only at the $\alpha/\alpha$ lath interface
(e) no appreciable precipitation of $\beta$ particles within primary $\alpha$ at both ageing temperatures of 540°C and 515°C. Compositional analysis of the $\beta$ phase was carried out by Energy Dispersive Spectroscopy (EDS) in TEM. The average composition in sample aged at 515°C was showing 40-50wt%Nb whereas, samples aged at 540°C was showing 75-80%Nb. This study thus shows that a temperature of 540°C is required to attain equilibrium concentration...
of Nb (85%) in β precipitates during ageing for a period of 24Hrs. In other words, ageing treatment at 515°C for 24 Hrs, may lead to higher probability of compositional and associated microstructural changes under reactor operating conditions. Finally autoclaving treatment was carried out at 290°C for 120 hrs, which did not modify the microstructure to any noticeable extent (fig.7). Mechanical properties of the selected samples were evaluated using tensile testing machine.

Table 1 shows the mechanical properties of the final tubes that were processed in two different aging conditions. It can be observed that the aim to produce fine grained microstructure with fine precipitates of equilibrium βNb phase (i.e stabilized Microstructure) with mechanical properties similar to typical CWSR pressure tube could be achieved.

Table 2 lists the crystallographic textural evolution as characterized by Kearns orientation parameter (f), which represents the fraction of basal poles oriented in a given direction. The texture after second extrusion was predominantly basal poles oriented in the transverse direction. In the present study, effect of quenching rate on the texture evolution has been examined. The tubes were soaked at 883°C, and quenched in water. Water quenching was performed in horizontal as well as vertical type of furnaces. In the case of former, sample transfer time was longer and effective cooling rate was lower than the vertical furnace.

It has been observed that tube quenched with higher effective cooling rate (quenched in vertical furnace) exhibited nearly random texture. The major difference between the two cases are the volume fraction of the primary α phase which is 25 to 30%, when quenched from horizontal furnace and 5 to 10%, when quenched from vertical furnace. This observation shows that some degree of basal poles alignment along axial direction happens during quenching with lower primary alpha volume fraction sample. This is equivalent to quenching from higher soaking temperatures. This has been attributed to the presence of higher amount of β phase at the higher soaking temperature and subsequent to quenching produces randomly oriented α, giving rise to bulk random texture. However, further deformation and ageing treatments of the water quenched samples (horizontal furnace) did not change the texture substantially. The tubes aged in two different conditions (540°C and 515°C) exhibited nearly similar texture values. This suggested that deformation as well as ageing treatment did not modify texture significantly.

<p>| Table 1 . Mechanical Properties of Full Scale Heat Treated Pressure Tube Spools (90.25mm OD X 3.8mm WT) |
|---------------------------------------------------------------|-------|-------|-------|-------|-------|</p>
<table>
<thead>
<tr>
<th>Tube Condition/Mech properties</th>
<th>UTS(MPa)</th>
<th>YS(Mpa)</th>
<th>% EL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RT</td>
<td>HT (300°C)</td>
<td>RT</td>
</tr>
<tr>
<td>HT Ageing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>883°C/30m 540°C/24 h</td>
<td>749</td>
<td>494</td>
<td>581</td>
</tr>
<tr>
<td>883°C/30m 515°C/24 h</td>
<td>770</td>
<td>497</td>
<td>560</td>
</tr>
<tr>
<td>CWSR PRESSURE TUBES (TYPICAL VALUE)</td>
<td>735</td>
<td>502</td>
<td>553</td>
</tr>
</tbody>
</table>
B) Modified Cold Worked Stress Relieved Pressure Tube By Radial Forging Manufacturing Route:

CWSR Zr-2.5%Nb alloy pressure tubes for Indian PHWR are currently fabricated involving two stage hot extrusion and two-stage pilgering with an intermediate annealing treatment. In the earlier studies it has been reported that pressure tubes having thicker radial thickness of alpha grains with large aspect ratio and additionally consisting of larger circumferential basal pole texture has shown better dimensional stability. The variability in the microstructure and texture along the length of the pressure tube introduced during their fabrication leads to the variability in the dimensional change during service of the tube. In order to explore the possibility of enhancing and optimizing the presently followed fabrication route, a comprehensive fabrication trials were taken up involving variation in three major stages of the fabrication schedule which have significant effect on the pressure tube properties, in particular, the mechanical strength and microstructural features important for deformation, such as basal pole texture and grain shape and size. These important stages of fabrication include, (i) primary breakdown of the ingot in single or multiple steps involving press and radial forging as against presently followed single step extrusion, (ii) extrusion to tubular blank with higher reduction ratio as against the present practice of lower ratio, and (iii) cold pilgering in single pass as against currently followed two pass to achieve final dimension of the pressure tube. In case of single pass pilger

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**Table 2: Texture coefficient in three principle directions of the tube**

<table>
<thead>
<tr>
<th>Condition</th>
<th>( f_R )</th>
<th>( f_T )</th>
<th>( f_L )</th>
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<tr>
<td>After second extrusion</td>
<td>0.29</td>
<td>0.61</td>
<td>0.10</td>
</tr>
<tr>
<td>As ((\alpha+\beta)) water quenched (883°C/30 Mins) (effective higher cooling rate)</td>
<td>0.30</td>
<td>0.33</td>
<td>0.37</td>
</tr>
<tr>
<td>As ((\alpha+\beta)) water quenched (883°C/30 Mins) (effective lower cooling rate)</td>
<td>0.38</td>
<td>0.49</td>
<td>0.13</td>
</tr>
<tr>
<td>As aged 540°C/24 Hrs, (after WQ)</td>
<td>0.36</td>
<td>0.50</td>
<td>0.14</td>
</tr>
<tr>
<td>As aged 515°C/24 Hrs, (after WQ)</td>
<td>0.37</td>
<td>0.51</td>
<td>0.12</td>
</tr>
<tr>
<td>Cold worked pressure tube</td>
<td>0.28-0.32</td>
<td>0.60-0.65</td>
<td>0.07-0.012</td>
</tr>
</tbody>
</table>

