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BARC NEWSLETTER

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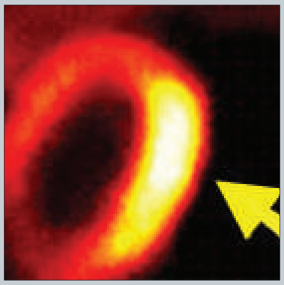
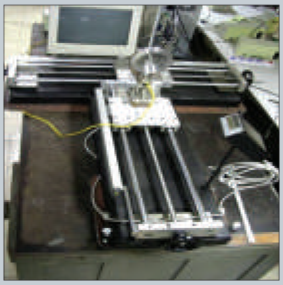
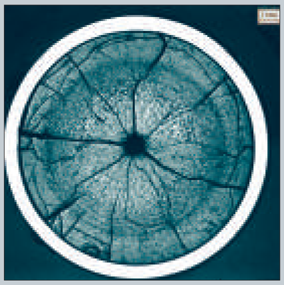
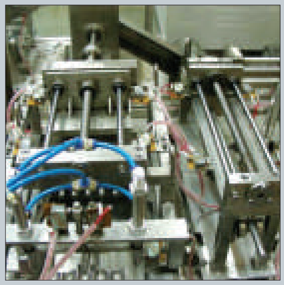

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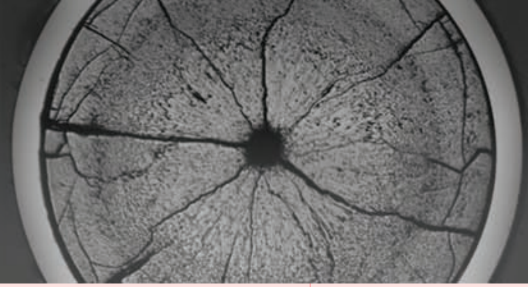

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From the Editor's Desk

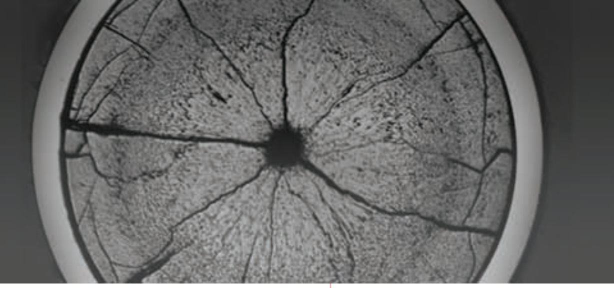
You have with you the fourth issue of the BARC Newsletter, in its new format. You can also notice in this issue, that the articles covered are from different areas of research in BARC. I am happy to inform you that we are getting good response from our Scientists and Engineers. This response encourages us to be more selective in choosing articles for our future issues.

We would like to inform you, that our BARC Newsletter has received the internationally recognized ISSN number. Two unique numbers were allotted to us by the National Centre for ISSN in India this month. One for the print version ISSN: 0976-2108 and another one for the online version ISSN: 0976-2116. This means that the BARC Newsletter will now be internationally identified by these unique numbers, in the International Serials Directory as well as in all the national and international databases.

I would like to thank you all, for your response in sending us the award winning papers, for the Founder's Day Special Issue of the BARC Newsletter. We are happy to inform you, that this year a record number of 67 papers were received by us.

We hope that you all continue to support us in our endeavour, to take this newsletter to greater heights.

K. Bhanumurthy
On behalf of the Editorial Committee



स्वतंत्रता दिवस की 63 वीं वर्षगांठ रविवार, दिनांक 15 अगस्त 2010

डॉ. आर. के. सिन्हा,
निदेशक, भापअ केंद्र
द्वारा संबोधन

"प्रिय साथियो,

सबसे पहले मैं आप सभी को अपने प्रिय देश के स्वतंत्रता दिवस की 63 वीं वर्षगांठ के अवसर पर बधाई देता हूँ। आज की सुबह, हम सब यहां न केवल अपने राष्ट्रध्वज का आदर और सम्मान बनाए रखने की शपथ लेने के लिए उपस्थित हुए हैं बल्कि उन सभी शहीदों को अपनी श्रद्धांजलि अर्पित करने हेतु भी एकत्रित हुए हैं जिन्होंने देश की स्वतंत्रता के लिए अपना सर्वोच्च बलिदान दिया है। इस अवसर पर, हम अपने सैन्य बलों के सदस्यों का भी अभिवादन करते हैं जो हमारे देश को सुरक्षा प्रदान करते हैं।

इस अवसर पर हम अपने कार्यों का पुनरावलोकन करते हैं और विगत कुछ समय में प्राप्त उपलब्धियों का लेखा-जोखा करते हैं। हमारा अधिदेश बिल्कुल स्पष्ट है। विद्युत उत्पादन एवं गैर विद्युत अनुप्रयोगों हेतु नाभिकीय ऊर्जा की वृद्धि की दिशा में हमारे प्रयासों से अपने समाज के लोगों का जीवन स्तर को ऊँचा उठाने में मदद मिलनी चाहिए और हम राष्ट्र की सुरक्षा को सुदृढ़ बनाते हुए नाभिकीय विज्ञान एवं प्रौद्योगिकी के क्षेत्र में अपने देश को अग्रणी बनाये रखने के प्रति समर्पित हैं। मैं, हाल में किए गए कुछ महत्वपूर्ण विकास कार्यों तथा प्राप्त की गई उपलब्धियों को बताने के लिए कुछ उदाहरण देना चाहता हूं।

अनुसंधान रिएक्टर

जैसा कि आप सभी जानते हैं, इस वर्ष हमने दो बहुत महत्वपूर्ण उपलब्धियां प्राप्त की हैं, इनमें से पहली यह है कि इस वर्ष 10 जुलाई को सायरस अनुसंधान रिएक्टर के सफलतापूर्वक प्रचालन के 50 वर्ष पूरे हुए और दूसरी यह है कि अभी हाल ही में अर्थात इस वर्ष 8 अगस्त को ध्रुवा रिएक्टर वे सफलतापूर्वक प्रचालन के 25 वर्ष पूरे हुए। सायरस रिएक्टर को 80.6% के उपलब्धता गुणक पर प्रचालित किया गया। वर्ष के दौरान 650 से भी अधिक नमूनों को किरणित किया गया। छोटे आकार के पदार्थ कूपनों के प्रतिबिंबन के लिए अप्सरा के न्यूट्रॉन रेडियोग्राफी सेट-अप को सायरस में स्थानांतरित कर सफलतापूर्वक कमीशन किया गया।

अनुसंधान रिएक्टर ध्रुवा को 79% से अधिक उपलब्धता गुणक पर प्रचालित किया गया। ध्रुवा रिएक्टर, 805 नमूनों के किरणन के अलावा न्यूट्रॉन किरणपुंज अनुसंधान हेतु राष्ट्रीय सुविधा के रूप में प्रचालनरत रहा।

इसकी 25 वर्ष की सेवा-काल वे साथ हाल ही में इसके अनेक उपस्कर और घटकों का उन्नयन, उनकी पुनर्सज्जा तथा प्रतिस्थापन किया गया। इसमें विद्युत उपस्कर तथा स्विच गियर, मुख्य नियंत्रण कक्ष में यंत्रीकरण तथा नियंत्रण पैनल, द्वितीयक उष्मा विनिमय उपस्कर, भुक्त शेष ईंधन भंडारणबे जल शुद्धिकरण प्रणाली, रिएक्टर ट्रिप लाजिक से जुड़े नियंत्रण एवं यंत्रीकरण, शीतलक प्रवाह मानीटरन प्रणाली, आपातकालीन क्रोड शीतलन प्रणाली और ॲलार्म देने वाली प्रणाली शामिल है।

52 वर्ष की उत्कृष्ट सेवा के पश्चात, अप्सरा को उन्नयन के लिए पिछले वर्ष जून में शटडाउन किया गया। वर्तमान अंतर्राष्ट्रीय मानदंडों के अनुसार रिएक्टर वे एचईयू ईंधन की जगह अल्प समृद्ध यूरेनियम ईंधन का प्रयोग किया जाएगा और उन्नयन के पश्चात अधिकतम तापीय न्यूट्रॉन फ्लक्स को 6.5 X 10^{13} न्यूट्रॉन/से.मी^{2} /सेकंड तक बढ़ाया जाएगा। वर्ष के दौरान रिएक्टर के आंशिक डीकमीशनन से संबंधित अनेक गतिविधियों को सफलतापूर्वक एवं सुरक्षित रूप से पूरा किया गया। इसके फलस्वरूप, पानी के ईंधन समुच्चयों को निकालकर अलग कुंड में उनका भंडारण करना, रिएक्टर क्रोड, विद्युत प्रणाली उपस्कर एवं नाभिकीय तथा नियंत्रण यंत्रीकरण का विघटन, प्राथमिक एवं द्वितीयक शीतलक प्रणालियों का डीकमीशनन आदि कार्य पूरे किए गए। उन्नयन के बाद अब यह रिएक्टर किरणपुंज नली अनुसंधान, रेडियो आइसोटोप उत्पादन, न्यूट्रॉन संसूचकों वे अंशांकन तथा परीक्षण, पदार्थ परीक्षण और बड़े पैमाने पर शील्डिंग प्रयोगों, परीक्षणों के लिए बेहतर सुविधाएं प्रदान करेगा ।

उच्च फ्लक्स अनुसंधान रिएक्टर (एचएफआरआर) का संकल्पनात्मक अभिकल्पन पूरा किया गया। एचएफआरआर का अभिकल्पन प्रथमत: उच्च विशिष्ट सक्रियता वाले रेडियो आइसोटोपों की बृहत मात्रा में आवश्यकताएं पूरी करने तथा विज्ञान के अग्रणी क्षेत्रों में मूल अनुसंधान हेतु उन्नत सुविधाएं उपलब्ध कराने और नाभिकीय ईंधन एवं रिएक्टर पदार्थों के विकास एवं परीक्षण संबंधी अनुप्रयुक्त अनुसंधान की मांग को पूरा करने हेतु किया गया है।

एएचडब्ल्यूआर कार्यक्रम

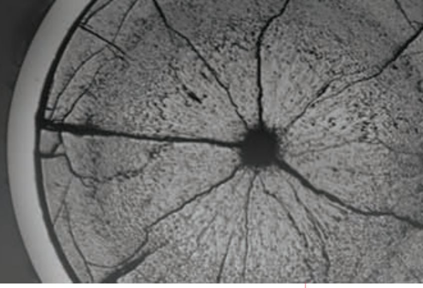
प्रगत भारी पानी रिएक्टर (एएचडब्ल्यूआर) तथा भावी पीएचडब्ल्यूआर हेतु क्रांतिक सुविधा को विभिन्न प्रयोगों के लिए 83 अवसरों पर प्रचालित किया गया। एएचडब्ल्यूआर क्रांतिक सुविधा का प्रयोग करते हुए, संदर्भ क्रोड के प्राकृतिक यूरेनियम प्रयोगात्मक क्लस्टर में सूक्ष्म संरचना फ्लक्स मापन किया गया। इसके साथ, संदर्भ क्रोड के लिए नियोजित सभी प्रयोग पूरे किए जा चुके हैं।

7 ThO_2 पिनों तथा 12 प्राकृतिक यूरेनियम पिनों वाले एक मिश्रित पिनगुच्छ को एएचडब्ल्यूआर क्रांतिक सुविधा के केंद्रीय स्थान पर लोड किया गया।

भापअ केंद्र द्वारा आरएंडडी केंद्र तारापुर में एनपीसीआईएल के साथ संयुक्त रूप से एक प्रमुख एएचडब्ल्यूआर परीक्षण सुविधा स्थापित की जा रही है। सुविधा के सभी प्रमुख घटक संविरचन के प्रगत स्तर पर हैं। इस सुविधा के लिए आवश्यक प्रोटोटाइप ईंधन भरण मशीन का विनिर्माण करके इसे सौंप दिया गया है। इस सुविधा के लिए आवश्यक भवन का सिविल निर्माण कार्य चल रहा है।

एएचडब्ल्यूआर के निश्चेष्ट विष इंजेक्शन प्रणाली (पीपीआईएस) में काम में लाने के लिए "प्वाइज़न इंजेक्शन पैसिव वाल्व" के प्रोटोटाइप का विकास एवं अभिकल्पन करके अनुकारित परिस्थितियों में उसका परीक्षण किया गया। वायर्ड शटडाउन सिस्टम्स के विफल हो जाने की स्थिति में इस वाल्व से रिएक्टर का पैसिव शट डाउन किया जा सकता है। एएचडब्ल्यूआर की विभिन्न संरक्षा प्रणालियों वे लिए विकसित किया गया यह तीसरा निश्चेष्ट वाल्व है जिससे पैसिव वाल्व डिजाइन और विकास के क्षेत्र में हमारी प्रौद्योगिक परिपक्वता सिद्ध होती है।

कैलेंड्रिया के भीतर मंदक प्रवाह वितरण एवं द्रवीय विष इंजेक्शन के अध्ययन हेतु एक सोपानी परीक्षण मॉडल एवं परीक्षण सुविधा का कमीशनन किया गया। केंद्र में घरेलू तौर पर विकसित 3MW के यंत्रीकृत ईंधन छड़ के एक अतिरिक्त क्लस्टर के साथ समग्र जांच सुविधा का आवर्धन किया गया। इस आवर्धित सुविधा से वाहिका शक्ति मापन एवं अस्थिरता संसूचन हेतु नई तकनीकों का मान्यकरण करना संभव हो पाएगा।



उच्च तापीय रिएक्टर कार्यक्रम:

संहत उच्च तापीय रिएक्टर (सीएचटीआर) के सभी घटकों का अभिकल्पन पूरा होने के पश्चात, क्रोड घटकों तथा अन्य रिएक्टर प्रणालियों को दर्शाते हुए एक 3 डी लेआऊट तैयार किया गया है।

रिएक्टर स्टार्ट-अप एवं नियमन वे प्रयोजन हेतु क्रोड के अंदर और रिएक्टर पात्र वे बाहर संसूचन स्थानों में न्यूट्रॉन फ्लक्स का अनुमान लगाने के लिए मोंटे कार्लो अनुकरण किए गए। हाइड्रोजन उत्पादन सहित उच्च तापीय प्रक्रिया ऊष्मा अनुप्रयोगों हेतु उच्च तापीय रिएक्टर (एचटीआर) के प्रारंभिक क्रोड का अभिकल्पन पूरा किया गया।

थोरियम ईंधन अध्ययन

आधुनिक पीडब्ल्यूआर में विखंड्य पदार्थों के पुनर्चक्रण के साथ थोरियम-यूरेनियम आधारित ईंधन के प्रयोग से जुड़े। ईंधन प्राचलों के विभिन्न मामलों तथा आर्थिक रूप से उनकी सक्षमता का मूल्यांकन किया गया और भुक्तशेष ईंधन के प्रत्यक्ष निपटान का विकल्प लेकर समृद्ध यूरेनियम ईंधन का प्रयोग करते हुए संदर्भित मामलों से उनकी तुलना की गई।

अतिक्रांतिक परीक्षण सुविधा

अतिक्रांतिक परीक्षण सुविधा में अतिक्रांतिक कार्बन डाईआक्साइड के साथ अस्थिरता परिघटना पर विस्तृत डाटा तैयार किया गया। तत्पश्चात, इस सुविधा में कुछ परिवर्तन करके इसे अतिक्रांतिक जल के साथ प्रचालन योग्य बनाया गया। इस सुविधा का कमीशनन करके अतिक्रांतिक स्थिति में जल के साथ सफलतापूर्वक प्रयोग किए गए।

पीएचडब्ल्यूआर कार्यक्रम

एनपीसीआईएल को पीएचडब्ल्यूआर संबंधी गतिविधियों में अनुसंधान एवं विकास सहायता प्रदान करने की जिम्मेदारी भापअ केंद्र पर है।

कालप्रभावन प्रबंधन वे अंतर्गत, भापअ केंद्र के इंजीनियरों ने आरएपीएस-3 दाब नलियों में सिल्वर सैंपलिंग अभियान में भाग लिया।

540 मेगावाट पीएचडब्ल्यूआर शीतलक चैनलों के सुदूर अनुरक्षण के लिए मैन-रेम बचत उपकरणों का विकास किया गया है। इसके पहले विकसित दो विशिष्ट उपकरण, जैसे कि चैनल को खाली किए बिना, बंद सीलपेस की मरम्मत की सुविधा उपलब्ध कराने के लिए चैनल आइसोलेशन प्लग तथा फीडर बर्प प्रशीतन के लिए चैनल फ्लो अरेस्टर असेंबली को और भी बेहतर बनाया गया और इसका निदर्शन करके इसका प्रयोग करने के लिए इसे टीएपीएस-3 तथा 4 वे सुपुर्द किया गया।

टीएपीएस-4 में ईंधन भरण मशीन के प्रचालन में एक असामान्य घटना होने के कारण उत्तरी ईंधन भरण मशीन शीर्ष से किरणित ईंधन गुच्छों को सुरक्षित ढंग से निकालने के लिए एनपीसीआईएल को तकनीकी सहायता प्रदान की गई।

नाभिकीय ईंधन कार्यक्रम

भापअ केंद्र, कलपाक्कम स्थित एफबीटीआर एवं पीएफबीआर (निर्माणाधीन) सहित द्रुत रिएक्टर कार्यक्रम के लिए प्लूटोनियमयुक्त ईंधनों की आपूर्ति करता है। एफबीटीआर के लिए यूरेनियम-प्लूटोनियम मिश्रित कार्बइड ईंधन का उत्पादन भापअ केंद्र में जारी है। एफबीटीआर से निकले प्लूटोनियम को संसाधित करके बनाई गई पिनों का एक ईंधन उप समुच्चय एफबीटीआर में किरणित किया जा रहा है। इससे एफबीटीआर हेतु ईंधन चक्र पूरा होता है। एएफएफएफ, तारापुर में संविरचित पीएफबीआर प्रयोगात्मक मॉक्स ईंधन पिनों को एफबीटीआर क्रोड वे मध्य में लोड किया गया और अब यह 100,000 MWd/T वे डिजाइन लक्ष्य बर्नअप को पार कर गया है। A3F में पीएफबीआर हेतु मॉक्स ईंधन पिनों का

नियमित उत्पादन प्रारंभ हो गया और हाल ही में एक नयी ईंधन पिन वेल्डिंग लाइन का कमीशनन किया गया।

भापअ केंद्र ने एएचडब्ल्यूआर के लिए एकीकृत ईंधन चक्र सुविधा के संकल्पनात्मक अभिकल्पन पर भी कार्य प्रारंभ किया है।

ईंधन किरणन कार्यक्रम के अंतर्गत (ThO_2-1%PuO_2) मॉक्स ईंधन पिनों तथा (Th-1%U235)O_2 पिनों का संविरचन किया गया जिन्हें ध्रुवा क्रोड की ईंधन स्थिति में लोड किया जाएगा । ईंधन का हार्डवेयर तथा गुटिकाओं की ज्यामितीय संरचना एएचडब्ल्यूआर ईंधन जैसी ही होगी।

सायरस में AC-6 गुच्छ में 21,000 MWd/T तक बर्न अप में (ThO_2-4%PuO_2) किरणित ईंधन पिनों का पश्च किरणन परीक्षण किया गया। पीआईई से (Th-Pu) मॉक्स ईंधन के उत्कृष्ट आचरण की पुष्टि हुई जिसमें सूक्ष्म संरचनात्मक परिवर्तन नगण्य थे और समान प्रकार के यूरेनियम आधारित ईंधनों की तुलना में विखंडन गैस उन्मोचन भी काफी कम पाया गया। विस्तारित बर्नअप हेतु दो ईंधन पिनों का पुन:किरणन किया जाएगा।

आंतरिक जेलेशन सोल-जेल प्रक्रिया का प्रयोग करते हुए यूरेनियम ऑक्साइड में 53% PuO_2 युक्त मॉक्स माइक्रोस्फियर सफलतापूर्वक तैयार किए गए। इन माइक्रोस्फियरों का प्रयोग आईजीसीएआर स्थित एफबीटीआर में परीक्षण पिन किरणन के लिए किया जाएगा।

अतिचालक कार्यक्रम

आईपीआर में संलयन अनुसंधान कार्य हेतु आवश्यक Nb_3-Sn आधारित अतिचालक चुंबकों के लिए विभिन्न विन्यासों के केबल इन कंड्यूट का विकास एवं संविरचन भापअ केंद्र द्वारा प्रारंभ किया गया है। इस प्रगत अतिचालक संविरचन के लिए प्रक्रम चित्र का विकास अब कर लिया गया है तथा इसके परीक्षण किए जा रहे हैं।

नाभिकीय पुन:चक्रण बोर्ड (3नआरबी)

एनआरबी का गठन पिछले वर्ष सितंबर 2009 में नाभिकीय विद्युत रिएक्टरों के भुक्त शेष ईंधन के पुनर्संसाधन हेतु एक विस्तार कार्यक्रम शुरू करने तथा देश में नाभिकीय अपशिष्ट प्रबंधन सुविधाओं का विकास करने के लिए किया गया।

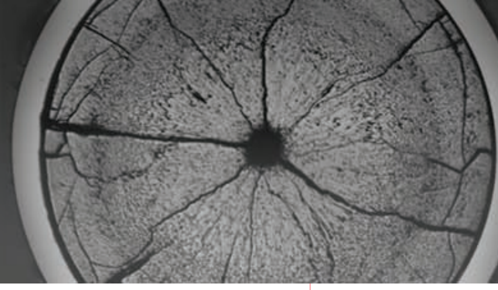
तारापुर स्थित परियोजनाओं यथा प्रिफ्री का नवीकरण (आरओपी), अतिरिक्त अपशिष्ट टैंक फार्म (एडब्ल्यूटीएफ), एकीकृत नाभिकीय पुन:चक्रण संयंत्र (आईएनआरपी), अपशिष्ट प्रबंधन सुविधाएं (डब्ल्यूएमएफ), भुक्त शेष ईंधन भंडारण सुविधा (एएफएसएफ) की गतिविधियों को एनआरबी के अधीन लाया गया। इसी तरह, कलपाक्कम स्थित परियोजनाओं यथा पी 3ए (तृतीय पुनर्संसाधन संयंत्र) तथा अपशिष्ट अचलीकरण संयंत्र (डब्ल्यूआईपी) को भी एनआरबी के अधीन लाया गया है तथा अच्छी प्रगति कर रही है।

ईंधन पुनर्संसाधन एवं अपशिष्ट प्रबंधन गतिविधियां

एमएपीएस के भुक्तशेष ईंधन के संसाधन हेतु कलपाक्कम स्थित कार्प सुविधा सुचारू रूप से प्रचालनरत रही। सीडब्ल्यूएमएफ, कलपाक्कम में प्लास्टिक/पालिथीन अपशिष्ट की गलन सघनता हेतु पाइलट सुविधा का प्रचालन जारी रहा ताकि इंजीनियरी स्तर का डाटा तैयार किया जा सके।

ट्रांबे स्थित प्लूटोनियम संयंत्र प्रचालनरत रहा। थोरिया ईंधन पुनर्संसाधन के दौरान पहले उत्पन्न हुए अपशिष्ट को यूरेनियम थोरियम पृथक्करण सुविधा (यूटीएसएफ) में थोरियम की पुन:प्राप्ति के लिए संसाधित किया गया।

ट्रांबे स्थित डब्ल्यूआईपी में नए संसाधन चक्र की स्थापना हेतु अपरिवर्तन (मॉडिफिकेशन) कार्य जैसे कि सल्फेट पृथक्करण,



अम्ल की पुन:प्राप्ति तथा वाष्पित्र प्रणाली अब पूर्ण होने ही वाले हैं।

अपशिष्ट प्रबंधन के क्षेत्र में अनुसंधान तथा विकास प्रयासों के अंतर्गत, ओजेनेशन आधारित एक प्रक्रम का मध्यम स्तर के ऐसे जलीय द्रव अपशिष्ट के उपचार हेतु सफलतापूर्वक प्रदर्शन किया गया जिसमें विलीन जैव पदार्थों की मात्रा अत्यधिक थी।

रेडियोसक्रिय द्रव बहि:स्त्रावों में नाइट्रेटों के जैव पदार्थों को 1000 पीपीएम तक कम करने हेतु एक मार्गदर्शी संयंत्र लगातार प्रचालनरत है। प्रयोगशाला अध्ययनों से यह साबित हुआ है कि यह लगभग 25000 पीपीएम तक के नाइट्रेट सांद्रण के लिए जैव-निम्नन प्रक्रम प्रभावी हो सकता है।

अनुकारित अपशिष्ट का उपयोग करके सीजियम की पुन:प्राप्ति करने के लिए मॉलिब्डो-फॉस्फेट पर आधारित एक पूरे पैमाने का इंजीनियरिंग लूप स्थापित करके सफलतापूर्वक प्रचालित किया गया।

कोल्ड क्रुसिबल इंडक्शन मेल्टर का प्रयोग करने वाली काचन प्रौद्योगिकी ने अनुकारित अपशिष्ट भरण (फीड) परीक्षण सफलतापूर्वक पूरा करके एक और मील का पत्थर पार किया है।

रेडियोसक्रिय अपशिष्ट में मौजूद ^{90}Y तथा ^{106}Ru जैसे उपयोगी आइसोटोपों की नियमित रूप से पुन:प्राप्ति करके रेडियोभेषज प्रभाग में उनका उपयोग किया जा रहा है।

पदार्थ और धात्विकी :

वाशी स्थित पीएमडी के पुनर्सुसज्जित (रिफर्बिश्ड) संयंत्र से बेरिलियम और बेरिलिया का उत्पादन शुरू हो गया है तथा जितने विशेष बेरिलियम आकारों की जरूरत है उनका संविरचन करके उन्हें विशिष्ट प्रयोक्ताओं को सुपुर्द कर दिया गया है। भावी संलयन रिएक्टर (फ्यूचर फ्यूजन रिएक्टर) के प्रजनकों में संभावित उपयोग के लिए बेरिलिया तथा लिथियम टाइटेनेट वाले न्यूट्रॉन गुणन तथा ट्रीशियम के उत्पादन हेतु सेरामिक बनाने का काम पहली बार पूरा किया गया है।

प्रगत रिएक्टरों में दाब नलिकाओं वे सेवाकाल में वृद्धि करने हेतु, आठ अलग अलग मार्गो के साथ Zr-2.5 Nb मिश्रधातु दाब नलिकाओं के संविरचन प्राचलों का अध्ययन भापअ केंद्र से इनपुट लेकर एनएफसी में किया गया। ऊष्मा उपचारित Zr-2.5Nb मिश्रधातु के सूक्ष्म संरचना और तनन गुणधर्मों का प्रयोगशाला स्तर पर संसाधन और अभिलक्षणन भी पूरा किया गया। एएचडब्ल्यूआर के लिए ऊष्मा उपचारित दाब नलिकाओं के संविरचन हेतु प्रक्रम प्राचलों की स्थापना में इन अध्ययनों से सहायता मिली।

हल्के लड़ाकू विमान के लिए Ni-Ti मिश्रधातुएं तथा ऊष्मा संकुचन-योग्य फेरूल बनाने की प्रौद्योगिकी एक त्रि-पक्षीय समझौता ज्ञापन के तहत भापअ केंद्र द्वारा बैंगलूर स्थित हिंदुस्तान एरोनॉटिक्स लिमिटेड को हस्तांतरित की जा रही है।

स्वचालन तथा सुदूर प्रहस्तन

भारत सरकार, अंतर्राष्ट्रीय परमाणु ऊर्जा आयोग तथा वियतनाम सरकार के बीच एक अनुबंध के अंतर्गत, भापअ केंद्र ने वियतनाम के कैन थो ऑनकोलॉजी अस्पताल में एक भाभाट्रॉन-II की आपूर्ति, स्थापना तथा कमीशनन किया गया। इस यंत्र का उद्घाटन, दिनांक 28 अप्रैल, 2010 को किया गया।

भापअ केंद्र ने पहले देसी विकिरण-चिकित्सा सिम्युलेटर के विकास का कार्य पूरा कर लिया है। यह प्रणाली (सिस्टम) आंध्रप्रदेश के नेल्लूर स्थित भारतीय रेड-क्रॉस सोसाइटी अस्पताल में स्थापित की गयी है। ऐसी उम्मीद की जाती है कि इस विकास कार्य से परिष्कृत सिम्युलेटर कम मूल्य पर उपलब्ध हो पाएगा जिसके परिणामस्वरूप अधिक से अधिक लोग नैदानिक सुविधाएं प्राप्त करने में समर्थ हो सकेंगे।

भापअ केंद्र में अनुप्रयोगों की विस्तृत श्रृंखला हेतु सिक्स डिग्रीज ऑफ फ्रीडम वाली एक बहुपयोगी यांत्रिक युक्ति हेक्सापॉड का विकास किया गया है। इसका उपयोग, एक सिंक्रोट्रॉन विकिरण किरणपुंज रेखा में प्रकाशीय तत्वों के परिशुद्ध स्थिति निर्धारण तथा अभिविन्यास के लिए किया जा सकेगा । यह हेक्सापॉड, लगभग 1000 किलोग्राम वजन के एक निर्वात प्रकोष्ठ में रखे एक 1000 मि.मी. लंबे दर्पण को संभालने तथा संरेखित करने में समर्थ है। 10 माइक्रोन तक स्थित निर्धारण करने तथा 10 आर्क सेकेंड तक अभिविन्यास की अभिकल्पित यथार्थता प्राप्त की गई।

इलेक्ट्रॉनिकी एवं यंत्रीकरण

प्रभादेवी में माइक्रोइलेक्ट्रॉनिक्स केंद्र (सीएमईएमएस) का उद्घाटन दिनांक 02 अप्रैल, 2010 को किया गया। सीएमईएमएस, एएसआईसी, एचएमसी, संवेदकों (सेंसरों) और संसूचकों (डिटेक्टरों) के अभिकल्पन, विकास, निदर्शन (मॉडलिंग), परीक्षण तथा पैकिंग के लिए एक वीएलएसआई अनुसंधान एवं विकास सुविधा है।भूकंपी घटनाओं के रात-दिन लगातार मॉनीटरन के लिए एक भूकंपी डाटा केंद्र की स्थापना भापअ केंद्र में की गई है। भूकंपी घटना के स्थान निर्धारण के लिए वास्तविक काल संकेत संसूचन तथा इसकी पहचान और अधिसूचना के लिए विभिन्न आंतरिक अनुप्रयोग साफ्टवेयर विकसित किए गए हैं। सुनामीजन्य भूकंपों की पहचान हेतु ज्वार मापी आंकड़ो से प्राप्त घटना की सूचना को भूकंपी सूचना के साथ जोड़ने के लिए प्रणालियों का विकास किया गया है।

नाभिकीय संरक्षा तथा संरक्षा संबंधी अनुप्रयोगों के लिए टीपीएलसी-32 (ट्रॉबे प्रोग्रामेबल लॉजिक कंट्रोलर) नामक एक नामक 32 बिट सी एंड आई प्लैटफॉर्म का विकास किया गया है। इस साझा प्लैटफॉर्म का उपयोग करते हुए, ध्रुवा के लिए चार तंत्रों अर्थात रिएक्टर ट्रिप लॉजिक तंत्र, आपातकाल क्रोड शीतलन तंत्र, स्टार्ट-अप लॉजिक तंत्र तथा सचेतक उद्घोषणा तंत्र के आदिरूप का विकास किया गया है। इस प्रोग्राम के चरण-2 के अंतर्गत, टीपीएलसी-32 में अतिरिक्त विशेषताएं जोड़ी जाएंगी ताकि एएचडब्ल्यूआर के पूर्णत: वितरित नियंत्रण तंत्र के विकास हेतु इसका नियोजन किया जा सके।

रेडियोसक्रिय पदार्थों की गतिविधि के संसूचन और संरक्षा कार्मिकों द्वारा जांच हेतु उपयुक्त सीसीटीवी कैमरों को क्रियाशील करने के लिए एक तंत्र का विकास तथा नियोजन किया गया। भापअ केंद्र को आवश्यक स्तर की सुरक्षा प्रदान करने के लिए चलाई जा रही गतिविधियों वे अंग के रूप में, परिसर के वुछ महत्वपूर्ण क्षेत्रों में एकीवृत भौतिक बचाव प्रणालियां नियोजित की गईं।

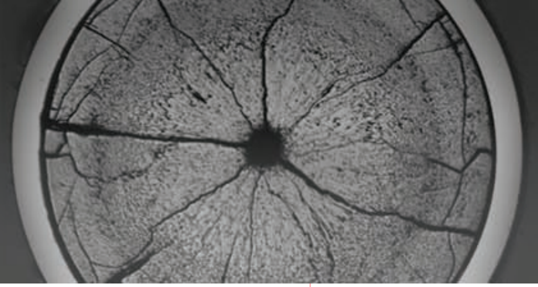
एक अद्वितीय तथा संहत हस्त स्कैन बायोमेट्रिक सिस्टम (एचएसबीएस) का एक प्रोटोटाइप विकसित किया गया। यह एक आरएफआईडी कार्ड रीडर पर इंटरपेस किया जा सकता है और संपूर्ण तंत्र के कार्मिकों के सत्यापन के लिए अकेले अलग रूप में (स्टैंड एलोन मोड) या दूर से अप्रत्यक्ष ढंग से भी काम कर सकता है।

भापअ केंद्र के इलेक्ट्रॉनिकी प्रभाग में विकसित गैर-आक्रामक (नॉन-इंवेसिव) रक्त चाप मॉनीटर की प्रौद्योगिकी को हाल ही में एक अन्य निजी निर्माण संस्था को हस्तांतरित किया गया।

किरणपुंज प्रौद्योगिकी विकास

दो इलेक्ट्रॉन किरणपुंज वेल्डिंग यंत्रों, जिनमें से एक, 100 केवी, 4 किलोवाट रेटिंग तथा दूसरा 80 केवी, 12 किलोवाट रेटिंग का है, की स्थापना क्रमश: नाशिक के एक निजी उद्योग तथा आईआईटी खड़गपुर में की गई है । आईआईटी खड़गपुर की सुविधा का उपयोग, धातुओं तथा सुपर मिश्रधातुओं की ईबी वेल्डिंग से संबंधित अध्ययनों तथा परमाणु ऊर्जा विभाग वे लिए महत्वपूर्ण घटकों के सैम्पल प्रोडक्ट वेल्डिंग के प्रदर्शन के लिए किया जाना है।

उच्च ताप पर्यावरण में आवेश घनत्व मापन हेतु एक नए इरिडियम आधारित लैंगमुइर प्रोब कलेक्टर असेम्बली का विकास किया गया। वीएसएससी त्रिवेंद्रम के एक उच्च एन्थैल्पी प्लाज्मा प्लूम (7000 के) में इस प्रोब का सफलतापूर्वक परीक्षण



किया गया जिसका उद्देश्य, दोबारा प्रवेश करने वाले (री-एंट्री) वाहनों की जांच हेतु अंतरिक्ष मिशनों में नियोजन के लिए इसकी उपयुक्तता को जांचना था।

हॉल-6 इलेक्ट्रॉन किरणपुंज वाष्पित्र को एसीईबी गनों के साथ, नियंत्रण प्रणाली, गन तथा अन्य उपकरण उपतंत्रों की लंबी अवधि की क्षमता को परखने वे लिए क्रमश: 80 तथा 160 घंटों के लिए अभियान के रूप में चलाया गया। इस अभियान के दौरान अधिकतम लगभग 150 किलोवाट ऊर्जा तथा 100 मिनट तक रुके या बंद हुए बिना लगातार प्रचालन की उपलब्धि प्राप्त हुई।

भापअ केंद्र द्वारा विकसित लेजर समर्थित विसंदूषण तंत्र का परीक्षण प्रगत ईंधन संविरचन सुविधा (एएफएफएफ) में पीएफबीआर ईंधन पिनों की सफाई के लिए किया गया। 1064 एनएम तथा 532 एनएम के लेजर तरंगदैर्ध्यों पर UO_2 और PuO_2 प्रदूषण के साथ किए गए प्रयोग से जो परिणाम प्राप्त हुए उनमें अवशिष्ट गतिविधि स्वीकार्य स्तरों से काफी कम रही। इसे अब एएफएफएफ ईंधन संविरचन रेखा के साथ एकीकृत किया जा रहा है।

खारघर के इलेक्ट्रॉन किरणपुंज केंद्र में 10MeV/10kW RF लाइनेक का 24 घंटे वे लिए 3kW किरणपुंज ऊर्जा पर लगातार प्रचालन किया गया जिसका उद्देश्य, इसवे स्थिर तथा सुरक्षित प्रचालन का सत्यापन करना था। 3MeV DC इलेक्ट्रॉन त्वरक को 1.1MeV किरणपुंज ऊर्जा तथा 1kW किरणपुंज ऊर्जा पर प्रचालित किया गया।

भौतिक विज्ञान

इस वर्ष की शुरुआत में माउंट आबू की टैक्टिक गामा किरण दूरबीन ने सक्रिय गैलेक्सीय नाभिक Mrk 421 से टेरा इलेक्ट्रॉन वोल्ट (टाईवी) ऊर्जाओं पर फ्लेयरिंग गामा किरण गतिविधि को संसूचित किया। दिनांक 17 फरवरी 2010 को दूरबीन ने, वस्तु से प्रतिघंटे 50 गामा किरणों से भी अधिक के उच्च अभिवाह का अवलोकन किया। इसे एक महत्वपूर्ण घटना माना गया है।

भापअ केंद्र में पहली बार एक नए टाईम ऑफ फ्लाइट सेकंडरी आयन द्रव्यमान स्पेक्ट्रममापी (टाओएफ-एसआईएमएस) का विकास तथा कमीशनन किया गया। इस सेटअप का इस्तेमाल सब-माइक्रॉन (300 नैनोमीटर) विभेदन (रिज़ॉल्यूशन) तथा अत्यन्त उच्च द्रव्यमान विभेदन (10,000 से अधिक) के साथ प्रतिदर्श पृष्ठों का रासायनिक प्रतिबिम्बन दिखाने के लिए किया जा रहा है।