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Fig 8. Six different Manufacturing Trial Routes (Including current practice-route A) for Fabrication of CWSR Zr-2.5%Nb Pressure Tubes
Processing, blank extrusion was carried out with a high extrusion ratio (12.75:1) to achieve the same final tube dimension as in the case of two pass pilger processing (with extrusion ratio – 7.3:1). On the basis of the identified variables in each of the stages a total of six processing routes (including the current one-Route A) was arrived for the present study (Fig.8). The fabrication trials which are reported were actually performed on full industrial scale (used for manufacturing 6m long pressure tube). The microstructures developed in different processing routes (A-F) have been characterized through SEM and TEM at three distinct stages viz., (i) after breaking of the as-cast structure, (ii) after extrusion of beta quenched-hollow billet, and (iii) after final cold work. The morphology of the alpha phase, distribution and composition of the beta phase and crystallographic texture were ascertained. Mechanical property evaluation was also done to establish structure-property relationship.

In case of single stage extrusion routes (routes C and F), the primary breakdown of the ingot was obtained at a temperature of 800°C by employing a extrusion ratio of 2.3:1 on a 3780T horizontal extrusion press. The developmental trials for breaking of cast structure in Zr-2.5%Nb ingot by forging of was carried out for first time and major process parameters such as forging temperature, reduction per pass, forging strain rate were established. In single press forging routes (routes A and B), the same amount of reduction was obtained by open die forging of ingot using a 1500T forging press. During the ingot processing campaign another variance in terms of the primary breakdown of ingot was also employed by carrying out forging in two stages starting with a 550 mm Ø arc melted ingot. Two different methods of forging were tried out, viz., press forging and radial forging (Routes D and E respectively). In case of latter, deformation was imparted through closed die forging. The present radial forging trials were carried out on a GFM SX-65 type machine with a capacity of 1200T. The deformation in radial forging results from a large number of short strokes at high speed by four hammer dies arranged radially around the work piece as shown in fig 9a&b. In addition, the forging work piece is rotated to obtain a forged surface with an acceptable surface finish. In case of single press forging, working was carried out at 950°C just in the β region, whereas, in double forging routes first stage reduction from 550 mm Ø ingot (forging ratio - 2.5:1) was carried out at 1050°C the second stage reduction from 350mm Ø to 230mm Ø was accomplished at lower temperature of 840°C in two phase region consisting of both α and β phase. Since the ingot...
starting diameter is 550 mm (considerably larger than single stage process routes of 350mm), we had employed higher temperature for first forging stage as employed elsewhere. This ensured processing of the ingot entirely in β phase region of the Zr-2.5Nb alloy thereby lowering the deformation load along with the added advantage of homogeneous distribution of all the alloying elements. The TEM micrographs given in figs. 10 a-d show the microstructures obtained after the final breakage of the as-cast structure in all the routes i.e., in an ingot of 230 mm Ø. In case of all the forging routes viz., single forging, double press forging and double radial forging the microstructure was found to be coarser in comparison to that of extrusion. This could be attributed to the higher temperatures employed in the forging routes. TEM micrographs of the forged ingots clearly show the higher width of β phase sandwiched between relatively longer α/α interfaces, which has been found to be desirable from diametral creep point of view. Moreover, the final microstructure developed after radial forging, as observed in Figs. 10(c), clearly indicated the homogeneity of deformation as well as equal interspacing of the β phase in α phase matrix as compared to microstructures developed by other trial routes. Radial forging leading to an improvement in microstructural uniformity has been reported elsewhere as well. In case of breaking the cast structure through extrusion, noticeable variation could be observed in the morphology (thickness, aspect ratio) of the α phase in contrast to that of forged microstructures, Fig 10d. This suggests towards relatively higher deformation heterogeneity in the extrusion process during breaking down the cast structure of ingots in comparison to the forging mode of deformation.

Once the cast structure was completely broken, the Zr-2.5Nb solid billets were undertaken for deep hole drilling to make inner diameter followed by expansion to obtain desired size of hollows. Further, hollows were β-quenched from 1000°C to achieve randomization of texture and homogenization in terms of chemical composition. Beta quenched hollow billets were extruded with different extrusion ratios(ER) to produce initial tubular blanks for CWSR pressure tube fabrication. SEM and TEM micrographs are shown in Fig 11(a-e) and 12 (a-d) respectively. It may be observed that deformation imparted during the extrusion of hollow billets resulted in blanks with microstructures having dispersion of long and thin α and β phases in lamellar morphology. Micrographs clearly indicated that higher ER lead to better continuity of β phase in the extrusion direction and also reduced variability in microstructure

![Fig11. Secondary electron micrographs of SEM of extruded blank of the pressure tube](image_url)  
(a) and (b) extruded with low ER (7.5:1) (cast structure broken by double forging) and extruded with high ER (12.8:1) (c) and (d) cast structure broken by single extrusion (e) and (f) cast structure broken by double radial forging. (g) and (h) transverse section of (e) and (f).

Fig12. Bright field micrographs of TEM of the pressure tube blank extruded with different extrusion ratio with ER 7.3:1 (Route –A) (a) leading end and (b) trailing end of tube and with ER 12.75:1(Route –E) (c) leading end and (d) trailing end of tube.
The extruded blanks in all the trials were subjected to a stress relieving operation at 480°C for 3h, which did not bring any significant changes except removing the thermal stresses introduced in the blanks during the quenching operation carried out after extrusion. Extruded and stress relieved blanks were cold pilgered in single or two pass to achieve final dimension of (OD &WT) of the pressure tube.