लिथियम हेप्टाबोरेट (Li2B4O7) के एकल क्रिस्टलों को डोजिमेट्रिक अनुप्रयोगों हेतु विकसित किया गया है। Cu के साथ अपमिश्रित लिथियम बोरेट (LBO) क्रिस्टलों ने सूक्ष्म Gy से 100Gy तक की विशाल रेंज में गामा विकिरण के प्रति असाधारण संवेदनशीलता प्रदर्शित की।

एक एन्जाइम की त्रिविमीय परमाणु स्तर की संरचना का निर्धारण किया गया जो क्षारीय स्थितियों में यूरेनियम के जैव-अवक्षेपण के लिए उपयोगी है।

रासायनिक विज्ञान

एक अद्वितीय राष्ट्रीय जैव परिदूषण परीक्षण लूप सुविधा का निर्माण कलपाक्कम में किया गया जिसका उद्देश्य एक नई और उन्नत समुद्रीजल ग्रहण प्रणाली (सीवाटर इन्टेक सिस्टम) वे साथ पावर रिएक्टरों में शीतलन जल प्रणाली से संबंधित जैव परिदूषण तथा जैव संक्षारण समस्याओं का अध्ययन करना है। उत्पन्न आंकड़े, पीएफबीआर में उपयोग किए जाने वाले टाइटेनियम ऊष्मा विनिमयकों में जैव परिदूषण नियंत्रण के लिए लाभदायक होंगे।

Si(111) अवस्तर पर उच्च गुणवत्ता वाली पतली डायमंड फिल्में तैयार करने के लिए एक एमपीसीवीडी

(माइक्रोवेव-प्लाज़्मा केमिकल वेपर डिपोज़ीशन) प्रणाली की स्थापना की गई है। ** 20 m मोटाई वाली और 1x1cm की प्रतिबल रहित डायमंड फिल्मों को विभिन्न हाईड्रोजन-मेथेन अनुपात एवं गैस दाबों के अंतर्गत निक्षेपित किया गया है ।

प.ऊ.वि., अनुसंधान संस्थानों, विश्वविद्यालयों और अर्धचालक उद्योगों के प्रत्याशित प्रयोक्ताओं को पहली बार परा-शुद्ध गैलियम, आर्सेनिक, Ge एवं CsI की आपूर्ति की गई ।

स्वदेश में विकसित ग्लास सेटअप का उपयोग करते हुए 600-825°C ताप की परास में लौह-ऑक्साइड आधारित पदार्थों के ऊपर सल्फ्यूरिक-अम्ल के उत्प्रेरक अपघटन पर अध्ययन किए गए । ये अध्ययन उच्च ताप-रसायन-ऊष्मा प्रक्रम का उपयोग करते हुए हाइड्रोजन के उत्पादन हेतु जारी अनुसंधान गतिविधियों का एक भाग हैं ।

न्यूट्रॉन सक्रियण विश्लेषण का प्रयोग करते हुए बृहत नमूना अभिलक्षणन हेतु हार्मोनाइज्ड विधि और फॉरेन्सिक अध्ययन में उसके अनुप्रयोगों का विकास किया गया और विभिन्न आकारों एवं आकृतियों के विश्लेषण हेतु वैधीवृत किया गया ।

विकिरण रासायनिकी एवं आइसोटोप

पार्किन्सनिज्म (कम्पनशील लकवा) से पीड़ित रोगियों के निदानात्मक मूल्यांकन हेतु Tc-99m लेबल्ड ट्रोडैट तैयार करने हेतु एक किट सफलतापूर्वक तैयार की गयी है और जसलोक अस्पताल एवं अनुसंधान केंद्र के सहयोग से इसकी उपयोगिता का निरुपण किया गया। उपचार के तहत रोगियों की प्रगति की मॉनीटरन प्रक्रिया हेतु डोपेमाइन रिसेप्टर एक बहुत उपयोगी उपकरण साबित होगा। इस उत्पाद की अच्छी माँग होने की संभावना है ।

भारतीय अंतरिक्ष अनुसंधान संगठन (इसरो) के अनुरोध पर Fe-55वाले रेडियोसक्रिय स्रोतों को विशेष रुप से तैयार कर उनकी आपूर्ति की गई। इन स्रोतों का प्रयोग एस्ट्रोसैट उपग्रह, जिसे इसरो द्वारा शीघ्र ही लांच किया जाना है, में मौजूद स्कैनिंग स्काई मॉनिटर डिटेक्टरों की जांच के लिए किया जाएगा। इसरो ने इन देशी स्रोतों को आयतित (इम्पोर्टेड) स्रोतों से भी बेहतर माना है और इससे विदेशी मुद्रा की पर्याप्त बचत हुई है।

रेडियो ट्रेसर अनुप्रयोगों के एक भाग के रूप में तलछट आवागमन गतिविधि के परीक्षण और डम्पिंग क्षेत्रों का पता लगाने के लिए रेडियोट्रेसर Sc-46 का उपयोग करके कोलकाता पोर्ट एवं विशाखापट्टनम हार्बर में प्रयोग किए गए ।

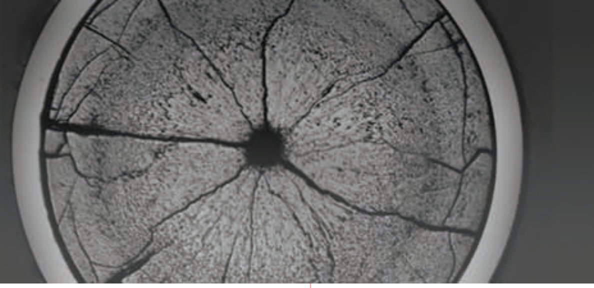
रासायनिक इंजीनियरी एवं प्रौद्योगिकी

आईआईटी, कानपुर के सहयोग से सिलिकॉन अवस्तर हेतु नैनों परिष्करण प्रक्रम वे लिए विकसित "केमो मेकेनिकल मैगनेटो- रियोलॉजिकल फिनिशिंग" (CMMRF) तकनीक के लिए अन्तर्राष्ट्रीय पेटेन्ट फाइल किया गया ।

नाभिकीय निर्लवणीकरण निदर्शन संयंत्र (एनडीडीपी) कलपाक्कम के बहु-चरणीय फ्लैश खंड के सफल कमीशनन के पश्चात, उत्पादन की दर धीरे-धीरे बढ़कर 75% अभिकल्पन क्षमता तक पहुंच गई है । डिस्टिल्ड गुणवत्ता वाला ऐसा जल प्राप्त किया गया है जिसमें पूर्णतया विलीन ठोस (टीएसडी) 5ppm तक ही रह गए हैं । एमएसएफ संयंत्र के साथ, समुद्री जल प्रतिलोम परासरण (एसडब्ल्यूआरओ) संयंत्र दिन-रात लगातार चलाया जाता रहा है ।

आयात स्थानापन्न के रूप में (1000 x 1000) mm आकार की पॉली - सल्फोन झिल्ली को आंतरिक संसाधनों से स्वगृहे विकसित किया गया है। प्रायोगिक तौर पर इस झिल्ली का उपयोग प्रीफ्री के विद्युत- अपघटनी झिल्ली प्रकोष्ठ में यूरेनाइल नाइट्रेट को यूरेनस नाइट्रेट में बदलने के लिए किया जाता है।

बृहन्मुंबई महानगरपालिका (एमसीजीएम) ने भापअ केंद्र के साथ एक समझौता ज्ञापन (मेमोरेंडम ऑफ अंडरस्टेंडिंग) पर हस्ताक्षर किया है जिसके तहत महानगरपालिका ने 100 मिलियन लीटर प्रतिदिन (एमएलडी) क्षमता के समुद्री जल निर्लवणीकरण संयंत्र की स्थापना हेतु हमारा तकनीकी मार्गदर्शन मांगा है। भापअ केंद्र, एमसीजीएम को तकनीकी पहलुओं पर



तकनीकी सुविज्ञता तथा परामर्श देने हेतु सहमत हुआ है।

भारतीय सेना द्वारा निगरानी के प्रयोजन के लिए अवरक्त संवदेक पर आधारित ताप प्रतिबिम्बकों (नाइट विज़न डिवाइस) हेतु एक माइक्रो क्रायो-कूलर का विकास किया गया है। इस क्रायो-कूलर को ईएमई स्कूल बड़ौदा में नाइट विजन डिवाइस के साथ सफलतापूर्वक समाकलित किया गया ताकि उसकी कार्यप्रणाली का प्रदर्शन किया जा सके।

30 LPH क्षमता वाले पायलट स्केल तरलित संस्तर ऊष्मा विनाइट्रीकरण संयंत्र की स्थापना की गई ताकि यूरेनाइल नाइट्रेट सहित नाभिकीय ईंधन चक्र की विभिन्न नाइट्रेट धाराओं के उष्मा विनाइट्रीकरण प्रक्रम का विकास किया जा सके। इससे पूर्व, अमोनियम डाइ-यूरेनेट फिल्टरेट हेतु तरलित संस्तर उष्मा विनाइट्रीकरण का विकास 5 एलपीएच क्षमता के बेंच स्केल पर किया गया था। इस पायलट स्केल सुविधा के साथ बेंच स्केल संयंत्र के द्वारा दो पैमानों पर विनाइट्रीकरण प्रक्रम पर अध्ययन किए जा सकते हैं जो उत्पादन के प्रयोजन हेतु संयंत्र के अभिकल्पन के लिए इंजीनियरी आंकड़े उत्पन्न करने के लिए अनिवार्य हैं।

नाभिकीय कृषि तथा खाद्य प्रौद्योगिकी

कृषि के क्षेत्र में, दो नई ट्रांबे फसल किस्में भारत सरकार के कृषि मंत्रालय द्वारा जारी कर अधिसूचित की गईं। रबी तथा यूटेरा (राइस फालो) कृषि स्थितियों के लिए उपयुक्त एक उच्च उपज देनेवाली, शीघ्र पकनेवाली, रोग प्रतिरोधक किस्म टीएम-2000-2 (पायरी मूंग) छत्तीसगढ़ राज्य में वाणिज्यिक कृषि के लिए जारी कर अधिसूचित की गयी। शीघ्र पकनेवाली तथा कीड़ो। को सहनेवाली एक अन्य किस्म टीजेटी 501 (ट्रांबे जवाहर तूर) को मध्य क्षेत्र (महाराष्ट्र, मध्यप्रदेश, छत्तीसगढ़ और गुजरात राज्यों) में व्यापारिक कृषि के लिए जारी कर अधिसूचित किया गया। इसके साथ ही जारी की गई और खेती के लिए कृषि मंत्रालय, भारत सरकार द्वारा अधिसूचित, ट्राम्बे फसल की विभिन्न किस्मों की कुल संख्या 39 तक पहुँच गई है ।

जैवखाद के संरूपण हेतु दो पेटेन्ट प्रदान किए गए है: एक ज़िंक खाद संरूपण के लिए है और दूसरा मोलैसेज आधारित आसवन संयंत्रों से जैव-आपंक का प्रयोग करते हुए फास्फ़ोरस खाद संरूपण के लिए है।

खाद्य पदार्थो की पैकेजिंग के लिए काइटोसैन और गार गम मिश्र का प्रयोग करते हुए उच्च गुणधर्म वाली जैव-निम्नन योग्य फिल्में तैयार की गईं। लीची के संगरोध उपचार एवं निधानी आयु बढ़ाने के लिए नवाचारों (प्रोटोकॉल्स) का विकास किया गया है। बैंगन के ब्राउनिंग (एनज़ाइम) पॉलिफिनॉलऑक्सीडेज को क्लोन किया गया और उनका अभिलक्षणन किया गया।

प्रौद्योगिकी हस्तांतरण

पिछले एक वर्ष की अवधि में दस विभिन्न प्रौद्योगिकियाँ 20 विभिन्न पार्टियों को हस्तांतरित की गईं। इन प्रौद्योगिकियों में जल शुद्धीकरण और उपचार प्रौद्योगिकियों, जिनमें पेय जल से ऑरसेनिक/फ्लोरीन को हटाया जाता है, से लेकर चिकित्सीय यंत्रीकरण जैसे हाथ में लेकर चल सकने वाला छोटा टेली ईसीजी यूनिट तथा प्रतिबिंब विश्लेषण तंत्र आदि तक शामिल हैं ।

होमी भाभा राष्ट्रीय संस्थान

समविश्वविद्यालय की स्थापना की गई है जिससे भापअ केंद्र में शैक्षणिक संस्कृति का विस्तार दृष्टिंगत रहा है। यह गर्व का विषय है कि एचबीएनआई वे कार्यों की समीक्षा हेतु प्रोफेसर जयन्त नारलीकर की अध्यक्षता में विश्वविद्यालय अनुदान आयोग द्वारा विशेषज्ञ समिति बनाई गई है जिसने एचबीएनआई के विशिष्ट गुणों को अभिस्वीकृत किया है और इसके अनुसंधान प्रकाशनों की बड़ी संख्या व गुणवत्ता की प्रशंसा की है ।

सुरक्षा एवं प्रत्यक्ष संरक्षा

हमारे केन्द्र तथा इसकी विभिन्न संस्थापनाओं की प्रत्यक्ष संरक्षा अत्यंत महत्वपूर्ण है । भापअ केंद्र के सुरक्षा एवं सीआईएसएफ के कार्मिकगण हमारी स्थापना को प्रत्यक्ष सुरक्षा उपलब्ध कराने में सराहनीय कार्य करते रहे हैं। मैं, भापअ केंद्र के अग्निशमन कर्मचारियों की प्रशंसा करता हूँ कि वे हमारे केंद्र की विभिन्न स्थापनाओं की सतत निगरानी करते हैं । मैं अपने केन्द्र के सभी अधिकारियों और कर्मचारियों की भी सराहना करता हूँ कि वे सुरक्षा कर्मियों को उच्चस्तर की सुरक्षा प्रणालियों के प्रभावशाली कार्यान्वियन संबंधी कार्यों में अपना सहयोग प्रदान करते हैं। अंततः, मैं अपने सभी साथियों से आग्रह करता हूँ कि वे वर्तमान परिस्थितियों में सदैव सावधान एवं सतर्क रहें ।

भूदृश्य एवं स्वच्छता अनुरक्षण

हमारे भूदृश्य एवं स्वच्छता अनुभाग वे कार्मिकों का योगदान की स्पष्ट झलक इस परिसर वे सुंदर परिवेश में दिखाई देती है। आपने अवश्य ध्यान दिया होगा कि कंप्यूटर केन्द्र और ध्रुवा के मध्य स्थित कैना गार्डन का पुनःअभिकल्पन व विकास किया गया है। इसमें शाहबाद पत्थरों से बने घास-युक्त जोड़ों वाले मार्ग, लॉन, सुनहरी दूरान्त बाड़ जिसके चारों ओर विधिवत फूलों की क्यारियाँ हैं और मार्गों के किनारे गार्डन लाइटें लगाई गई हैं। ट्रांबे परिसर के अलावा नए प्रशिक्षण विद्यालय, अणुशक्तिनगर के आसपास के परिवेश को भव्य रूप से सुशोभित किया गया है। इसके अतिरिक्त, गुलाब और गरबेरा के पूलों को नियंत्रित वातावरण में उगाने के लिए दो परागघर स्थापित किए गए हैं और उपलब्ध खुले हुए स्थानों में ट्रांबे पहाडियों पर पेड़ लगाए जाते रहे हैं ताकि वार्षिक कार्यक्रम के अनुसार भूमि संरक्षण एवं पर्यावरणीय प्रदूषण घटाने में सहायता मिल सके।

प्रशासन एवं लेखा

इसके अतिरिक्त मैं अपने उन सहकर्मियों की प्रशंसा करता हूँ जो प्रशासनिक एवं लेखा संबंधी कार्यों को करते हुए बड़ी निपुणता और प्रवीणता के साथ इस केंद्र के विभिन्न कार्यक्रमों में सहयोग कर रहे हैं।

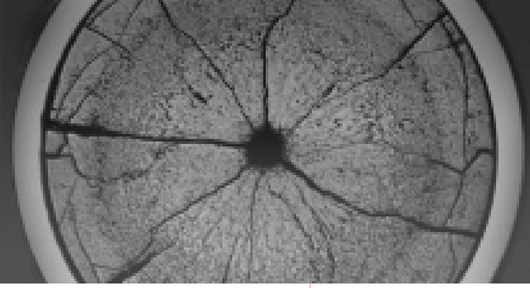
निष्कर्ष

प्रिय साथियो,

यहाँ मैंने वर्ष के दौरान किए गए कार्यकलापों की संक्षिप्त झलक ही प्रस्तुत की है । मुझे पता है कि समय की कमी के कारण बहुत सी बातों की चर्चा मैं नहीं कर पाया हूँ इसका अर्थ यह नहीं कि वे कम महत्वपूर्ण हैं । मेरे प्रिय साथियों ट्रांबे की ये पहाड़ियां गवाह हैं कि पिछले पांच दशकों के दौरान इस केंद्र ने कितनी प्रगति की है । हमने इस प्रगति के विभिन्न पड़ाव पूरे किए हैं । बढ़ते हुए अन्तर्राष्ट्रीय सहयोग के परिदृश्य में, आज वैश्विक चुनौतियों का सामना करने के लिए हमें अपनी कुछ नीतियों में परिवर्तन करना होगा और भारतीय नाभिकीय कार्यक्रम से संबंधित क्षेत्रों में अपनी श्रेष्ठता बरकरार रखते हुए इसे और ऊँचाई पर ले जाना होगा। मुझे विश्वास है कि भापअ केंद्र में हम सब -- वैज्ञानिकों, तकनीकीविदों एवं प्रशासकों के सम्मिलित सहयोग से देशवासियों की सभी आशाओं को पूरा कर सकेंगे और भा.प.अ. केंद्र की परम्परा के अनुसार भविष्य की चुनौतियों का सामना कर सकेंगे ।

मित्रों, अंत में इस अत्यंत शुभ दिन के अवसर पर आइए, हम यह दृढ़ संकल्प करें कि अपने लोगों के कल्याण के लिए हम नाभिकीय विज्ञान एवं प्रौद्योगिकी के अग्रणी क्षेत्रों में उत्कृष्टता को बनाए रखने हेतु पूर्ण समर्पण की भावना से कार्य करेंगे ।

- जय हिन्द -"



63rd Anniversary of the Independence Day

Dr. R.K. Sinha,
Director, BARC

"Dear colleagues,

Let me first extend my greetings to you all, on the occasion of the 63rd anniversary of the independence day of our country. This morning, we have assembled here not only to take a collective pledge to preserve the honour and dignity of our national flag and pay our homage to those who have made supreme sacrifices for the sake of freedom of our country. We also salute the members of our armed forces, who provide the security of our country.

We take this opportunity to take stock of what we have achieved in the recent past. Our mandate is very clear. Our work towards the growth of nuclear energy for power production and non-power applications should lead to improving the quality of life of our people, and we remain dedicated towards enhancement of national security and keeping our country in the forefront of nuclear science and technology. Let me cite a few examples to illustrate some of the notable development work carried out and achievements made recently.