The intermediate annealing carried out at 550°C for 6h after the first pass pilgering operation, in case of two pass processing, resulted in recovery and/or partial recrystallization. In general, all the single pass pilgered blanks, as compared to two-pass pilgered blanks, exhibited a predominant increase in the length of the α filaments together with a continuous β film along the α/α interfaces. Moreover, single pass pilgering resulted in more homogenous and pre-dominantly lamellar microstructure from leading end to trailing end as compared to two-pass pilgering with intermediate annealing. In addition, the beta phase could be seen to be present in a continuous manner at the α/α interfaces as opposed to a globular distribution noticed in case of routes with two stages of cold work. Aspect ratio of the α phase of the final autoclaved pressure tube manufactured by different trial routes has been tabulated and presented in Table 3. It could be seen from the table that a substantial reduction in α grain width has occurred from that of the as extruded blanks after the pilgering operation. Extrusion at a high ratio followed by single pass pilgering in routes D and E, where double stage press and radial forging were employed respectively for breaking of the as-cast structure, led to a significant increase in both the width and the length of the α grains thereby resulting in a very high aspect ratio. In fact, tubes produced using route E not only exhibited the

| Table.3 Morphological features of grains | | | | | |
|---|---|---|---|---|
| Routes | Location | AR | Length | Width |
| As extruded pressure tube condition | | | | |
| A (low ER) | Leading | 1:4:30 | 6-15 | 0.2-1.0 |
| Trailing | 1:4:40 | 10-20 | 0.2-0.6 |
| B (High ER) | Leading | 1:5:40 | 15-22 | 0.2-0.5 |
| Trailing | 1:6:55 | 15-23 | 0.2-0.4 |
| Final pressure tube condition (autoclaved) | | | | |
| Double pass pilgered | | | | |
| A | Leading | 1:4:35 | 5-12 | 0.2-0.4 |
| Trailing | 1:5:40 | 8-13 | 0.1-0.3 |
| F | Leading | 1:4:30 | 8-10 | 0.1-0.3 |
| Trailing | 1:5:45 | 6-11 | 0.1-0.3 |
| Single pass pilgered | | | | |
| B | Leading | 1:6:55 | 12-18 | 0.2-0.4 |
| Trailing | 1:5:45 | 14-22 | 0.1-0.4 |
| C | Leading | 1:6:60 | 10-14 | 0.2-0.5 |
| Trailing | 1:5:50 | 12-19 | 0.1-0.4 |
| D | Leading | 1:5:50 | 14-21 | 0.2-0.5 |
| Trailing | 1:5:60 | 12-20 | 0.2-0.6 |
| E | Leading | 1:10:65 | 25-30 | 0.4-0.5 |
| Trailing | 1:10:70 | 25-32 | 0.35-0.45 |

between leading and trailing of extruded tube. This indicates that extrusion plays a major role in generating the tube microstructure. Since higher extrusion ratio implies relatively larger amount of plastic work, fraction of deformation heat generation also increases which can, to some extent, compensate the heat loss from trailing end. This can bring down the difference between the leading ends trailing end and is evident from the results shown. Further, It may be observed that higher ER resulted in α grains with higher aspect ratio, see Table 3. The TEM micrographs of the extruded blanks indicated dynamic recrystallization of the α phase during hot extrusion. The chemical composition as determined by TEM_EDS analysis of the two phases α and β was found to consist of ~1.4 wt%Nb and 17.2% Nb respectively.

The extruded blanks in all the trials were subjected to a stress relieving operation at 480°C for 3h, which did not bring any significant changes except removing the thermal stresses introduced in the blanks during the quenching operation carried out after extrusion. Extruded and stress relieved blanks were cold pilgered in single or two pass to achieve final dimension of (OD &WT) of the pressure tube.

The intermediate annealing carried out at 550°C for 6h after the first pass pilgering operation, in case of two pass processing, resulted in recovery and/or partial recrystallization. In general, all the single pass pilgered blanks, as compared to two-pass pilgered blanks, exhibited a predominant increase in the length of the α filaments together with a continuous β film along the α/α interfaces. Moreover, single pass pilgering resulted in more homogenous and pre-dominantly lamellar microstructure from leading end to trailing end as compared to two-pass pilgering with intermediate annealing. In addition, the beta phase could be seen to be present in a continuous manner at the α/α interfaces as opposed to a globular distribution noticed in case of routes with two stages of cold work. Aspect ratio of the α phase of the final autoclaved pressure tube manufactured by different trial routes has been tabulated and presented in Table 3. It could be seen from the table that a substantial reduction in α grain width has occurred from that of the as extruded blanks after the pilgering operation. Extrusion at a high ratio followed by single pass pilgering in routes D and E, where double stage press and radial forging were employed respectively for breaking of the as-cast structure, led to a significant increase in both the width and the length of the α grains thereby resulting in a very high aspect ratio. In fact, tubes produced using route E not only exhibited the

<p>| Table. 4 Texture variations between the leading and trailing ends | | | | |</p>
<table>
<thead>
<tr>
<th>Fabrication Route</th>
<th>Location</th>
<th>F_R</th>
<th>F_T</th>
<th>F_A</th>
<th>F_T - F_R</th>
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<td>Double pass pilgered</td>
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<td></td>
<td></td>
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<tr>
<td>F</td>
<td>Leading</td>
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<tr>
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<td>0.03</td>
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<tr>
<td>C</td>
<td>Leading</td>
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<td>0.10</td>
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<td>0.68</td>
<td>0.06</td>
<td>0.42</td>
</tr>
<tr>
<td>Trailing</td>
<td>0.28</td>
<td>0.68</td>
<td>0.04</td>
<td>0.40</td>
<td></td>
</tr>
</tbody>
</table>
highest aspect ratio of the alpha phase (~1:10:70) but also showed minimum microstructural variation throughout the length of the tube. In case of route A i.e., the route which is presently being followed at NFC for manufacturing of cold worked Zr-2.5Nb pressure tubes, α grains were not lamellar in all the regions. Moreover, the length and width of the α filaments were also found to be smaller amongst all the fabrication trials. The β was not found to be continuous in many regions; instead they had globulized both at the α/α interface as well as within the α grains. The Nb content in the β phase varied from 15 to 45 wt %.

The texture components of the pressure tubes manufactured with different routes are presented in Table 4. The routes that involved higher extrusion ratio (routes B, C, D & E) and single cold pilgering showed relatively higher F₁ and F₁-F₅, values compared to the ones having lower extrusion ratio and two stage cold work( Routes A & F). Cold work subsequent to hot extrusion did bring about some subtle changes in the texture although the gross nature of texture produced during the hot extrusion was retained. In other words changes in texture from hot extrusion stage were minimum when only one pass of cold pilgering was involved. It may be pointed out that such a texture (with high F₁ and lower F₅) is expected to be beneficial from the point of view of diametrical creep during the service life. Two pass pilgering, with one additional intermediate annealing however, resulted in the decreased F₁ component in the final texture. This observation is also in line with the known understanding that annealing results in the rotation of basal poles. In addition, routes involving higher extrusion ratio were found to have minimal differences in texture along the length of the tubes. Table 4 shows the mechanical properties of the tubes produced from the various routes described above after autoclaving operation. In essence the variation in the mechanical properties among tubes produced from different routes is not found to be significant. However, it can be noticed that, the forging route samples are showing slightly higher ductility. Rest all other properties were nearly same in all the pressure tubes produced with different routes. Further, the properties obtained by modified routes do meet the existing specifications for the pressure tubes in PHWRs.

Based on these observation of satisfactory mechanical properties, and improved microstructural and textural properties of double radial forged route with higher extrusion ratio followed by single cold work by pilgering (route E) seems to be a promising modification to existing practice of pressure tube manufacturing at NFC.
India has embarked on a three stage nuclear power programme to meet and sustain its ever growing energy requirements. Fast Breeder Reactors form the crucial second stage where in the spent fuel from the first stage (Pu$_{239}$) is used to generate energy and the fertile Th$_{232}$ in the blanket is converted into fissile U$_{233}$. Alloy D9 hexcans are used in PFBR as wrappers tubes in the manufacture of fuel sub-assemblies and various reactivity control mechanisms (fig.1).

**Seamless stainless steel hexcan**

Hexcans are used as wrappers for fuel sub-assemblies in Prototype Fast Breeder Reactors (PFBR) since they provide highest packing efficiency in the hexagonal close packed lattice. They are to be manufactured conforming to the stringent chemical, dimensional, mechanical and metallurgical requirements. These hexcans are conventionally manufactured by seam-welded route and seamless route through draw bench. The hexcans are to be manufactured with a nominal retained cold work of 20% (uniform across the cross section). This helps improve the void swelling resistance of the hexcans at operating temperature and fast neutron flux. This can only be achieved by hexcan-to-hexcan pilgering. Throughout the world hexcans are being produced by drawing process.

**Circular to hexcan route**

NFC has developed a unique production process for manufacturing of these Hexcans by pilgering of cylindrical tubes on a special purpose mill.

The initial process route developed by Special Tubes Plant, NFC for manufacturing of hexcans consists of pilgering circular tubes to hexcans with an average retained cold work of 20%. However pilgering of hexcans from the ingoing circular tubes leads to non-uniform cold work across the cross-section with corners being more cold-worked than the faces. This was ascertained by carrying out micro hardness profiling on the cross section of the hexcans. It was observed that microhardness is highest at the corners and drops progressively towards the centre of the face of hexcan (fig. 2), thus creating a huge variation in microhardness from corner to centre of face (~70 VHN), thus indicating differential cold work.

**Fig 1. Seamless D-9 Hexcans for PFBR**
This variation in cold work across the cross section can lead to differential and unpredictable behavior of hexcans inside the reactor, which is not acceptable. Therefore a process needs to be developed to achieve uniform cold work across the cross section.

Hexcan to Hexcan Pilgering

Many possibilities were studied in order to overcome this problem of differential cold work and decision was taken to produce hexagonal tube by pilgering an in-going solution annealed hexagonal tube while maintaining a nominal cold work of about 20%. It was envisaged that in this method there will be uniform cold work across the cross section since there is only wall reduction even at corners. Many challenges were faced during the process development of hexcan to hexcan route.

Challenges faced

1. Occurrence of twist ad bow: Pilgering of hexcans itself had a host of challenges. Pilgered tubes exhibited bow and twist beyond acceptable limits requiring labourious correction. To overcome the above necessary toolings were developed in-house and manufactured over a series of iterations. Several modifications carried out in the tooling has yielded acceptable tubes in the as pilgered condition.

2. Tooling modification: The mill was originally designed to accept only circular tubes. Feeding of hexagonal tubes as input materials necessitated several modifications in the machine itself. Major amongst these are modification of mandrel rod, inlet chuck jaws, guide bushes, pusher mechanism etc.

3. Synchronization between ingoing hexcan and mandrel: The in-going hexcan has to be in-phase with the mandrel to ensure smooth entry into the rolling zone. Therefore the inlet chuck jaws, mandrel rod supporters, the guide bushes and the pusher tube have to be suitably synchronized.
4. **Solution Annealing:** Considering the criticality of the chemical composition of alloy D9 hexcans it was felt necessary to carry out their solutioninsing treatment in vacuum. Therefore a vacuum furnace with Argon quenching facility was indigenously designed and developed to carry out the annealing / quenching treatment of the hexcans.

With continuous innovation and diligent efforts the above mentioned challenges were overcome.