Research Reactors

As you all know, we have achieved two very important milestones this year, namely, completion of 50 years of successful operation of CIRUS research reactor on July 10 this year and completion of 25 years of successful operation of DHRUVA reactor, very recently i.e. on August 8 this year.

CIRUS reactor was operated with its availability factor at 80.6 %. More than 650 samples were irradiated during the year. The neutron radiography setup of Apsara for imaging small size material coupons was shifted to CIRUS and commissioned successfully.

Research reactor DHRUVA, was operated with an availability factor of more than 79 %. Besides irradiation of more than 805 samples, DHRUVA continued to serve as a national facility for neutron beam research.

With its service life of 25 years, upgradation, refurbishment and replacement of several equipment and components has been carried out recently. These include electrical equipment and switch gears, instrumentation and control panels in the main control room, secondary heat exchange equipment, spent fuel storage bay water purification system, control and instrumentation related to reactor trip logic system, coolant flow monitoring system, emergency core cooling system and alarm annunciation system.

After 52 years of excellent service, APSARA was shut down in June last year for upgradation. The High Enriched Uranium fuel of the reactor will be replaced by Low Enriched Uranium fuel in line with the current international norms and the maximum thermal neutron flux will be enhanced to 6.5 x 10^{13} neutrons/ cm^2/sec after the upgradation. Several activities pertaining to partial decommissioning of the reactor were successfully and safely handled during the year. As a result, removal and storage of fuel assemblies in a separate water pool, dismantling of the reactor core, electrical system equipment and nuclear and control instrumentations, decommissioning of primary and secondary coolant systems, etc. have been completed. The upgraded reactor will provide enhanced facilities for beam tube research, radio-isotope production, calibration & testing of neutron detectors, material testing and bulk shielding experiments.

The conceptual design of a High Flux Research Reactor (HFRR) has been completed. HFRR is designed primarily to meet the large requirements of high specific activity radio-isotopes and to provide enhanced facilities for basic research in frontier areas of science and for applied research related to development and testing of nuclear fuel and reactor materials.

AHWR programme

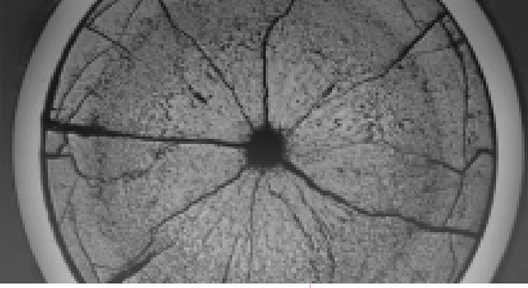
Critical Facility for Advanced Heavy Water Reactor (AHWR) and future PHWR's was operated on 83 occasions for conducting various experiments. Using the AHWR Critical Facility, fine structure flux measurement in the natural uranium experimental cluster of the reference core was carried out. With this, all the experiments planned for reference core have been completed.

A mixed pin cluster consisting of 7 ThO_2 pins and 12 Natural Uranium pins was loaded in central location of the AHWR Critical Facility.

A major AHWR Test Facility is being setup by BARC, jointly with NPCIL at R&D Centre, Tarapur. All major components of the facility are in an advanced stage of fabrication. The prototype fueling machine required for this facility has already been manufactured and delivered. The civil construction of building required for this facility is in progress.

A prototype 'Poison Injection Passive Valve' to be used in Passive Poison Injection System (PPIS) of AHWR has been designed, developed and tested successfully under simulated conditions. This valve facilitate passive shutdown of the reactor in the event of failure of wired shutdown systems. This is the third passive valve developed for various safety systems of AHWR proving the technological maturity in the area of passive valve design and development.

A scaled test model and a test facility to study moderator flow distribution and liquid poison injection inside the calandria has been commissioned. The Integral Test Facility has been augmented with an additional 3MW instrumented fuel rod cluster simulator developed in-house. The augmented facility will also enable validation of new techniques for channel power measurement and instability detection.



High Temperature Reactor Programme

After completion of design of all the components of Compact High Temperature Reactor (CHTR), 3D layout showing in-core components as well as other reactor systems has been prepared.

Monte Carlo simulations have been performed to estimate the neutron flux in the core and at detector locations outside the reactor vessel for the purpose of reactor startup and regulation. Design of initial core of High Temperature Reactor (HTR) for high temperature process heat applications, including hydrogen production, has been completed.

Thorium fuel studies

The fuel cycle parameters and economic competitiveness of different cases involving usage of Thorium-Uranium based fuel with recycle of fissile materials in a modern PWR were evaluated and compared with the reference case using enriched uranium fuel with direct disposal option of spent fuel.

Supercritical test facility

Extensive data were generated on instability phenomena with supercritical carbon dioxide in the supercritical test facility. Subsequently, the facility has been modified for operation with supercritical water. The facility has been commissioned and experiments with water at supercritical condition were performed successfully.

PHWR Programme

BARC is responsible for providing R&D support to NPCIL for the PHWR related activities.

As a part of ageing management, BARC engineers participated in Sliver sampling campaign at RAPS-3 pressure tubes.

Man-rem saving tools have been developed to facilitate the remote maintenance of 540 MWe PHWR coolant channels. The two specific tools developed earlier, viz., Channel isolation plug to facilitate closure seal face repair without draining the channel and the Channel flow arrestor assembly to facilitate the feeder ice freezing were handed over to TAPS-3&4 for use.

Technical support was provided to NPCIL in achieving safe retrieval of irradiated fuel bundles from the North fuelling machine head, following an unusual occurrence in the operation of this fuelling machine at TAPS-4.

Nuclear Fuels Programme

BARC supplies Plutonium bearing fuels for the Fast Reactor Programme, including FBTR and PFBR (under construction) at Kalpakkam. The production of Uranium-Plutonium mixed carbide fuel for FBTR is continuing in BARC. One fuel sub-assembly carrying pins made with reprocessed plutonium from FBTR fuel is undergoing irradiation in FBTR. This marks the closing the fuel cycle for FBTR. The PFBR experimental MOX Fuel pins fabricated at AFFF, Tarapur loaded in the centre of FBTR core has now exceeded the design target burn-up of 100,000 MWd/T. The regular production of MOX fuel pins for PFBR has started at A3F and a new fuel pin welding line has been recently commissioned.

BARC has also started work on conceptual design of Integrated Fuel Cycle Facility for AHWR.

As part of the fuel irradiation programme, (ThO_2-1%PuO_2) MOX fuel pins and (Th-1%U235)O_2 pins have been fabricated to be loaded in fuel position of DHRUVA core. The fuel hardware and the pellet geometry will be similar to that for the AHWR fuel.

Post Irradiation examination of (ThO_2-4%PuO_2) fuel pins irradiated upto 21,000 MWd/T burn-up in AC-6 cluster in CIRUS has been completed. The PIE has confirmed excellent behaviour of (Th-Pu) MOX fuel with negligible micro-structural changes and much lower fission gas release compared to similar U based fuels. Two of the fuel pins will be taken up for re-irradiation for extended burn up.

MOX microspheres containing 53% of PuO_2 in uranium oxide have been successfully prepared using internal gelation sol-gel process. These microspheres will be used for test pin irradiation in FBTR at IGCAR.

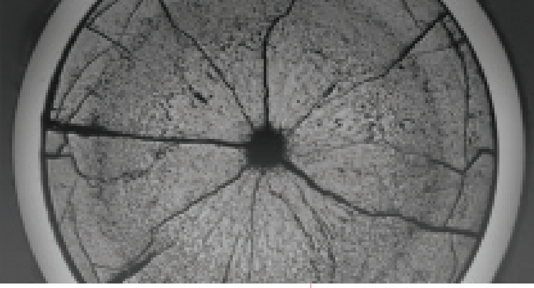
Superconductor Programme

BARC has initiated development and fabrication of cable in conduit conductor for various configurations for Nb_3-Sn based superconducting magnets required for fusion research work at IPR. The flow sheet for this advanced superconductor fabrication has now been developed and trials are in progress.

Nuclear Recycle Board (NRB)

NRB was formed last year in September 2009 to undertake an expansion programme for reprocessing of spent fuel from nuclear power reactors and develop nuclear waste management facilities in the country.

Activities of projects such as; Revamping Of PREFRE (ROP), Additional Waste Tank Farm (AWTF), Integrated Nuclear Recycle Plant (INRP), Waste Management Facilities (WMF), Spent Fuel Storage Facility (SFSF), all located at Tarapur have been brought under NRB. Similarly, the projects P3A (3rd reprocessing plant) and Waste Immobilisation Plant (WIP), located at Kalpakkam are also brought under NRB and are progressing well.



Fuel Reprocessing and Waste Management activities

The KARP facility at Kalpakkam continued to operate smoothly to process spent fuel from MAPS. At CWMF, Kalpakkam, operation of a pilot facility for melt densification of plastic / polythene waste, was continued to generate engineering scale data.

The Plutonium Plant at Trombay continued to operate. The waste generated earlier during thoria fuel reprocessing has been processed to recover thorium in the Uranium Thorium Separation Facility (UTSF).

At WIP, Trombay, modification jobs for installation of new processing cycles such as sulphate separation, acid recovery and evaporator systems are now nearing completion.

As a part of R&D efforts in the area of waste management, a process based on ozonation has been successfully demonstrated for the treatment of intermediate level aqueous liquid waste containing large amounts of dissolved organics.

A pilot plant is in continuous operation for biodegradation of nitrates upto 1000 ppm in radioactive liquid effluents. The laboratory studies have established that the biodegradation process can be effective for nitrate concentration upto about 25000 ppm.

A full scale engineering loop based on molybdo-phophate was setup and operated successfully for recovery of cesium using simulated waste.

Vitrification technology employing Cold Crucible Induction Melter has crossed another milestone by successful completion of simulated waste feed experiments.

Useful isotopes such as ^{90}Y and ^{106}Ru present in radioactive waste are being recovered regularly for use in Radio Pharmaceuticals Division.

Materials & Metallurgy

Production of beryllium and beryllia from the refurbished plant of PMD at Vashi has commenced and the required number of special beryllium shapes have been fabricated and handed over to specific users. Preparation of ceramic for neutron multiplication and tritium generation comprising beryllia and lithium titanate has been accomplished for the first time for potential use in breeders of future fusion reactor.

Towards increasing the life of pressure tubes in advanced reactors, fabrication parameters of Zr-2.5Nb alloy pressure tubes with eight different routes have been studied at NFC with inputs from BARC. Also, lab scale processing and characterisation have been carried out in terms of microstructure and tensile properties of the heat-treated Zr-2.5Nb alloy. These studies helped to establish the process parameters for fabricating heat treated pressure tubes for AHWR.

The technology for preparation of Ni-Ti alloys and heat shrinkable ferrules for the Light Combat Aircraft is being transferred by BARC to HAL, Bangalore, under a tripartite MoU.

Automation & Remote Handling

Under an agreement between IAEA, Govt. of India and Govt. of Vietnam, BARC has supplied, installed and commissioned one Bhabhatron-II at Can Tho Oncology Hospital in Vietnam. The machine was inaugurated on the 28th April, 2010.

BARC has completed the development of the first indigenous Radiotherapy Simulator. The system is installed at the Indian Red Cross Society Hospital, Nellore, AP. It is expected that this development will make sophisticated simulator available at reduced cost resulting in diagnostic facilities becoming affordable to larger population.

Hexapod, with six degrees of freedom a versatile mechanical support for a wide range of applications has been developed at BARC. This will find its use in the precision positioning and orientation of optical elements in a synchrotron radiation beam line. The hexapod is capable of supporting and aligning a 1000 mm long mirror placed in a vacuum chamber weighing about 1000 kg. The designed accuracies of positioning within 10 microns and orientation within 10 arc sec have been obtained.

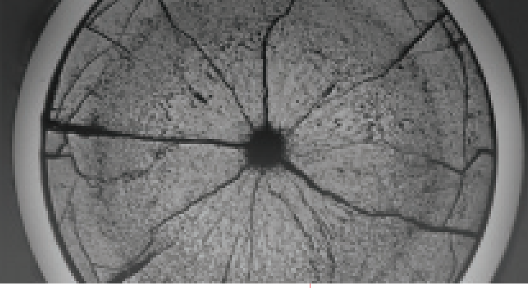
Electronics & Instrumentation

Centre for Microelectronics (CMEMS) at Prabhadevi was inaugurated on April 2, 2010. CMEMS is a VLSI R&D facility for design, development, modeling, testing and packaging of ASICs, HMCs, sensors and detectors.

A seismic data center has been setup in BARC for round the clock monitoring of seismic events. Several in-house application software have been developed for real time signal detection and for identification and notification of seismic event location. Systems have been developed to link event information obtained from tide gauge data with seismic information for identification of tsunamigenic earthquakes.

A standard 32 bit C&I platform called TPLC-32 (Trombay Programmable Logic Controller) has been developed for nuclear safety and safety related applications. Using this common platform, prototype of 4 systems; viz. Reactor Trip Logic System, Emergency Core Cooling System, Start UP Logic System and Alarm Annunciation System for DHRUVA has been developed. Under Phase-2 of this program, additional features will be added to TPLC-32 to deploy it, for the development of entire Distributed Control System of AHWR.

A system was developed and deployed to detect movement of radioactive materials and activate appropriate CCTV cameras for scrutiny by security personnel. As part of the ongoing process of providing the requisite level of security for BARC, integrated physical protection systems were deployed in some of the vital areas in the campus.



A prototype of a unique and compact Hand Scan Biometric System (HSBS) has been developed. It can be interfaced to an RFID card reader and can operate in a stand-alone mode or also in a remote manner for verification of personnel across the network.

The technology of Non-Invasive Blood Pressure monitor, developed at Electronics Division, BARC was transferred to a third private manufacturing concern recently.

Beam Technology Developments

Two electron beam welding machines, one of 100 kV, 4 kW rating and the other of 80 kV, 12 kW rating have been installed at a private industry in Nashik and at IIT Kharagpur respectively. The facility at IIT Kharagpur is intended to be used for studies related to EB welding of metals and super alloys and demonstration of sample product welding of components of interest to DAE.

A novel iridium based Langmuir probe collector assembly for charge density measurements in high temperature environment has been developed. The probe was successfully tested in a high enthalpy plasma plume (7000K) at VSSC Trivandrum to test its suitability for deployment in space missions for test of the Reentry Vehicles.

The Hall-6 electron beam evaporator with AC EB guns was run in campaign mode for 80 and 160 hours respectively, for long duration qualification of control system, gun and other accessory subsystems. A maximum of about 150 kW power and 100 minutes of tripless operation was achieved during this campaign.

The laser assisted decontamination system developed by BARC was tested for cleaning the PFBR fuel pins at Advanced Fuel Fabrication Facility (AFFF). Experiments carried out with UO_2 and $Pu0_2$ contamination at laser wave lengths of 1064 nm and 532 nm resulted in residual activity well below the acceptable levels. This is now being integrated with the AFFF Fuel fabrication line.

The 10 MeV / 10 kW RF Linac at Electron Beam Centre, Kharghar, was continuously operated at 3kW beam power for 24 hours to verify its stable and safe operation. The 3 MeV DC Electron Accelerator has been operated at 1.1 MeV beam energy and 1 kW beam power.

Physical Science

The TACTIC gamma ray telescope at Mt. Abu detected flaring gamma ray activity at Tera Electron Volt (TEV) energies from the Active Galactic Nuclei Mrk 421 early this year. On the 17^{th} of Feb, 2010 the telescope observed a high flux of more than 50 gamma rays/h from the object. This is considered to be a significant event.

A novel time of flight Secondary Ion Mass Spectrometer (TOF–SIMS) has been developed and commissioned for the first time in BARC. The set up is being utilised to perform chemical imaging of sample surfaces with sub-micron (300 nanometer) resolution and very high mass resolution (greater than 10,000).

Single crystals of Lithium Heptaborate (Li2B4O7) have been grown for dosimetric applications. Lithium borate (LBO) crystals doped with Cu showed excellent sensitivity to gamma radiation over a large range from micro Gy to 100 Gy.

Three dimensional atomic level structure of an enzyme useful for bio-precipitation of Uranium under alkaline conditions has been determined.

Chemical science

A unique national Biofouling Test Loop Facility has been constructed at Kalpakkam to study biofouling and biocorrosion problems related to cooling water systems in power reactors, with a new and improved seawater intake system. The generated data will be useful for biofouling control in titanium heat exchangers such as those used in PFBR.

A MPCVD (microwave-plasma chemical vapor deposition) system has been set up for the preparation of high quality thin diamond films on Si(111) substrate. Stress-free diamond films of ~ 20 μm thickness and 1x1cm have been deposited under different hydrogen –methane ratio and gas pressures.

For the first time, ultra-pure gallium, arsenic, Ge and CsI have been supplied to prospective users in DAE, research institutes, universities and semiconductor industries.

Studies on catalytic decomposition of sulfuric acid over iron oxide based materials were carried out in the temperature range of 600-825^{0}C employing an indigenously developed glass setup. These studies are a part of the ongoing research activities for production of hydrogen using high temperature chemico-thermal process.

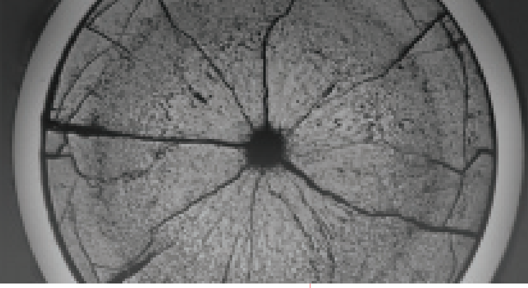
A harmonised procedure for large sample characterisation using neutron activation analysis and application in forensic studies, has been developed and validated for analysis of various sizes and shapes.

Radiochemistry & Isotope

A kit for preparation of Tc-99m labeled Trodat, for diagnostic evaluation of patients suffering from Parkinsonism, has been successfully prepared and demonstrated for its utility in collaboration with the Jaslok Hospital & Research centre. Imaging of dopamine receptors will be a very useful tool for monitoring the progress of the patient under treatment. This product is expected to have good demand.

Radioactive sources containing Fe-55 were specially prepared and supplied to ISRO, at their request. These sources will be used to check the Scanning Sky Monitor detectors present in the satellite ASTROSAT, to be launched soon by ISRO. These indigenous sources are deemed by ISRO to be better than even imported sources and have resulted in significant saving in foreign exchange.

As a part of radiotracer applications, experiments using radiotracer Sc-46 were performed in Kolkata port and Visakhapatanam Harbour to examine the sediment transport behaviour and to find out dumping sites



Chemical Engineering & Technology

An international patent for "Chemo-Mechanical Magneto–Rheological Finishing" (CMMRF) technique developed for nano finishing process for silicon substrate in collaboration with IIT, Kanpur has been filed.

After successful commissioning of Multi-Stage Flash (MSF) Section of Nuclear Desalination Demonstration Plant (NDDP) Kalpakkam, production rate has been gradually increased to 75% design capacity. Distilled quality product water with total dissolved solids (TDS) upto 5 ppm has been achieved. Along with MSF plant, the Sea Water Reverse Osmosis (SWRO) plant has been in operation on round-the-clock basis.

Poly-sulphone membrane of (1000x1000) mm size, as import substitute, has been developed in-house. The use of this membrane for conversion of uranyl nitrate to uranous nitrate in electrolytic membrane cell of PREFRE on trial basis has yielded encouraging results.

Municipal Corporation of Greater Mumbai (MCGM) has signed a Memorandum of Understanding (MOU) with BARC seeking our technical guidance in setting up 100 Million Litres per Day (MLD) seawater desalination plant. BARC has agreed to offer technical expertise and advice to MCGM on technical aspects.

A micro cryo-cooler for Infrared Sensor based Thermal Imagers (Night Vision Device) has been developed for Surveillance purposes by the Indian Army. The Cryo-cooler was successfully integrated with Night Vision Device at EME School Vadodara to demonstrate the functioning.

A pilot scale fluidised bed thermal de-nitration plant of 30 LPH capacity has been set up for development of thermal de-nitration process for different nitrate streams of nuclear fuel cycle including Uranyl Nitrate. Earlier, fluidized bed thermal de-nitration process for Ammonium Di-Uranate filtrate was developed on bench scale of 5 LPH capacity. This pilot scale facility together with the bench scale plant will enable study of de-nitration process on two scales, which is essential for generation of engineering data for design of plants for production purpose.

Nuclear Agriculture & Food Technology

In the field of Agriculture, two new Trombay crop varieties have been released and notified by the Ministry of Agriculture, Govt. Of India. The first one is TM-2000-2 (PAIRY MUNG), a high yielding, early maturing, disease resistant variety suitable for Rabi and Utera (RICE FALLOW) cultivation conditions. The second one is TJT 501 (TROMBAY JAWAHAR TUR) with early maturity and tolerance to insects. With these, the total number of Trombay Crop varieties released and notified by Ministry of Agriculture, Govt. Of India for commercial cultivation has reached thirty nine.

Two patents are granted for biofertiliser formulations : one for Zinc fertilizer formulation and another for Phosphorus fertilizer formulation using bio-sludge from molasses based distilleries.

Biodegradable films with superior properties were prepared using chitosan and guar gum composite for packaging food. Protocols for quarantine treatment and shelf-life extension of litchi were developed. Polyphenoloxidase, the browning enzyme, from brinjal was cloned and characterized.

Technology Transfer

Ten different technologies have been transferred to twenty different parties during the last one year period. The technologies range from water treatment and purification technologies such as those for removal of Arsenic/fluorine from drinking water to those in the field of medical instrumentation, such as hand held tele-ECG units and image analysis system.

Homi Bhabha National Institute

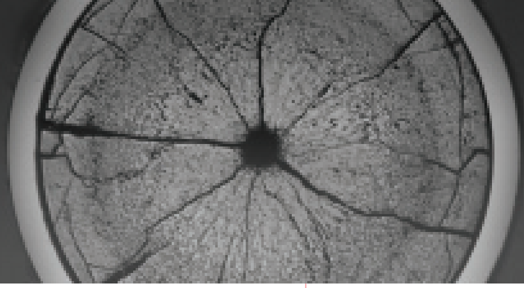
The Homi Bhabha National Institute set up as a Deemed to be University has started making visible contribution to spreading academic culture in BARC. It is a matter of pride that the expert Committee set up by the University Grants Commission under the Chairmanship of Prof. Jayant Narlikar to review the functioning of HBNI has acknowledged the unique character of HBNI and praised it for the high number and quality of its research publications.

Security, Physical Protection and Fire Services

Physical protection of our Centre and its various installations is of paramount importance. BARC security and CISF personnel have been performing a commendable task of providing the physical protection of our establishment. I would like to appreciate the BARC Fire Service personnel for maintaining a constant vigil on the various establishments of our centre. I also compliment all officers and staff of our centre for extending their cooperation with the security personnel in discharging their duties effectively for implementing the higher level of security procedures. Finally, I urge all my colleagues in our centre to remain vigilant and alert in the present environment.

Landscape & Cosmetic Maintenance

The contribution made by the personnel of our Landscape & Cosmetic Maintenance Section is aptly demonstrated by the beautiful ambience of this venue. You must have noticed that the Canna garden located between Computer Centre & Dhruva has been redesigned and developed by adding paths made of Shahabad stones with grassy joints, lawn turf, golden duranta hedges around formal flower beds (parterres) and garden lights alongside the paths. Besides the Trombay campus, even the surroundings of new New Training School, Anushaktinagar has been beautifully landscaped for providing excellent ambience. In addition, two polyhouses have been installed for growing cut flowers of roses and gerbera in controlled environment and tree plantation on Trombay Hills at available open spaces continued to be carried out as an yearly programme helping in soil conservation and in mitigating environmental pollution.



Administration and Accounts

I further compliment my colleagues discharging administrative and accounts functions for very effectively and efficiently supporting the various programmes of our Centre.

Conclusion

Dear Colleagues, For a Centre of more than 15,000 people, it is impossible to provide even a fraction of our recent work, in the given time. I have attempted to give here only an indicative glimpse of our activities during the year. Due to constraint of time, I could not cover many more which are by no means less important. My dear colleagues, these Trombay hills have been witness to the growth of this Centre during last five decades. We have gone through several phases of this growth. Today, in the scenario of emerging international co-operation, we need to redefine some of the strategies to deliver globally competitive outputs to retain and further develop our superiority in the areas considered relevant for the Indian nuclear programme. With the synergistic effort of all of us in BARC – scientists, technicians and administrators, I am sure, we will be able to meet the expectations of all our countrymen and rise to the occasion to meet the future challenges in a manner consistent with the tradition of BARC.

Friends, finally on this very special day, let us firmly resolve and rededicate ourselves to continue our pursuit of excellence in the frontier areas of nuclear science and technology for the betterment of life of our people.

- Jai Hind -"

RESEARCH ARTICLE

Impact of Fluorodeoxyglucose-Positron Emission Tomography (FDG-PET) in the Management of Patients with Cancer and other Serious Disorders: A Clinical Case Based Approach

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Abstract

In this pictorial review, the impact of FDG-PET is illustrated with specific clinical case examples that would demonstrate the power and promise of this molecular imaging technique in managing a wide variety of disorders. The case vignettes depicted in this communication represent the ones where this modality can be utilized in the routine clinical scenario and can prove substantially beneficial to the patients of cancer and other serious disorders. Related discussions are drawn along with individual cases to enable the readers understand the further prospects of PET that are being explored at the present.

Keywords: FDG-PET, PET-CT, Oncology, Cancer, Infection, Cardiology, Neurology, Evidence Based Medicine, Personalized Medicine, Molecular Imaging.

Introduction

The specialty of Nuclear Medicine is a dynamic branch of Medicine that deals with the use of unsealed radiopharmaceuticals for the diagnosis and therapy of cancer and a wide array of disorders involving cardiology, orthopedics, neurology and psychiatry disciplines. Diagnostic imaging with conventional nuclear medicine provides a great deal of critical information in diseases involving the aforementioned systems while therapeutic nuclear medicine is of great benefit to the patients suffering from thyroid diseases (esp. thyrotoxicosis and thyroid cancer), neuroendocrine tumors, painful skeletal metastases, joint disorders and lymphomas. The recent addition of positron emission tomography (PET) to its armamentarium has added a new dimension that is being employed in the day-to-day clinical practice in the appropriate settings in cancer and other serious disorders.

A relatively new and evolving concept in the clinical domain is individualizing treatment based upon PET and PET-CT results that significantly improves patient management. The success of this new concept significantly depends upon the success of development in the field of molecular imaging, with functional imaging with current and future novel PET tracers and this is likely further enhance the scientific basis of medical practice [1, 2].

A. Staging of Cancer

FDG [Fluorodeoxyglucose (^{18}F)]-PET (Fig. 1) plays a crucial role in the staging of wide variety of malignancies (both initial staging and restaging in the subsequent course) including lymphoma, lung carcinoma, esophageal carcinoma and so on.

Case 1 A 65 year old female, known patient of Diffuse large B cell lymphoma.(Fig. 2)

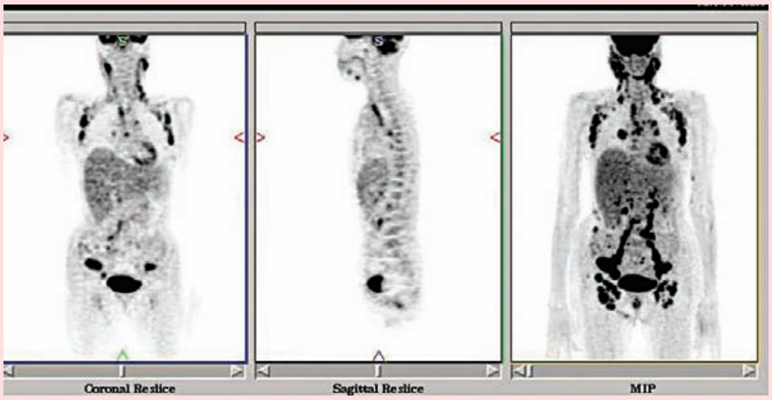


Fig. 1: FDG-PET demonstrates extensive disease involving bilateral neck nodes, axillary and mediastinal nodes, paraaortic and iliac nodes in the abdomen and inguinal nodes.

Case 2. A recently diagnosed patient of primitive neuroectodermal tumor (PNET) of right proximal tumor who was referred for disease evaluation. Patient did not receive any treatment at the time of FDG-PET imaging. (Fig. 2)

Fig. 2: In this known patient of PNET, there is intense FDG uptake at the site of primary with central photopenia suggesting necrosis within the tumor. Also note the FDG uptake in the bone marrow of vertebrae, pelvis and upper limbs bilaterally and proximal left femur suggesting bone marrow metastasis.

Learning Point

I. Introduction of FDG-PET has completely replaced CT for staging patients of lymphoma and provides two discrete advantages:

1. FDG-PET provides whole body status in a single examination.
2. A baseline scan forms the basis of evaluation of further treatment response.

II. Metastasis to the skeleton starts at the red bone marrow and FDG-PET is superior to bone scan in this respect as it detects metastasis at the level of bone marrow. The result of FDG-PET rivals MRI in this respect.

B. Early Response Assessment in Patients of Cancer by FDG-PET

Case 3 and Fig. 3 FDG-PET images at diagnosis (left panel: A) and following 3 cycles of chemotherapy (right panel: B) in a 30 year old male, a known patient of Diffuse large B cell Lymphoma demonstrating avid FDG uptake in the chest and abdomen that shows near total resolution after 3 cycles of chemotherapy.

Learning Point

Early identification of non responders to primary chemotherapy by FDG-PET imaging following 2-3 cycles of chemotherapy is a major advance in the management of lymphoma since the non-responding patients can be moved into the salvage schedules utilizing aggressive strategies earlier without administering ineffective chemotherapy that is not only expensive but also toxic and result in significant morbidity without benefit.

Case 4. A 45-year-old man presented with a 12X 10-cm sized mass (with central necrosis) abutting the body and tail of pancreas and left kidney (but intervening fat plane was maintained) on baseline CT scan. The mass extended from the level of pancreatic body up to the level of aortic bifurcation. The baseline FDG-PET (Fig. 4a) showed uptake at the periphery of mass (arrow-marked). The 1-month post-treatment FDG-PET (Fig. 4b) showed disappearance of the FDG uptake from the periphery of the mass indicating a complete metabolic response (CMR). The CT scan at this time showed persistence of the mass (Fig. 4c and d) with contrast enhancement (reprinted with permission[3]).

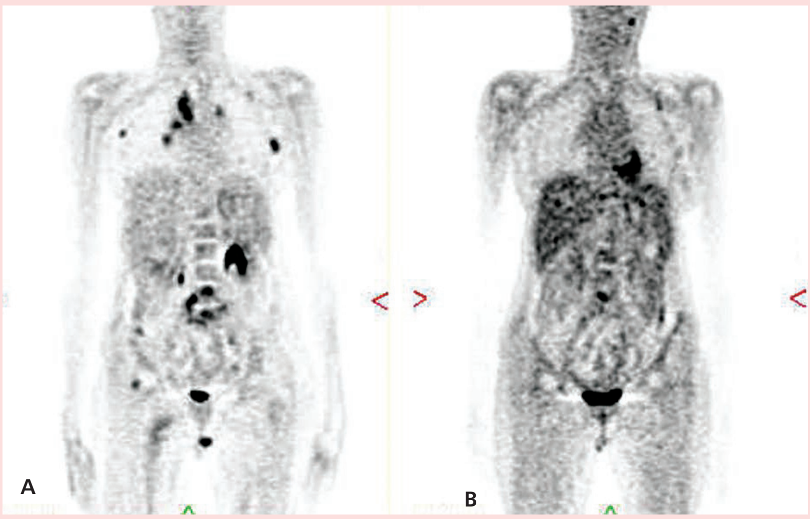
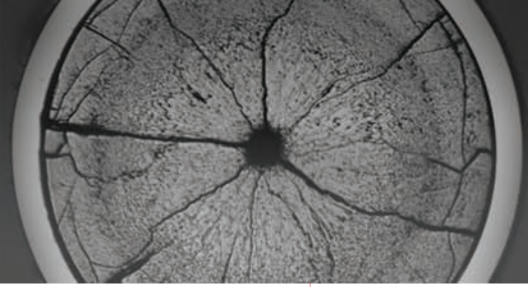


Fig. 3 FDG-PET images at diagnosis (left panel: A)



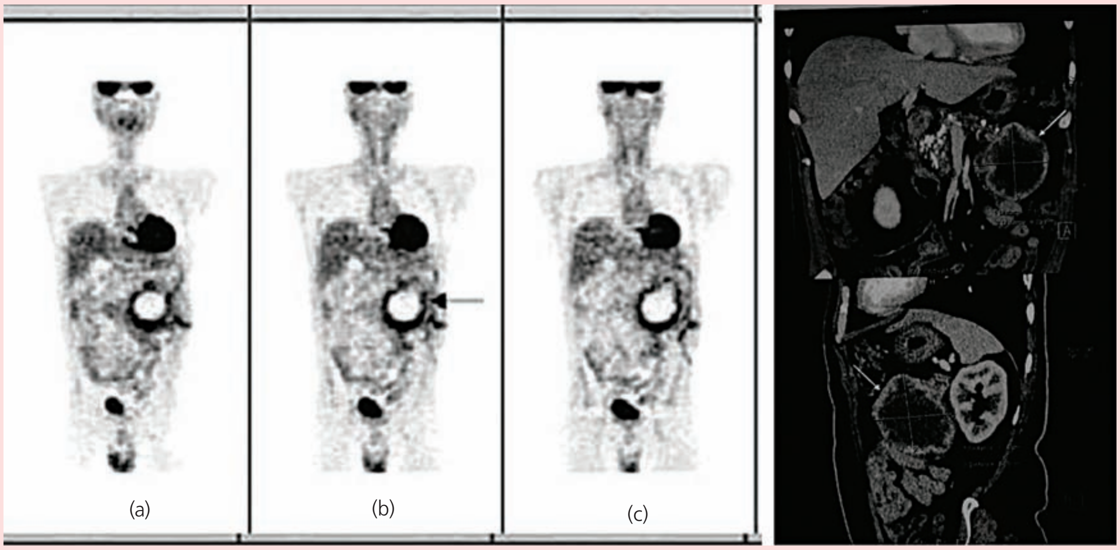


Fig. 4: Baseline FDG-PET: (a) Uptake at the periphery of mass (b) Disappearance of the FDG uptate (c)and (d) Persistence of the mass

Learning Point

The dramatic change in the tumor metabolic activity following successful therapy (chemotherapy, radiotherapy or molecular targeted therapy e.g. in GIST) has made FDG-PET the modality of choice for monitoring therapeutic response in several malignancies and revolutionalized the management by reliably segregating responding patients from non responders where alternative therapies can be employed at the very outset.

C. Assessment of Disease Viability and Differentiating them from Post-Treatment Fibrosis

Case 5 (Fig. 5) A 65 yr old male, diagnosed patient of *sacral chordoma* (Tumour involving S3-5 and coccyx), post surgery and radiotherapy. CT and MRI were inconclusive on the nature of soft tissue residue at the site of primary tumor for differentiating post radiotherapy fibrosis and viable active disease. The patient had complaints of low backache just right to the midline.

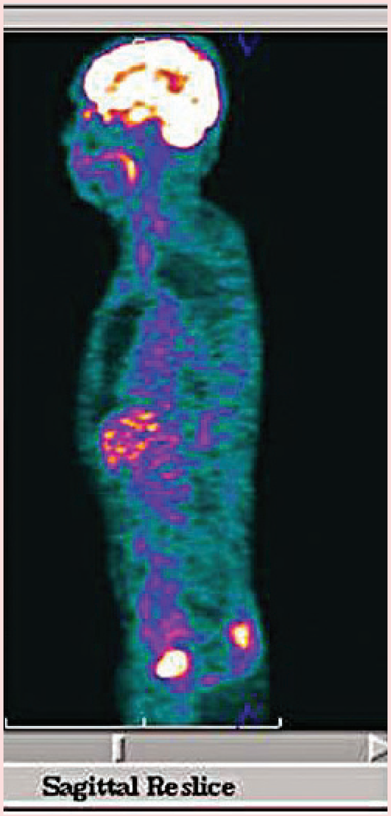


Fig. 5: FDG-PET showing intense focal uptake in the region of the sacrum suggesting persistent active disease at the site of primary.

Case 6 and Fig 6. In this known patient of second primary malignancy of brain there was query with regard to the viability of the disease. MRI was inconclusive. FDG-PET demonstrated intense focal uptake at the mentioned site suggesting persistent active disease.

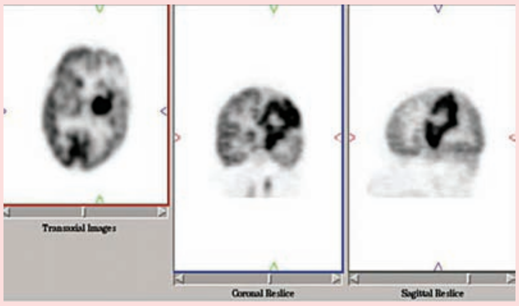


Fig. 6: FDG-PET demonstrating primary malignancy

Learning Point

Differentiating viable disease following treatment from viable active disease is a challenge to the attending physicians. This problem particularly pertains to patients in whom a remnant of what was originally a large mass is still visible on CT or MR. It is in this setting of the "residual mass", that to date PET has been shown to have the greatest utility.

D. Patients of thyroid Cancer with raised tumor marker and normal radioiodine scan

Case 7 and Fig 7. A 23 year old female, a diagnosed patient of Papillary Carcinoma Thyroid, who recently demonstrated serum thyroglobulin (Tg) level (tumor marker of thyroid carcinoma) of 414ng/ml, ^{131}I whole body scan was normal. FDG-PET demonstrated multiple diseased nodes in lower neck that helped determining the sites of disease and the reason for raised Tg in this patient. These were confirmed after excision.