**Uniformity of cold work in hex-to-hex pilgering**

The hexcans thus produced had more uniform cold work across the cross section. This was confirmed by microhardness profiling of the final hexcan cross section. It was observed that the microhardness variation between corner and face centre for the hex-to-hex pilgered hexcan (40VHN) was much lower than in that produced by round-to-hex route (70 VHN). Microhardness measurements were carried out on the 6 faces of the hexcan made by hex-to-hex route and it was observed that a reasonably average microhardness (~245 VHN) was maintained from the corner to centre of faces (fig. 2).

| Table 1: The requirement of Alloy D9 hexcans for PFBR are as follows: |
|---|---|---|
| SIZE | APPLICATION |
| (A/F) WT | |
| 131.6mm 3.2mm | Fuel Sub assembly, Blanket Sub-Assembly, Reflector Sub-Assembly, IB,C Control Rods, Control & Safety Rods, Diverse Safety Rods, Instrumentation Sub-Assembly, Purger Sub-Assembly, Diluent Sub-Assembly Source Sub-Assembly, |
| 110.8mm 2.0mm | Control & Safety Rod Assembly |
| 120.0mm 2.0mm | Source Assembly (Be Outer Sheath) |
| 70mm 2.0mm | Source Assembly (Be Inner Sheath) |

NFC could successfully develop and manufacture the tooling for all the above sizes. All the above mentioned hexcans have been delivered marking a major milestone in the history of DAE.
Safety Evaluation of Indian Nuclear Power Plants post Fukushima incident

The design, construction, commissioning of a Nuclear Power Plant (NPP) is done with the prevalent Atomic Energy Regulatory Board (AERB) Codes and Guides and takes into account feedback available from the operating experience of national and international plants.

Later during operational life of the Plant, its safety performance is regularly evaluated by the internal review process at NPCIL and AERB. Periodic Safety Reviews (PSR) and related improvements in safety of the plant are carried out as per regulatory practices at the time of periodic reviews. The national and international Operational Experience provides another means of on line safety review and keeps the features up to date. For example, the reviews of and lessons learnt from Narora Atomic Power Station (NAPS) fire incident, Madras Atomic Power Station (MAPS) Tsunami event, Three Mile Island (TMI) accident and Chernobyl accident have been used to improve safety wherever required.

As part of this practice the lessons learnt from event at Fukushima are being reviewed.

- Accident at Fukushima Nuclear Power Plants (NPP) in Japan occurred on March 11, 2011, due to Earth Quake followed by Tsunami.

- On 15th March, 2011, CMD NPCIL constituted four task forces to review consequences of occurrences of similar situations in INDIAN NPPs under operation, which broadly fall into four categories:
  1. Boiling Water Reactors (BWR) (TAPS 1&2)
  2. Pressurized Heavy Water Reactors (PHWRs) at RAPS 1&2
  3. PHWRs at MAPS 1&2
  4. Standard PHWRs from NAPS onwards

These task force were asked to make a quick assessment of safety of Indian NPPs assuming non availability of motive power and design water supply routes and recommend improvements, so that situation as it developed at Fukushima can be avoided even under adverse conditions.

- All the task forces submitted their reports by end of March 2011, based on preliminary information available on Fukushima event at that time.

- The details of this event are still unfolding. The observations of International community are also being tracked so as to provide additional input to the action plans for Indian NPPs.

- The reports of the Task Forces were summarised in a document titled “Safety Evaluation of Indian NPPs Post Fukushima Incident” to provide an integrated picture for broad appreciation of the associated topics like description of Fukushima event, process of safety review and assessment in NPCIL along with specific recommendations applicable to respective plants.

- Subsequently, two more task forces were formed by CMD NPCIL, to assess safety of Indian NPPs under construction, assuming non-availability of motive power and design water supply routes.
  - One task force for VVER, Pressurized Water Reactors (PWR) under construction at KKNPP.
  - One task force for 700 MWe, PHWRs under construction at KAPP 3&4 and RAPP 7&8.

Reports of the Task Forces and associated background is available in

http://npcil.nic.in/WriteReadData/Post_Fukushia3.html
The application of radioisotopes and radiation technology in healthcare industry, agriculture and research is one of the most significant peaceful uses of nuclear energy next to nuclear power generation. Early realization of the importance of radioisotopes and radiation technology for societal benefits and national development by the Department of Atomic Energy, Government of India resulted in development and setting up adequate infra-structural facilities in the country for harnessing the benefits of nuclear technology for the benefit of mankind. Accordingly, the Board of Radiation and Isotope Technology (BRIT) was carved out of Bhabha Atomic Research Centre (BARC) in the year 1989, as an independent unit under DAE with the intention of popularizing this technology for welfare of the people in the country.

Radiation processing of healthcare products has graduated from one of laboratory curiosity to commercially viable activity as demonstrated by the facilities like ISOMED at Trombay, Rashmi at Bangalore and SARC at Delhi. All these facilities are based on Cobalt-60 isotope as source of radiation. Radiation processing using gamma radiation has been applied to a variety of healthcare products for sterilization purpose. Another technology for sterilization of healthcare products employs electron beam from accelerators. Although this technology has the advantage of turning “on” and “off” the electron beam, it has the following prerequisite viz high input electric power infrastructure to handle very high throughputs to be commercially viable and some problems of uniformity in dose absorption. In science and technology nothing new supplants another but only supplements the things that are already in use. In this spirit, we should look at EB technology that certainly has very high potential in future as we graduate in our infrastructure facilities including utilities, transport etc.

Irradiation, as a sterilization technology, has a certain elegance which whilst recognized by many, is understood in depth by relatively few. The attraction of the technique lies in the fact that it is a physical process capable of comprehensive control as well as being highly reproducible. In many ways it can be argued that it comes close to being the ideal sterilization method.

**RADIATION STERILIZATION**

Radiation sterilization using gamma radiation from cobalt-60 source is a well established industrial process in India. It is a very efficient and convenient technique for achieving a high level of sterility in medical supplies. About two hundred commercial plants are in operation all over the world using this technique. ISOMED, the first radiation plant for sterilization of medical products was set up in India by the Department of Atomic Energy at Trombay with the assistance of the United Nations Development Programme.

Setting up of ISOMED had ushered in the radiation sterilization technology in the country. The facility was aimed at improving the quality of locally manufactured healthcare products and devices as well as practical demonstration of sterilization of large volumes of healthcare supplies on an industrial scale. The operation of ISOMED for the past three decades has unambiguously proved that both the above objectives have been fully met and now radiation sterilization has emerged as an efficient and effective industrial process. ISOMED now offers radiation
sterilization service to more than 1600 manufacturers of medical products and pharmaceuticals compared to the 12 in the year 1974.