Learning Point

In our preliminary experience, this group of surgically amenable disease is around 25% of patients. In these patients this modality makes an impact in patient management.

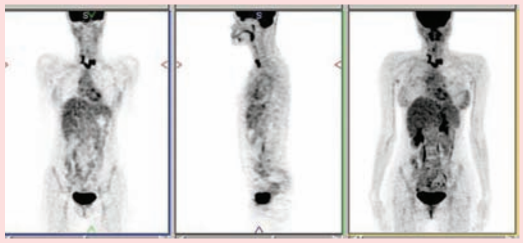


Fig. 7: Multiple diseased nodes

E. Patients of Colorectal carcinoma with raised tumor marker levels

Case 8 and Fig 8. In this patient of colorectal carcinoma, FDG PET was done for rising carcinoembryonic antigen (CEA) levels (tumor marker of colorectal malignancy). The FDG-PET 3D MIP image shows extensive metastasis in right

Fig. 8: FDG-PET showing extensive metastasis

scapula, spine, pelvis and an inguinal node suggesting timorous involvement at those sites.

Learning Point

FDG-PET is a highly sensitive modality and is used routinely in clinical parlance in patients of colorectal and ovarian malignancy with rising tumor marker levels for doing whole body survey.

F. Perfusion-Metabolism Mismatch in Hibernating Myocardium

Case 9 and Fig. 9. A classical example of hibernating myocardium is demonstrated where there is a perfusion defect (left panel: arrow) is noted in a patient who suffered from myocardial infarction. The FDG-PET cardiac study (right panel: arrow) shows hypermetabolism in the same defect region suggesting this to be viable myocardium.

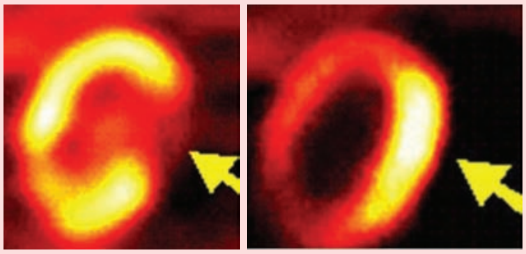


Fig. 9: Hibernating Myocardium

Learning Point

Myocardial hibernation is defined as a state of persistent ventricular myocardial dysfunction at rest (downregulation of contractile function) resulting from reduced myocardial blood flow with preserved viability. Identifying hibernating myocardium is of major interest in the cardiology practice as this represent myocardium that can be salvaged. "Flow-metabolism" mismatch is hallmark of this entity and presently considered as the gold standard for detecting hibernating myocardium.

G. FDG-PET in Dementia

Case 10 and Fig 10. In this patient with memory disturbances and a clinical suspicion of dementia, FDG-PET demonstrates the typical pattern of reduction in glucose metabolism in temporo-parietal cortices with relative preservation of primary visual and sensoriomotor cortices, striatum, and cerebellum which is considered typical for Alzheimer's Disease (AD).

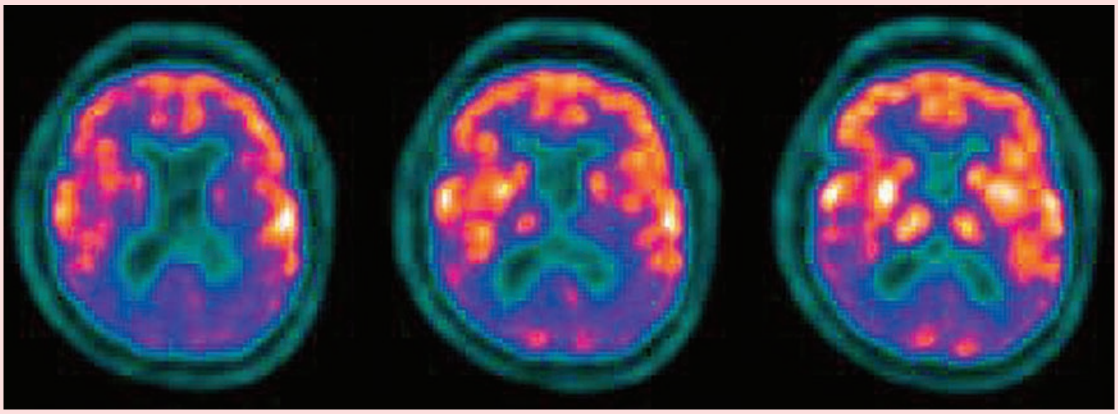


Fig. 10: Reduction in glucose metabolism

Learning Point

FDG-PET is a sensitive and accurate method for an early diagnosis of AD, when combined with traditional medical evaluation.

Other important uses of PET in evaluating Neurological Disorders include the following:

- Detecting Seizure focus in temporal lobe epilepsy: The efficacy of FDG-PET imaging is in localization of the epileptogenic site for surgical excision and potential cure. FDG-PET is very useful in detecting such sites with a sensitivity of 85% to 90% (2).

- Evaluation of movement disorders: Fluorine- 18-6-fluoro-L-DOPA (FDOPA) o r radiopharmaceuticals that bind to the dopamine transporter sites and therefore allow detecting the degree of the loss of the pre-synaptic dopaminergic neurons, has great potential to be routinely employed for the early and accurate diagnosis of Parkinson's disease and other movement disorders. Differentiating among various types of parkinsonian syndromes especially in the early stages is difficult by either clinical or conventional imaging (MRI) assessment, where this modality can be of significant help (2).

H. FDG-PET in Infection and Inflammatory Disorders

Case 11. A 44-year-old man after heart transplant presented with fever of unknown origin and inconclusive radiologic studies, including CT.

Fig 11. Coronal PET images demonstrates a focus of increased FDG activity in the aortopulmonary window and represents the source of infection. The patient completely recovered following drainage of the infected site in the mediastinum (reprinted with permission[4]).

Case 12. A 52-year-old man, who was treated with antitubercular drugs for 1 year without any benefit for an initial diagnosis of tuberculosis, and was referred for further evaluation. A rebiopsy of the inguinal nodes for a definitive diagnosis was confirmatory of sarcoidosis. He had a history of hypothyroidism, which is a frequent accompaniment of sarcoidosis due to the association of autoimmunity in this population.

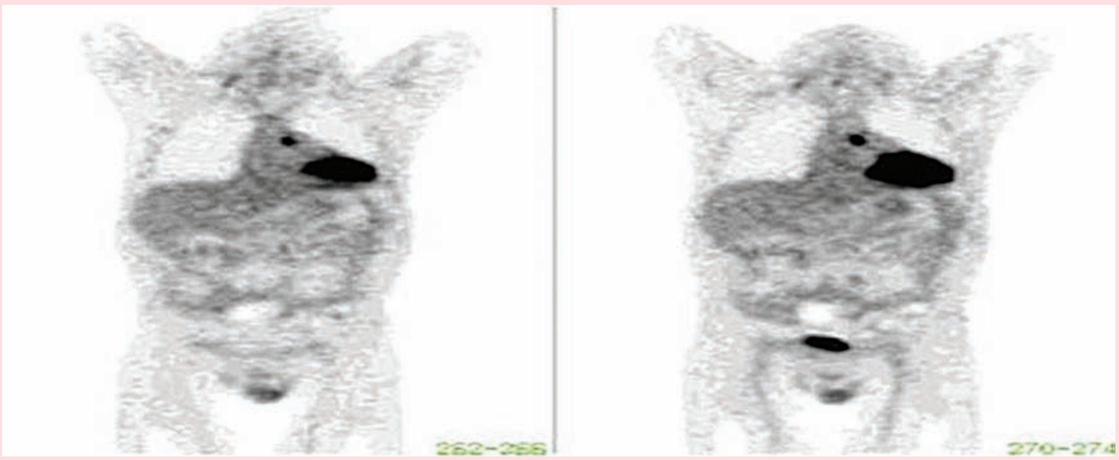


Fig. 11: Coronal PET images demonstrating a focus of increased FDG activity

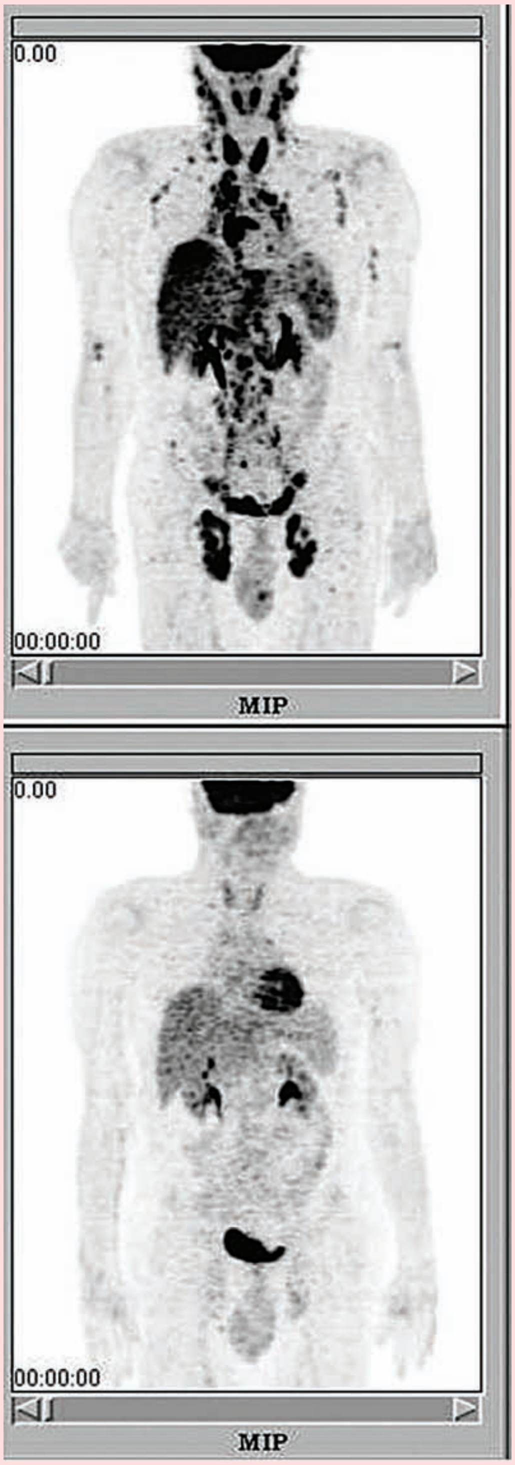


Fig. 12: Baseline FDG-PET study
(Upper panel:at diagnosis;
Lower panel: after treatment)

Fig. 12. Baseline FDG-PET study at diagnosis (upper panel) demonstrates multiple abnormal foci in bilateral neck nodes, mediastinal, axillary, and multiple abdominal (para-aortic and inguinal) nodes, and the liver, spleen, and thyroid. He was treated with oral corticosteroids and was referred for reassessment of his disease status with FDG-PET following 6 weeks of therapy. The post-treatment FDG-PET images (lower panel) showed remarkable improvement with near total resolution of the FDG hypermetabolism at the initially involved sites (reprinted with permission[5]).

Learning Point

The Case 12 underscores the value of FDG-PET imaging in whole-body monitoring of early response to therapy in patients of sarcoidosis (particularly those with extensive disease) that can be of great value in managing these patients.

Conclusion

This brief pictorial review was designed to illustrate to the readers certain specific clinical examples demonstrating the utility and impact of FDG-PET-based molecular imaging in the day-to-day medical practice. The potential prospect of this modality in assessing a variety of benign and malignant disorders for both research and clinical purposes is growing and is limitless. While initially its application was restricted to neurological disorders, oncology soon became the field where it was employed with great success. Detection of infection and inflammation is very fast becoming the second most common clinical application of FDG-PET imaging, furthering its role as an indispensable clinical modality. The 6 infective conditions in which FDG-PET has demonstrated its utility include (1) chronic osteomy elitis, (2) complicated lower-limb prostheses, (3) complicated diabetic foot, (4) fever of unknown origin, (5) acquired immunodeficiency syndrome (ie, AIDS), and (6) vascular graft infection and fistula. Studies have reported success in detecting inflammatory processes in disorders such as regional ileitis, sarcoidosis, rheumatologic disease, and vasculitis. The introduction of novel PET tracers has revolutionized clinical assessment of certain specific tumors e.g. gallium-68 labeled PET tracers (e.g. ^{68}Ga-DOTA-TOC, ^{68}Ga-DOTA-NOC) has added a new dimension to the management of patients with Neuroendocrine tumors. Imaging tumor proliferation with *3'-deoxy-3'-[18F]-Fluorothymidine(FLT)* and tumor hypoxia with [18F]Fluoromisonidazole (FMISO), ^{18}F-fluoroazomycin arabinoside (FAZA) and Cu-60 diacetyl-bis (N(4)-methylthiosemicarbazone [(60)Cu-ATSM)] aids in the understanding the tumor characteristics from different perspectives that can have important implications for targeted therapy based upon tumor biology. Several new PET tracers based upon certain distinct biochemical pathways are in the process of evolution and will likely enhance the role and reliability of this powerful imaging technique in near future.

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Thoron (^{220}Rn) Decay Products Removal in Poorly Ventilated Environments using Unipolar Ionizers: Dosimetric implications

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Abstract

Ionizers are proven to be effective in reducing the activity concentration of radon/thoron decay products in workplace environments. However, limited studies have been conducted specifically to check the efficacy of such systems for thoron rich environments. Further, for radon decay products reduction studies, the activity concentration decrease has been seen connected to an uncontrolled increase of unattached fraction which mainly contributes to the inhalation dose. These studies are however focused mainly on the experimental context and the need for a wide study particularly for thoron decay products seems to be necessary. The present study demonstrates the feasibility of ionizer based removal systems in differing volume and other parameter like ventilation. The chamber and room experiments have shown a concentration reduction factor upto 7 while promising reduction factor upto 4 was obtained for thorium oxalate storage shed having a large volume, source term & uncontrolled ventilation patterns. The change in the unattached fraction has been quantified and linked to the activity concentration reduction and the inhalation dose. A model has been presented to link the change in the size dependent thoron decay products concentration to the inhalation dose. The study proves that for realistically achievable activity reduction ratios of about 3-5 with the employment of ionizers, the inhalation dose in work place environments can be reduced by a factor of atleast 4.

Introduction

Inhalation of thoron (^{220}Rn), radon (^{222}Rn) and their decay products contributes significantly to the occupational radiation exposure in thorium processing and uranium mining industries. In particular, thoron studies attain importance in monazite rich areas found in India, China and Brazil. In the DAE context, they attain greater relevance as the 3-stage Indian nuclear power programme moves towards the use of thorium fuels. In the front end of the nuclear fuel cycle, the storage of thorium bearing powders (e.g. thorium oxalate) causes an economically strategic problem. As the storage area remains mostly idle, the use of a continuous full-time ventilation system is not economical. The workers use the area only for a short-time but the vulnerability to the inhalation dose delivered by the particulate decay products could still be high. While the use of active elements such as scrubbers, filters, electrostatic precipitators, etc. is widely employed for particle mitigation in industrial applications, electrical mitigation using unipolar ionizers is being considered as a viable option for reducing pollutant concentrations in indoor environments. Their efficacy for particulate radioactivity such as radon and thoron decay products has been demonstrated by a large number of studies (Bigu 1983; Sheets and Thompson 1995; Hopke *et al*. 1993). In addition, few studies also focus on the theoretical understanding of the particle reduction caused by ionizers (Mayya et al. 2004, Clement and Harrison 1996). Ionizer operation has been linked to an increase in the unattached fraction (Hopke *et al.* 1994; Henschel 1994). As this fraction (size range 2-10 nm) deposits entirely in the respiratory tract, the inhalation dose reduction becomes questionable in spite of a substantial activity reduction. Although for radon, studies have shown reduction in effective dose in spite of increase of unattached fraction (Tokonami *et al.* 2003; Kranrod *et al*. 2009), the question remains open for the thoron decay products. Further, the above studies were specific in nature and the need for a model to address the linking of increased unattached fraction with the activity reduction and inhalation dose reduction exists.

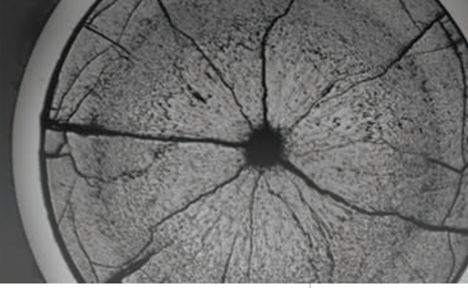
This work specifically addresses the effect of ionizer deployment on the estimated lung dose by combining the experimentally observed activity reduction information with dosimetric calculations for thoron decay products. Three levels of experiments have been conducted: (i) in a small chamber (1 m^3), (ii) in a room (16 m^3) and (iii) in a large thorium oxalate storage area (I.R.E. Alwaye). Measurements of activity concentrations and unattached fraction of the decay product atoms have been made pre- and post-ionizer deployment. The observed changes in these quantities have been used to predict the post-ionizer inhalation doses using dose conversion factors given in the recent dose response models (Ishikawa *et al.* 2007).

Experiments and methods

Three levels of experiments were carried out to test the ionizers for the capability to reduce the thoron and consequent decay product activity. The chamber experiments (volume 1 m^3) were to estimate the wire screen capture efficiency (used for unattached fraction measurement) and to test the ionizers for their ability to reduce activity concentrations in a controlled environment. The experiments carried out in a room (volume 16 m^3) representative of a typical indoor environment, were focused on implementing the ionizer effect in large volumes and unattached fraction measurements. The aim was to interpret the phenomenon physically and examine the size spectrum changes in relation to the effective dose calculations. As a third step, the ionizer assembly was also tested under large source term conditions in a thorium oxalate storage area of an operational thorium plant in I.R.E., Alwaye.

Instruments and techniques

Thoron gas concentration was measured by an on-line system based on alpha spectroscopy namely, RAD7. Activity concentrations of the decay products were measured by air sampling using a glass fibre filter paper followed by alpha counting of the substrate. The unattached fraction was measured by using a sampler with the glass fiber filter paper placed behind a 200 mesh wire screen. The alpha counts from the decay products deposited on the two substrates can be converted to the attached and the unattached fraction of the deposited decay products using the capture efficiency of the wire screen for the fine and coarse fraction respectively. The flow rate of sampling was maintained at 2.5 l min^{-1} minute for all measurements. The Negative Ion Generator (NIG) used for mitigating the decay products consists of an array of sharp needles maintained at a negative potential with respect to ground (H"5-15 KV) available in varying geometries and outputs (Bohgard and Eklund, 1998; Grabarczyk, 2001). The corona discharge at the needle tip creates bipolar ions; the negative ions are sprayed into the room while the positive ions are attracted to the metal surface. These negative ions migrate in the air space and attach to the aerosol particles resulting in their enhanced drift velocity towards the walls due to the electric field generated by space charge. The cleaning effectiveness of ionizer



based systems is parametrically linked to the room environment (Mayya *et al*., 2004). The ionizers used in the present study developed approximately 5.5 KV at the tip of the needles. The negative ion generation rate was 3.125 X 10^{12} s^{-1} (ion current of 0.5 μA) resulting in an ion density of approximately 10^{11} m^{-3} produced in the experimental room.