Single use prepacked sterilization medical products can now be made available on a large scale with the irradiation services offered by ISOMED. The use of these products will go a long way in reducing cross infection in hospitals. Radiation sterilization is a simple and safe process involving exposure of products to gamma radiation from a cobalt-60 source for a pre-determined time so as to receive a prescribed dose.

**ISOMED PLANT**

The plant essentially consists of:

- The radiation source housed in a concrete cell.
- An automatic system for conveying the product boxes into the irradiation cell exposing the boxes to the radiation field for a specified period and then taking them out of the cell.
- Laboratories for microbiology, dosimetry and physico-chemical studies
- Facilities for production of biological indicators and ceric-cerous dosimeters

Hermetically sealed medical products are packed in standard corrugated cardboard cartons of outer dimensions 59 cm length x 43 cm height x 34 cm width. These boxes are loaded in carriers, each having five shelves. Each carrier travels at a controlled speed on an overhead monorail; enters the irradiation cell through a labyrinth; five such passes through the cell ensure the exposure of the products to a minimum dose of 25 kiloGray recommended by the International Atomic Energy Agency (IAEA), British Pharmacopeia and United States Pharmacopeia. Exposure of medical products manufactured under Good Manufacturing Practices (GMP) to minimum radiation dose of 25kGy ensures sterility assurance level (SAL) of the order of 10-6. A complete system of interlocks protects personnel from radiation exposure and also prevents the products from receiving overdose or underdose in the event of a mechanical failure.

**Packaging**

The packaging should provide a complete barrier to the entry of micro-organisms and should be designed to facilities removal of contents. The materials to be sterilized are packed in impermeable films for example, polyethylene, cellophane-polyethylene or paper-polyethylene laminates, which can be heat, sealed thus ensuring maintenance of sterility. These laminates have good tear and impact strength, have customer appeal and are inexpensive. Other types of laminates can be designed for convenience and to suit the product. Unsupported polyethylene films of 300 gauge thickness are suitable for soft products and of 500 gauges for rigid products.

**Product Sterility**

Gamma radiation is very effective in inactivating micro-organisms. As the bacterial count of each item should be as low as possible, products should be handled as little as practicable in the course of manufacturing. Premises should be clean and dry, ventilated with clean air and the constructions and furnishings conducive to regular and thorough cleaning. A minimum radiation sterilization dose of 25kGy is employed for medical products as in most other countries. The dose provides an extremely high safety factor and when the product has low initial microbial count the probability of any microbial survival can be expected to be less than one in one million.

Advantages and Benefits of Radiation Sterilization:

- Product of any shape can be sterilized because powerful gamma rays penetrate right through the package and the product.
- Being a cold process, heat sensitive plastic, medical devices and pharmaceutical products can safely be sterilized.
- Flexibility in packaging as the products can be packed individually in sealed bags and sterilized in the fully packaged form.
- Since sterilization is effected after final packaging, product sterility is retained indefinitely provided the package is undamaged.
• This is a continuous, fully automated process with a single parameter to be controlled, namely the time of exposure. Steam sterilization and ETO apart from being batch processes; require more than one parameter to be controlled.
• Radiation Sterilization enlarges the market for ready to use pre-packaged products.

Products sterilized by this process do not become radioactive and are safe for use.

**ISOMED Services**

ISOMED offers regular irradiation services, guaranteeing a minimum dose of 25 kGy to medical products. ISOMED has also built up expertise in the following areas:

- Material selection; Packaging; Manufacturing; Microbiological testing; Feasibility study of radiation effects on product; Physicochemical and biological testing of the products; Supply of Ceric-carous Sulphate chemical dosimeters and Biological indicators.

**Products Commonly Sterilized by Radiation**

**List of the Products covered under Drugs and Cosmetic Act Rules, 1945 and are cleared by Food and Drug Administration, Maharashtra for routine sterilization for use in the country and for export purposes is as follows:**

- Absorbent Cotton Wool and Absorbent Gauze Products;
- Bandages – Crape, Cotton crape, Gauze
- Cotton – Buds, Pads, Swabs
- Dressing- Finger dressing, first field dressing, Paraffin gauze dressings, Shell dressings
- Kits – Maternity/Dai, Minor surgery, Vasectomy
- Sutures- With or without needles (Absorbable/Non-absorable)-Catgut, Linen, Polyester and silk.
- Hemostate Medical Devices: Absorbable gelatin sponge, Perfusion sets, Hypodermic Syringes and needles, Intra-uterine contraceptive devices (IUCD)
- Pharmaceuticals, Powders and Others: Debrisan, Neomycin sulphate powder, Prickly heat powder (containing boric and salicylic acid). Fluorescein sodium strips, Catalin tablets
- Ophthalmic Ointments in Collapsible Aluminum Tubes: Atropine Sulphate, Chloramphenicol, chlorotetracycline, Gentamycin sulphate, Neosporin (Neomycin sulphate, Polymixin and bactracin) Terracycline
- In Soft Gelatin Capsule: Chloramphenical
- Skin Ointments in Polyethylene Glycol Base: Neomycin sulphate Hydra-cortisone acetate, alphachymotrypsin
- Cosmetics: Artificial eyelash, Eyebrow pencil, Face powder, Kajal, Lipstick, Talcum powder
- Veterinary Products: Quinapyramine chloride and sulphate
- Ayurvedic Products and Raw Materials
- Special Products (mainly for export): Belladonna dry extract, Ergot powder, Papain Rawalfla serpentine

**List of the Products not covered under Drugs and Cosmetic Act Rules 1945:**

- Cellulosic: Nappies, Sanitary napkins, Tampons, Umbilical cord tapes
- Metallic Products: Aluminum caps and containers, Empty aluminum tubes (collapsible) Orthopaedic implants, Surgical blades, Surgical tools
- Plastic and Rubber: Cannulee, Catheters (Folley, Gibbon etc.) Pharmaceutical Containers/Closures, Droppers (eye, nasal), Plugs and sprinklers, Drapes (polyethylene Forceps, Hydrocephalus shunts, Latex rubber gloves and Bungs, Petri dishes, Scalp vein sets, Shunt valves, Silastic rings, Tapes (for sealing), Trays, Trolley Covers, Tublings (endotracheal, duodenal, feeding, Ryles etc.), Urine drainage bags
- Miscellaneous: Bone grafts (deproteinated, degreased and lyophilized) Bone wax, Cellulose acetate membrane (for bacterial filtration), Contract lens solutions, Face masks, Gelatin (photographic grade), Glass fibre filters, Glass vials and bottles (pharmaceutical), Hip joint, Normal salina and Ringer's lactate solution (for kidney perfusion and cleaning of wounds), starch (for gloves), Media strips and plates.
**Ready-to-Use Products from ISOMED**

**Biological Indicators**

The use of biological indicators (BI) is recommended in the Gazette of India, 1988 for records for checking instruments and apparatus of sterilization. According to United States Pharmacopoeia XXI, validation of sterilization process is to some extent predicted on BI rather than the sterility test. British Pharmacopoeia, 1988 recommends use of spores of Bacillus pumilus NCTC8241 (NCIB 8982, ATCC 14884), as BI for a minimum dose of 25 kGy of gamma radiation.

- BI in the form of paper disc impregnated with 1-10 million spores of non pathogenic radiation resistant strain of Bacillus pumilus, ATCC 14884 (with 90% killing at 2kGy) are prepared in ISOMED. These are individually sealed in polyaminated pouches. These are supplied in units of 50 pairs in polyaminated pouches in a box along with
- Technical information brochure providing the method of use
- A sample report sheet for entering the observations and
- A certificate of performance regarding its resistance and average population as designed in the technical information brochure.

**Kilogray Gamma Dosimeter System**

Radiation treatment of products demands strict adherence to regulations /guidelines prescribed under good radiation practice at irradiation plants. Measurement of absorbed dose in a product is essential and very important parameter of radiation process control. The dosimetry system employed for the measurement of absorbed dose should be accurate and reproducible. Ceric cerous sulphate solution in glass ampoules of 2 ml volume are available from ISOMED plant for measurement of high radiation dose (25 kGy). Ceric-cerous sulphate dosimetry system standardized and supplied include:

- Dosimeters, 2ml ampoules in a pack of 100 units
- Electrochemical cell
- Millivoltmeter
- Stand and Clamp
- Operation Manual
- Calibrated charts giving the mV vs. kGy outputs for various irradiation and dose measurement temperatures (software for generation of these charts is also available)

**Salient features of ceric-cerous dosimetry system**

- A simple electrochemical system for the measurement of absorbed dose
- Reliable and reproducible results within (+) 2% of the actual dose
- Linear response over a wide dose range encountered in sterilization
- Absorbed dose can be corrected for a variation in ambient temperature
- Prolonged shelf-life before and after irradiation
- International Dose Assurance Services (IDAS) for these dosimeters is carried out annually.

**Customer Registration**

The customer who wish to avail the radiation sterilization facility at ISOMED are issued a unique customer registration number when they come to process their products at ISOMED for the first time. ISOMED order form along with the set of instructions for customers is available from our website www.britatom.gov.in/IsomedForm.pdf.
Breast cancer in India requires immediate attention as it accounts for 20% of cancers in Indian women as per the statistical data about breast cancer incidence in India (1). Apart from the awareness program to encourage women for regular check-up for early detection of breast cancer, the technological development and advancement for accurate localization of the early lesion (cancerous cell) and use of this technology for designing diagnostic equipments to be used in Indian hospitals are equally important. The early detection of breast cancer requires accurate screening to find the cancerous cell well before they start showing symptoms. Early detection helps save thousands of life and it would save many more if the detection of very small (in order of mm) cancerous cell is ensured with high accuracy using accurate high resolution diagnostic equipments. However conventional X-ray mammography is not suitable for detection of such small lesions and hence there is a thrust in designing high resolution scinti-mammography devices by researchers worldwide as it relies on the functional image of the cell which enable accurate imaging in comparison to the structural image produced by X-ray mammography.

Way back in 1950 the achievement of two major milestones in the nuclear medicine development has opened up the path to use functional imaging procedure in cancer diagnosis. The first one is the development of Technetium-99m ($^{99m}$Tc) (half-life ~6 hours) radionuclide generator system by a group at Brookhaven National Laboratory where $^{99m}$Tc is eluted from the much longer-lived Molybdenum-99 ($^{99}$Mo) (half-life ~66 hours) which ensured the routine availability of $^{99m}$Tc. The second one is the Hal O. Anger's work on the development of the gamma camera for medical imaging which became the predecessor of the present day gamma camera. However, Anger camera suffers from lower resolution and hence inhibits early detection.

The commercial availability of high resolution scinti-mammography devices is very poor and diagnosis with those instruments are prohibitively expensive. Mammary gland Specific Gamma Imaging System(MSGIS) (2) Project has been taken up by VECC, Kolkata to design a high resolution and low cost gamma camera for breast cancer detection to improve the quality of life of common human being in our country.

MSGIS uses the same photo peak detection technique as used in Anger camera for an intensity based image generation where the spatial and energy resolution of the overall system is increased by the advanced detector and simultaneous data acquisition of thousands of detectors with the help of Application Specific Integrated Circuits(ASICs). It adopts molecular breast imaging technique which depends on the localization of the radio tracer. The most common radioisotope used for gamma imaging diagnostic purposes today is $^{99m}$Tc. A small amount of this tracing element is injected which is absorbed in the cells of the body. However, the radioisotopes are deposited in more number in cancerous cell as they have higher rate of metabolic activity. The tracing agent, deposited in the cells, emits gamma rays which are detected by the imaging system and a two dimensional intensity based image indicates the more concentration of gamma rays in a region by which doctor concludes the location of the lesion.