Experimental studies

A small source of thorium nitrate powder (8.7 grams) was placed inside the 1 m^3 chamber with an in-built stirrer and secular equilibrium was allowed to reach. The thoron gas activity concentration was found to be 1050$\pm$ 120 Bq/m^3. To obtain the capture efficiency of the wire screen for the fine and coarse fraction, a combination of the wire screen with the filter paper was loaded in the air sampler which was used to sample the chamber air for 10 minutes at a flow rate of 2.5 l min^{-1}. After a delay of 5 hours (to eliminate counts due to short-lived deposited decay products and of background radon decay products), the counts obtained on the wire-mesh and the filter paper were used to obtain the wire screen capture efficiencies. The ionizers were then placed inside the chamber and the effect on aerosol and activity concentration level was analyzed. Filter paper sampling was used to estimate the change in the decay products activity concentration. The physical parameters of the screen obtained using microscopy and the experiments mentioned above are listed in Table 1.

The next set of experiments was carried out in a typical room of volume 16 m^3. One wall of this room had provisions for on-line sampling of the room environment. Thorium nitrate powder was placed at approximately 30 cm height from the floor. Three ionizers were placed in the middle of the room at approximately the same height as the source at a mutual angle of 120 degrees in radial orientation. A fan was operated in the room to attain homogeneity. After establishing thoron equilibrium (average thoron level 250 Bq/m^3) and a steady decay product concentration, ionizers were operated for approximately two hours till decay product concentrations reached a steady value. To assess the variations in the decay product concentrations in the presence of ionizers, measurements at an interval of about 10-20 minutes were made using the decay product sampler. A few measurements were also carried out to assess the change in the unattached fraction. Finally, the ionizer system was field tested in a thorium oxalate storage area of a thorium processing facility where the source term was relatively large (8000-10000 Bq/m^3) and the ventilation pattern was uncontrolled as one side of the shed was open. Ionizers were placed at varying distances from the source and at varying mutual orientations. The air samples were taken and analyzed for the decay product activity concentration change in presence of the ionizers.

Table 1: Physical parameters of the wire screen used in the study

Diameter of wire of wire screen	0.050 mm
Mass of the wire screen used in the sampler (diameter 2.2 cm)	0.096 g
Solid fraction of the wire screen	0.429
Front to back ratio of the wire screen	1.28
Capture efficiency for the fine fraction	0.95$\pm$0.007
Capture efficiency for the coarse fraction	0.01$\pm$0.0014

Results and Discussion

Effect on thoron decay product (^{212}Pb) activity concentrations

The results of the activity concentrations of ^{212}Pb for the chamber, room and field conditions are presented in Fig. 1. In the chamber, the ^{212}Pb concentration decreased from 25 Bq/m^3 to 6 Bq/m^3, with a mean time of 15 minutes. The ionizers were kept operating overnight and a few samples were taken the next day. It was seen that the concentration reduced to an average steady value of 2 Bq/m^3 after H”1050 minutes of ionizer operation. Similarly, in the room experiment, the ^{212}Pb activity showed a five-fold reduction within 30 min of ionizer action. In the field study at the thorium oxalate storage facility, the large and inconsistent ventilation pattern resulted in non-prominence of the effect of ionizers for some of the orientations of the ionizer and sampling instruments. However, even with a large source term and widely varying ventilation, the ionizers were effective in reducing the activity concentration of ^{212}Pb for a suitable and optimum orientation. For example, in one such case, the ^{212}Pb activity concentration reduced from 400 Bq/m^3 to a steady value of 100 Bq/m^3 resulting in a 4-fold reduction. There was a considerable variation in the pre-ionizer activity concentration which may be attributed to the inhomogeneity of the air flow patterns as the shed had an entry area open to the ambient atmosphere. This field experiment provided the indication that the use of increased ion strength in these conditions may reduce the activity to an appreciable extent.

Effect on unattached fraction and deposition velocity of thoron decay products

The unattached fraction was observed to increase in the room experiment from 2 to 6.5 % in the presence of the ionizer. The physical explanation for this is as follows. In the presence of coarse particles (sizes >100 nm), the unattached fraction remains low at about 2-5%. However, on the operation of the ionizer, the coarse particles get depleted so that attachment of the

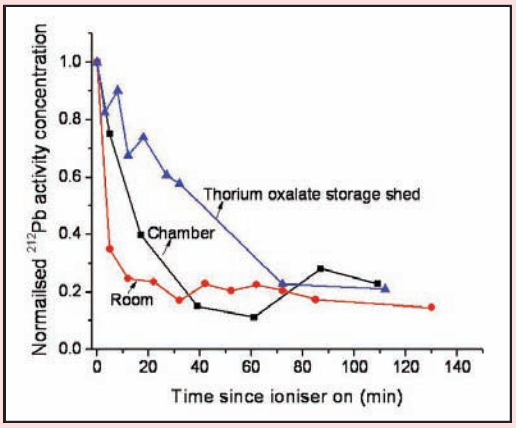


Fig. 1: Variation in the activity concentration of ^{212}Pb in the room, chamber and field environments

decay product in the fine size range (2-5 nm) is curtailed due to reduction in the ambient aerosols. This leads to an increase in the unattached fraction. This was confirmed by another experiment performed specifically wherein the unattached fraction was estimated through the measurements of decay products deposited on wire mesh, made at varying times since operation of the ionizer. The pre-ionizer unattached fraction was found to be in the range of 2-6%, measured over a period of about 20 h. As the ionizer was switched on, a rapid increase to 30% in about 6 h was seen (Fig. 2).

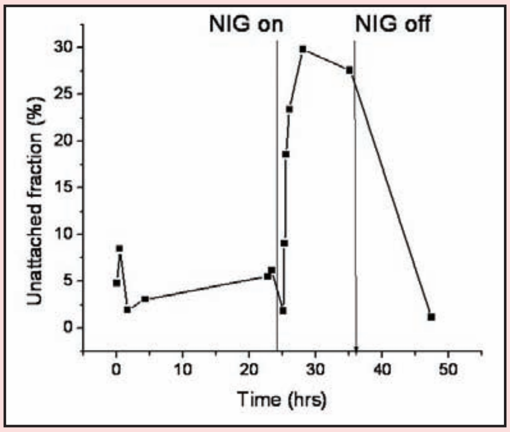


Fig. 2: Effect of ionizer on unattached fraction

Effect on the Inhalation dose

The dose calculations were made based on the model given by Ishikawa *et al*., 2007 which is based on the ICRP 66 Human Respiratory Tract model. This model expresses dose conversion factor (nSv/h/Bq/m^3) as a function of particle size in two different ranges namely, 1-10 nm and 10-10000 nm. For the extended formulations presented here, *A* is the decay product activity concentration (Bq/m^3), *p* is the unattached fraction, *D* and *D'* are the dose conversion factors for the median size of the unattached and the attached fraction respectively. The subscripts 1 and 2 pertain to pre- and post-ionizer conditions respectively. The dose reduction factor (DRF) which is the ratio of pre- and post-ionizer dose, can then be defined by

$$DRF = \frac{A_1 p_1 D_1 + A_1(1-p_1)D_1^{'}}{A_2 p_2 D_2 + A_2(1-p_2)D_2^{'}} \qquad (1)$$

On defining the Activity Reduction Ratio as $K = A_1/A_2$ and Unattached Fraction Increase ratio as $C = p_2/p_1$ we can rewrite the DRF in terms of the experimentally measured quantities as follows:

$$DRF = \frac{K\left[p_1 D_1 + (1-p_1)D_1^{'}\right]}{Cp_1 D_2 + (1-Cp_1)D_2^{1}} \qquad (2)$$

For an advantageous effect of the ionizer, DRF should be greater than 1. Its dependence on the Activity Reduction Ratio, *K,* can be analyzed by varying the unattached fraction (p_1) and unattached fraction increase ratio (*C*). It is thus possible to construct a domain over which the effectiveness of the ionizers in reducing the dose is ensured.

From room experiments, the activity median diameter for the coarse fraction as estimated using the Scanning Mobility Particle Sizer was found to increase from 93.9 nm to 148.9 nm after two hours of ionizer operation. The dose conversion factors corresponding to these values from Ishikawa *et al.*, 2007 were 150 nSv/h/Bq/m^3 and 100 nSv/h/Bq/m^3 respectively. In the absence of information on size of the unattached fraction (measured using wire-mesh sampler), an approximate size was chosen to represent this fraction. For the most conservative scenario, we selected the minimum (210 nSv/h/Bq/m^3) and maximum (770 nSv/h/Bq/m^3) value of DCF for pre-and post-ionizer conditions respectively. For the room experiments, with CRF of 5 and the unattached fraction increase from 2 to 6.5 %, the DRF was 5.27, which is quite significant. However, for the field study at the thorium oxalate storage shed, it was not possible to find the DRF, as the unattached fraction changes had not been measured. It can be inferred from the above formulation that DRF is always greater than 1 at ionizer plausible values of CRF. Extended information can be deduced from the three-dimensional plot (Fig. 3) where p_1 is varying from 0.01 to 0.2 and *C* from 1 to 10 at a test CRF of 3 (which is below the average CRF of the previous studies and this work).

The x-axis represents the initial unattached fraction; y-axis the increase in the same while using ionizers and the z-axis gives the DRF. As may be seen, the effective dose reduces for most practical situations with the operation of the ionizer. For a sizeable part of the plot, DRF is significant enough to validate the ionizer effect. In fact, DRF is always greater than 1, except at the extreme right when the unattached fraction is 15- 20% and its increase is quite high (greater than 5) which is unphysical (as for 100% unattached fraction, *C* can be utmost 5).

Conclusions

This study demonstrates the effectiveness of ionizers in reducing the activity concentration of thoron decay products in poorly ventilated rooms. Experiments in relatively uncontrolled ventilation, such as the thorium oxalate storage area also showed significant reduction. Contrary to the belief that increase of the unattached fraction will necessarily lead to an increased effective dose, the study proves that this increase can easily be offset if the achieved CRF is substantial. For the experimental cases discussed, DRF of 5.27 appears to be significant enough to prove the utility of ionizers as an effective tool. Even at the extreme cases, if CRF is more than a critical value (minimum activity reduction ratio) depending on the initial unattached fraction and its subsequent increase, DRF will be more than one. Further, the efficacy of removal can be enhanced by use of large ion current ionizer systems to evolve dose management strategies for thorium handing facilities.

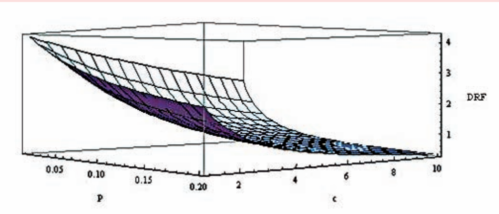


Fig. 3: 3D plot showing DRF as a function of *p* and *C*

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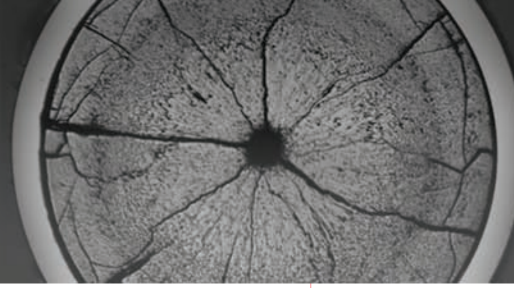

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Forthcoming Conference

National Conference on Advances in Nuclear Technology (ADNUTECH 2010)

The Department of Atomic Energy (DAE) and the Indian National Academy of Engineering will jointly organize a national conference at Anushaktinagar, Mumbai, on Dec. 2 and 3, 2010.

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RESEARCH ARTICLE

Application of Membrane-Based Separations in Environmental Remediation

Jayshree Ramkumar
Analytical Chemistry Division

Abstract

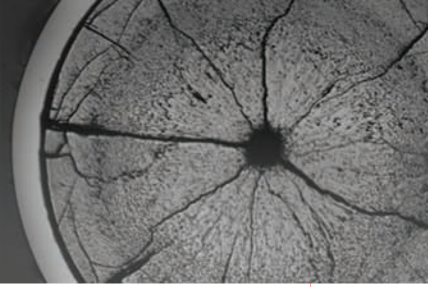
The use of membranes in remediation is of great importance. Solid membranes have been used for treatment of brackish water, gas separations based on the size of the pores of the membranes. Electrically charged solid membranes have been used for removal of anions and also in chloralkali industries. The ion exchange studies of Nafion membrane showed that the physical structure and hence the ion exchange capacity is greatly affected by aging and also the pretreatment procedures adopted. Liquid membranes have been used extensively to study the carrier activity of various organic compounds for selective transport of metal ions.

Introduction

"*Environment*" is defined as "*a sum of all social, economical, biological, physical or chemical factors, which constitute the surroundings along with man*". Environment has never been static and modifications occurs with improvement of technology and results in pollution, a term derived from the Latin word "*pollutionem*" meaning, "*to make dirty*". "*Environmental pollution*" is defined as the "*unfavourable alteration of the surroundings, wholly or largely as a by-product of man's actions*". The substances that cause pollution are known as "*pollutant*" which is defined as the "*substance that is present in the wrong place, at the wrong time and in the wrong quantity*". There is always an ongoing effort for developing newer procedures for the removal of these contaminants and this is known as remediation which simply means to "*provide remedy*". Separation is important from view of environmental remediation and industrial reactions. Separation can be achieved due to differences in physical or chemical properties of the components. The difference in physical properties of the solute is exploited for processes like distillation, centrifugation, etc. However, these separations are less selective and are useful only if there is a large difference in physical property. Therefore, the difference in chemical property of the component is made use of. The particular component is selectively complexed, separated and then removed from its complex to recover both the original component and the chemical reagent. Techniques, like precipitation, solvent extraction, ion exchange, and membrane separations are based on the chemical nature of the component. Membrane separations find a large number of applications due to advantages like cost effectiveness, easy operation, and high pre-concentration factor with a high degree of selectivity. The pre-concentration is useful for the determination of metal ions present at concentrations much lower than the detection limit of a particular instrument. In this report, the importance of different membrane based processes for various applications have been brought out.

Definition and Classifications of Membranes

Accroding to IUPAC, the "*membrane*" can be defined as "*a structure, having lateral dimensions*



much greater than its thickness, through which mass transfer may occur under a variety of driving forces." If one component of the mixture travels faster in the membrane, a separation can be achieved. Based on their nature, the membranes are classified into solid and liquid membranes.

Solid membranes of varying pore sizes and thickness are used in different processes like reverse osmosis, micro filtration, ultra filtration (Fig.1). Microfiltration, ultrafiltration and nanofiltration bring about separation on the basis of size exclusion principle and differ from each other on the basis of the size of the species being separated. Reverse osmosis occurs when a solution is pressurized against a solvent (usually water) selective membrane and the applied pressure exceeds the osmotic pressure difference across the membrane. All these processes have large applications in various industries and can be used on feed streams ranging from gases to colloids.

Apart from membranes with pores of different size, ion exchange membranes with charges are also used for remediation and industrial applications. Ionomers are a class of electrically charged membranes containing 15 mol % ionic content and have extensive industrial applications. Nafion membrane contains incompatible components: the fluorocarbon phase and the ionic phase (containing the ion and water molecules). These are separated to the limit that the covalent bonds hold them together. The rather special structure proposed is cluster type, containing the aqueous ions embedded in a continuous fluorocarbon phase (Fig.2). The clusters are interconnected by narrow channels, which determine the transport properties of ions and water molecules. The water content of the membrane is of great importance for its properties and is determined by the kind of polymer and also the counter-ion.

Liquid membranes appear as a new and prospective separation method due to its advantages over solid membranes. It is known that molecular diffusion in liquids is faster than in solids and therefore solid membranes with micron thickness cannot compete

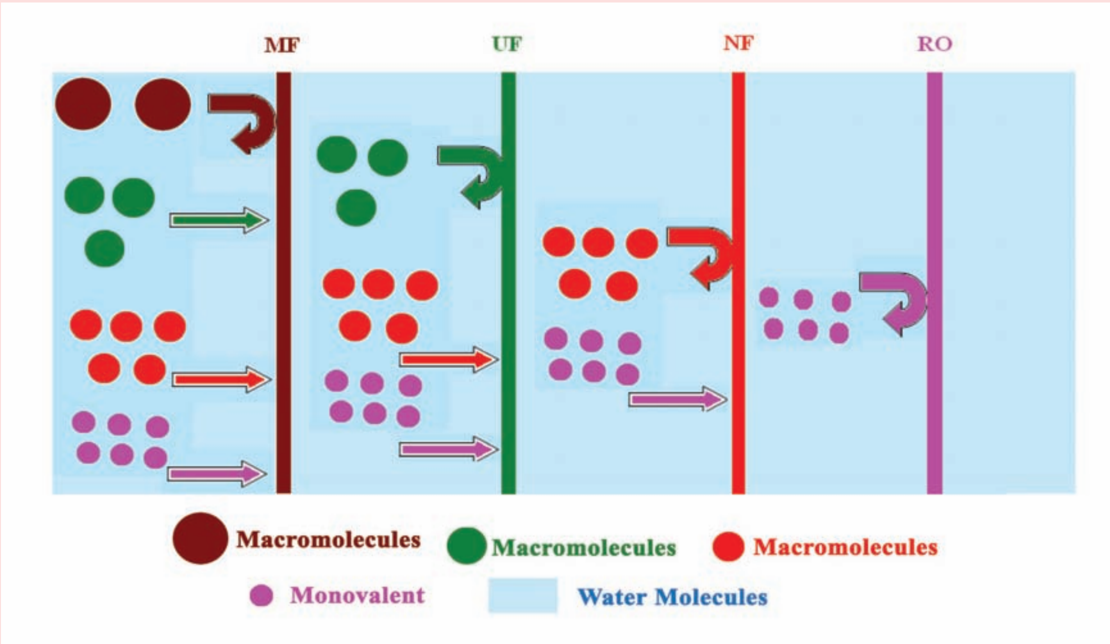


Fig.1: Membrane processes (MF-microfiltration, UF-Ultrafiltration, NF- nanofiltration, RO-Reverse Osmosis)

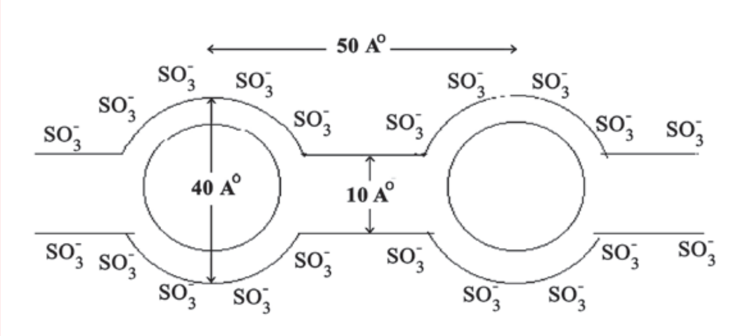


Fig.2: Cluster network model of Nafion

with liquid membranes with respect to the transfer intensity. Also polymeric membranes are less selective than liquid membranes. Liquid membrane (LM) based methods appear as viable alternative to solvent extraction methods as the latter require not only a large inventory of organic solvents but also suffer from drawbacks such as third phase formation and a large volume of secondary wastes. The different configurations of liquid membranes are shown in Fig.3.