Figure 1. The block diagram of MSGI system
This imaging system is an effective diagnostic tool for patients who have dense tissues, suspicious lumps which are not detected by conventional X-ray mammogram or ultrasound imaging. Magnetic Resonance Imaging (MRI) can offer high resolution diagnostic information however it is not suitable for those who suffer from claustrophobia as it needs the patient to be confined inside a large circular magnet for a substantial amount of time. The MSGIS camera allows imaging with no compression of the tissues and hence diagnosis with MSGIS is painless as compared to conventional gamma camera or X-ray mammography. Unlike standard devices, such as X-ray mammography, this imaging detector is capable of capturing more information of the tumor as the field of view of the camera is much smaller than the conventional one. The required radiation dose of this camera is within the acceptable limit. The development of MSGIS system will improve the capability of differentiation of an instrument between benign and malignant tissue by which the detection of small tumors will be possible. This will reduce the need for biopsy.

The basic design of the camera consists of three main sections as depicted in the Figure 1. The first section is the collimator which can be termed as a focusing device. It allows the camera to pass only the parallel gamma rays from the lesion by which the scattering problem is avoided in the image. The second section is the detector which is divided into two parts: the first part is the pixelized scintillators separated from each other by a white reflector that produces light photons from the gamma ray. The second part is used for the conversion of light photons to electrical charge by a Position Sensitive Photo Multiplier Tube (PSPMT). The third section is the most important section of the camera which consists of the signal processor of each detector and the synchronization circuitry required to produce an image. As the detection of 140 keV photo peak energy has to be highly accurate, the energy resolution of the camera is required to be very high and hence the electronic noise of the signal processing section needs to be minimized considering that detector Fano factor (signal fluctuation in detector) is very low. The conventional gamma camera uses Anger logic which employs four parallel processing circuits to find out the XY position of the signal in the detector whereas MSGIS considers to process all and thereby ensures high resolution.

The energy resolution and decay time of the scintillator detector, the signal to noise ratio (SNR) and required count rate of the overall system are the prime consideration for the design of the camera.

The camera operates in two modes (i) calibration and (ii) imaging. In calibration mode the gamma spectroscopy is done and the energy resolution of individual detector is measured. The acceptable energy window is derived from the calibration mode and is used in imaging mode in which the system captures many frames. The intensity information of each pixel in a frame is incremented by one if it receives a signal within the energy window found from the calibration mode and finally the image is normalized in gray scale. The camera suffers from the non-uniformity arising due to non-uniform response of the detector hence a correction is made in the electronics.

The data acquisition system of MSGIS consists approximately 2500 detectors signal which are to be processed simultaneously. The prototype camera with 256 (16x16) pixelized detector as shown in Figure 2 is developed to characterize the basic functionalities of the actual system. The detector with pixelated CsI(Tl) and PSPMT is connected in front of the data acquisition boards. A parallel hexa-hole collimator which ensures the resolution of the detector is placed in front of the detector.

The data acquisition of the prototype camera is divided into three parts. The detector is connected with a passive board which passes attenuated detector signals to the input of a Multi Anode Read Out Chip (MAROC) to follow the dynamic range of the MAROC ASIC. Each MAROC ASIC can process 64 channels simultaneously and hence four such boards are connected with the passive board to cater all detector signals of the prototype camera. The MAROC ASIC board is equipped with a 12 bit Analog to Digital Converter (ADC) to digitize the multiplexed charge output proportional to the energy of the photon. The
digitized signal of all channels are collected by a FPGA based controller board which is the master controller of the system. To identify the presence of radiation, the 12th dynode of the PSPMT is used to trigger the FPGA which, after receiving the trigger signal, starts the acquisition of data from the four MAROC boards and forms a image frame and this process continues till the image is generated.

The system is calibrated each time before extraction of an image which is done by the user by interacting with the FPGA board from a PC by USB interface. The energy window and non-uniformity correction is also done by the user with the help of an interactive software. The acquired image passes through several correction algorithms for artifact corrections.

The development of this planar scinti-mammography instrument can be extended to a SPECT (Single Photon Emission Computed Tomography) imaging system which will reconstruct 3-D image of the breast. The development of mechanical system with the ability of rotating and measuring the angular position of the detector with high accuracy and the development of 3-D reconstruction algorithm will enable the indigenous development of high resolution SPECT imaging device in our country. The sensitivity and specificity of the system need to be high enough to avoid any false result during diagnosis for the early detection, however. The integration of other modalities into this system with necessary detection algorithms will surely make it possible to detect breast cancer in very early stage and thus help us to kill this curse at the early stage itself.

References:

1. J R Oza, Jagruti D Prajapati2, Rohit Ram “A study on awareness toward the early detection of breast cancer on nursing staff in civil hospital, Ahmedabad, Gujarat, India”, Health line, ISSN 2229-337X, Volume 2 Issue 1 January-June 2011

Public Awareness Activities

DAE took part in the ‘Frontiers of Science 2012’ held at Kolkata, during September 3-4, 2012. DAE exhibited its strengths, programmes and achievements in the area of various cutting edge technologies. Delegations from Facility for Antiproton and Ion Research, (FAIR) and CERN also participated in the event.

The 16th National Exhibition with theme as ‘India Marching towards an Advanced Nation was held during September 7-11, 2012 at Nazrul Maidan, Narayantala, Kolkata. VECC Kolkata, also participated with DAE in this exhibition. Information (in Bengali and English) and several working models were displayed in this expo. The DAE pavilion had as many as 30000 visitors.

The Kerala State Industrial Development Corporation Ltd. organised Emerging Kerala 2012 during September 12-15, 2012 at Kochi, Kerala. DAE took part in the event and exhibited its achievements, contributions and current activities in the field of nuclear science and technology. Visitors to the pavilion comprised senior government officials, scientists, policy makers and leaders from industry.
India Based Neutrino Observatory (INO) planned to be setup in Theni District, Tamil Nadu. INO will be the only detector capable of answering the fundamental question of Neutrino Mass ordering.
Nuclear Power Station Control Room