Applications of Membrane Based Reactions

Table 1 gives a overall view of the various membrane based processes. MF is used in pharmaceutical and biotechnology industries. Based on UF, water purifier using polysulphone membrane has been developed at BARC for the environmental remediation purpose of treatment of industrial water. NF is used for the removal of dyes from ground water system as dyes are carcinogenic. Reverse osmosis is used extensively for desalting seawater and brackish water. Solid membranes are used for gas separations which are important for recovering and purifying industrial gases. The gas separation based on the differential diffusion of gases under pressure through polymeric membrane has been used in nuclear technology for the enrichment of uranium by passing gaseous uranium

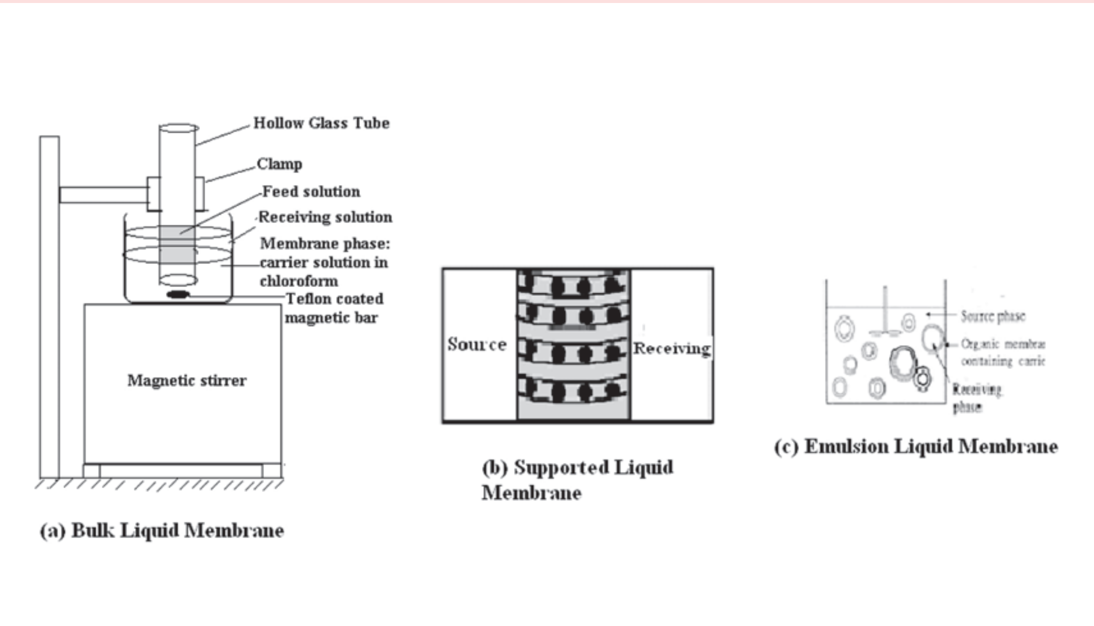


Fig.3: Configurations of liquid membranes

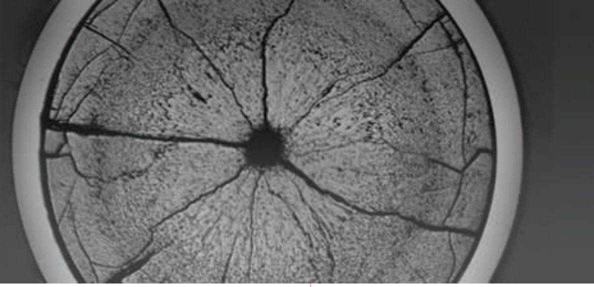


Table 1: Industrial applications of different separation processes

	Alternative Processes	Size of solutes retained	Driving force	Membrane Type	Applications	
					Other Industries	Nuclear Industry
MF	Sedimentation Centrifugation	0.1 - 10 μm	Pr. Diff. (0.5 - 1 bar)	Porous [Ceramics]	Separation of bacteria and cells	—
UF	Centrifugation	1 - 100 nm	Pr. Diff. (1 - 10 bar)	Microporous [Ceramics]	Separation of proteins	Retention of U, Th, Pu and RE
NF	Distillation, Evaporation	0.5 - 5 nm	Pr. Diff. (10 - 70 bar)	Microporous [Thin film composites, cellulosics]	Separation of dye, water softening	—
RO	Distillation, Evaporation,	< 1 nm	Pr. Diff. (10 - 100 bar)	Nonporous Thin film composites, cellulosics	Desalination of sea/brackish water, water purification	Decontamination of radioactive effluents

hexafluoride, UF_6, through semi-permeable membranes thus separating U^{235} and U^{238}.

Electrodialysis (Fig.4) is a separation process in which charged membranes and electrical potential difference are used to separate ionic species from and has been used for remediation of heavy metals from different solid waste products.[1] Electrodialytic remediation based on electromigration of heavy metal ions and ionic species within the soil matrix, and a separation of the soil and the process solutions, where the heavy metals are concentrated, with ion exchange membranes has been successfully used for removal ot toxic metal ions from the soil system. Removal of inorganic anions from drinking water supplies by membrane assisted processes that can be used for the removal of toxic inorganic anions from drinking water supplies highlights the importance of membrane bioreactors in environmental remediation.[2]. Nafion ionomer membrane is used in chloralkali industries (Fig.5) because of its chemical stability.

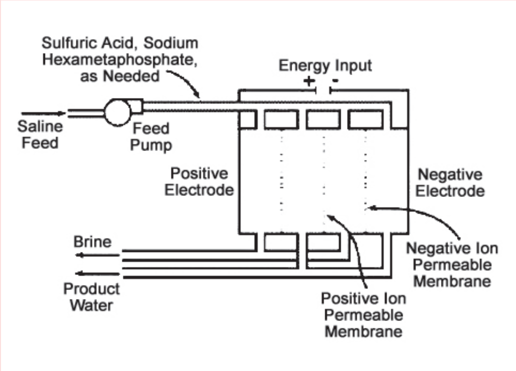


Fig.4: Electrodialysis setup

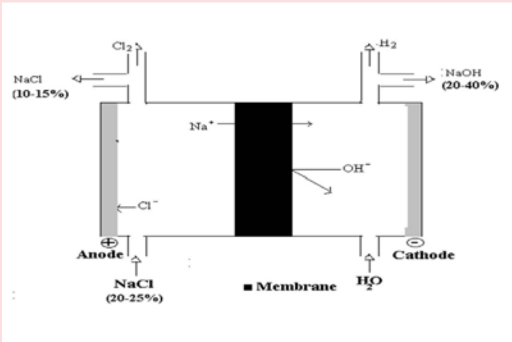


Fig.5: Schematic representation of chlor alkali electrolyzer.

RESEARCH ARTICLE

Ion Exchange Studies of Nafion Membrane

There are reports on the structural aspects of Nafion membrane[3]. The water sorption and ion exchange studies using Nafion membrane have been carried out extensively to study and understand the effect of shelf life on the uptake capacity of these membranes. Nafion membranes were subjected to various different pretreatment procedures and the water sorption and ion exchange capacity studies were carried out. The studies have shown that the physical structure of the exchangers get altered due to long - storage or aging, resulting in poorer water sorption and as a result, the ion exchange behavior is follows an unexpected trend and is also much lower[4,5] due to loss of elasticity or swelling characteristics of these membranes due to aging. Pre-treatment procedures adopted for Nafion 117 membrane has shown to affect these properties due to modification of the membrane structure and arrangement of the ionogenic groups. The permeation of transition metal ions through Nafion membrane showed that diffusion was dependent on the selectivity coefficient of the ion exchange process thus indicating that the initial stage of permeation is governed by ion exchange process[6].

Liquid Membrane Studies

Liquid membranes have been used extensively. Bulk liquid membranes (Fig.4a) are used on lab scale to evaluate the carrier activity of different organic carriers and have also been used for preconcentration of uranium from seawater sample prior to analysis[7,8]. There are reports on the use of supported liquid membranes (Fig.4b) for the separation of actinides and lanthanides[9, 10]. Emulsion based liquid membrane (ELM) system (Fig. 4c) composing of D2EHPA, SPAN80, kerosene and nitric acid has been successfully used for the recovery / concentration of uranium from a dilute solution (~0.5g/l) of uranyl nitrate to obtain a concentrated pure solution with 5 g/l of uranium [11].

Acknowledgements

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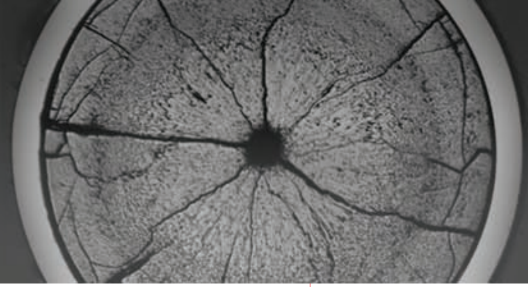

Evolution of Fuelling Machine Based Axial Creep Measurement System for Coolant Channels of PHWRs

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Refuelling Technology Division

Abstract

Axial creep monitoring of the coolant channels is required to be done during every bi-annual shutdown in Pressurized Heavy Water Reactors. Initially the data was measured using Optical Method, which had limitations like dependence on layout of fuelling machine vault, had significant men-rem consumption and was time consuming (about one week for measurement). Refuelling Technology Division, BARC has evolved a new technique called TMAC (Technique for Measurement of Axial Creep) which makes use of Fuelling Machines for remote approach to each coolant channel. The technique overcomes most of the problems faced during optical measurement. Recently an improvised system based on non-contact ultrasonic sensor, UMAC (Ultrasonic Measurement of Axial Creep), was developed to reduce measurement duration, as well as, making the measurement more operator friendly. UMAC provides graphical profile of channels and is less dependent on FM components. UMAC system has been handed over to all operating units of Indian PHWRs. This article summarizes the work related to both TMAC & UMAC.

1.0 Background

Axial permanent elongation as a consequent of in-reactor creep & growth of the coolant channels is required to be measured during every bi-annual shutdown in Indian Pressurized Heavy Water Reactors. In this article, the term 'creep' is used to represent the combined effect of creep & growth. Initially the data were measured using Optical Method. The method was manual and had dependence on layout within the fuelling machine vault and caused significant men-rem consumption. The measurement used to take about one week duration followed by calculation and report preparation.

To minimize the consumption of time and man rem during measurement, Refuelling Technology Division, BARC evolved a new technique called TMAC (Technique for Measurement of Axial Creep) which involves Fuelling Machines (FMs) for remote approach to each coolant channel [1,2]. The technique uses all three motion of Fuelling Machines as X (motion in horizontal plane parallel to reactor face), Y (vertical motion) and Z (motion in line with coolant channels) to carry out measurement remotely from control room. TMAC, which completes measurement in about 16 hrs, is currently used by all operating PHWR plants in India for the past two decades.

Recently, an improvised system based on non-contact ultrasonic sensor was developed and supplied to NPCIL. The system uses only X and Y motion of Fuelling Machines to scan the channels during measurement and thus reducing measurement time further to 4 hrs. UMAC system provides graphical channel profile and is more operator friendly.

2.0 Concept of Measurement

Axial creep of coolant channel can be measured by comparing the length of coolant channel with its original length. Since there is no direct method to measure this length, the creep is measured by measuring the gap between FM and channel face. The method requires a reference plane, which remains fixed throughout the reactor life. In the above method end fitting face (E-face) of Rehearsal Tube Facility (RFT) channel is used as a reference plane, which is assumed to remain fixed throughout the reactor life (as RFT channels do not experience high temperature and fast neutron flux, which cause the in-reactor creep). The original distance of channel E-face from FM face is measured from this reference plane at the time of starting of the reactor, which is known as base data. Every year distance of the channel E-face from the reference plane is measured on both sides. The deviation of the measured data from base data, after normalization, yield the creep occurred in the channel up to the time of measurement. Fig. 1 explains this measurement process and evaluation of the creep data.

L_R = Length of RFT channel at 20p C

L_C = Length of coolant channel at 20pC and 0 FPD

R_N = Distance between FM face to RFT E-face at North side at 20pC

R_S = Distance between FM face to RFT E-face at South side at 20pC

C_N = Distance between FM face to channel E-face at North side at 20pC

C_S = Distance between FM face to channel E-face at South side at 20pC

ΔC_N = Elongation of channel due to in-reactor creep at north side

ΔC_S = Elongation of channel due to in-reactor creep at south side

Creep = $\Delta C_N + \Delta C_S$

3.0 Technique for Measuring Axial Creep (TMAC)

TMAC system utilizes Z motion rectilinear potentiometer available in both FMs as sensors to measure required gap. The system mainly consists of a tool with aluminum face to be clamped in to Fuelling Machine snout, a Data Acquisition Card

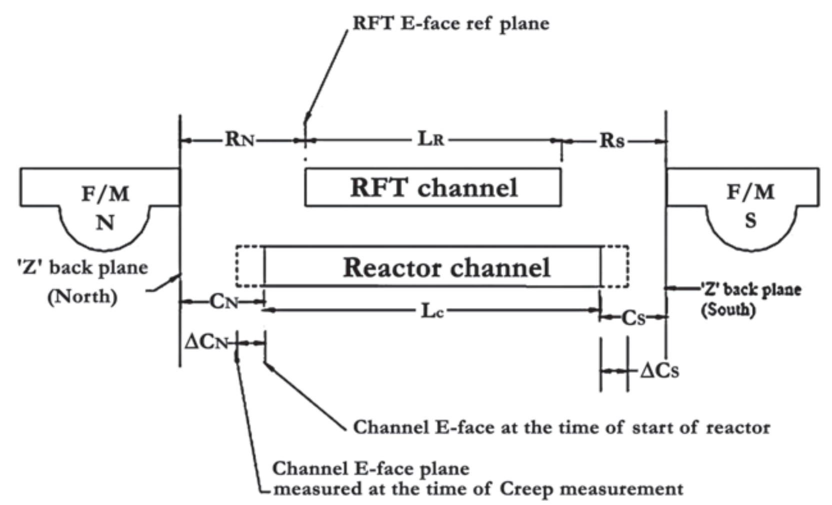
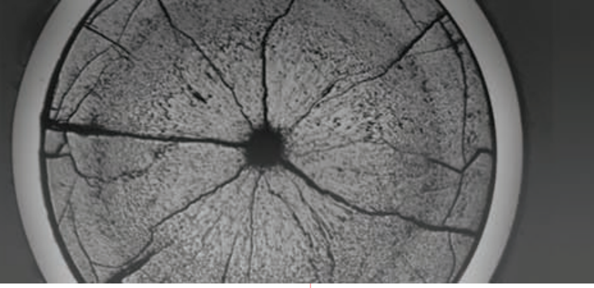


Fig. 1: Concept and evalution of creep measurement in UMAC



having in built signal processing & filtering unit and DOS based operator's console. The TMAC tool is designed in-house to make positive contact with the E-face of channel. Contacting face is made of soft aluminium material to avoid damage to the end fitting sealing face. To facilitate clamping in fuelling machine snout, it is shaped like a cut end fitting and becomes integral part of the fuelling machine after clamping. Its front face is swivel type joint to ensure the full contact with the E-face and get average reading of the creep. The total length of the tool is such that in z-back position of the fuelling machine, the tool does not interfere with the end fittings during X and Y motions of fuelling machine. The Data Acquisition Card of TMAC is a 12 bit Analog to Digital Conversion card and was developed indigenously to make a standardized system for all Indian PHWRs. Two models have been designed as a PC mounted ISA bus based card for 220MWe reactors and a standalone microcontroller based card, which communicates to the PC through a serial port, for 540MWe reactors. The potentiometer signals are acquired through these cards to operator interface for further processing. A DOS based operator interface program was developed to process measurement data and to evaluate the creep of the channel in the desired format. The program is designed to perform calibration and repeatability check as per recommended procedure and subsequently measures creep data with desired level of accuracy.

TMAC, which was handed over two decades back, was reviewed a few years back. Based on the feedbacks from different plants, the software and data acquisition system were revised and handed over to all 220MWe operating plants. The TMAC for 220MWe cannot be used for 540MWe reactors due to its different lattice structure and coolant channel dimension. Hence a new version of TMAC suitable for 540MWe PHWR was developed recently and handed over to TAPS 3&4.

4.0 Ultrasonic Measurement of Axial Creep (UMAC)

Development of Ultrasonic Measurement of Axial Creep (UMAC) is another step in advancement of the creep measurement technique for coolant channel of Indian PHWRs. This method reduces measurement duration further and makes the system more operator-friendly [3]. Similar to TMAC, this technique also uses FMs for creep measurement. UMAC has its own non-contact ultrasonic sensor(Fig. 2) for distance measurement which enables the FMs to scan the channels, while TMAC uses potentiometers available in machines and require physical butting of tool with the E-face of channel.

4.1 Overview

In this method the channels are scanned while moving FM in X or Y direction at a constant speed. A PC-based data acquisition system acquires and processes the data profile to evaluate the creep data. The system mainly consists of two non-contact ultrasonic sensors, sensor mounting tool, data acquisition system, 2-axis calibration manipulator and operator interface program. All hardware and software of UMAC, except the sensors are developed indigenously. Fig.-3 shows block diagram of the system.

4.2 UMAC- Sensor

UMAC, as shown in block diagram at Fig. 3, is based on a non contact ultrasonic principle where a sensor with sonic frequency of 400KHz is used to measure distance of channel face from machine face. The sensor is equipped with a compact controller module having standard electrical interface. The sensor and its controller were tested for its suitability at reactor environmental condition.

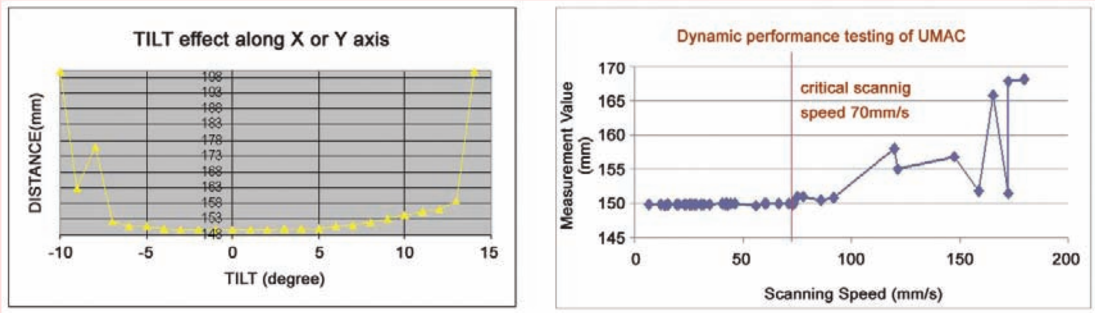


Fig 2: Experimental qualification of UMAC sensor under operating condition of FM tilt and FM scanning speed

Critical Scanning Speed of UMAC system and its effect on performance during tilt of machine were determined experimentally in the laboratory.

The characteristic obtained as shown in Fig. 2 provides maximum limit of FM tilt as well as FM speed which can be used during the measurement.

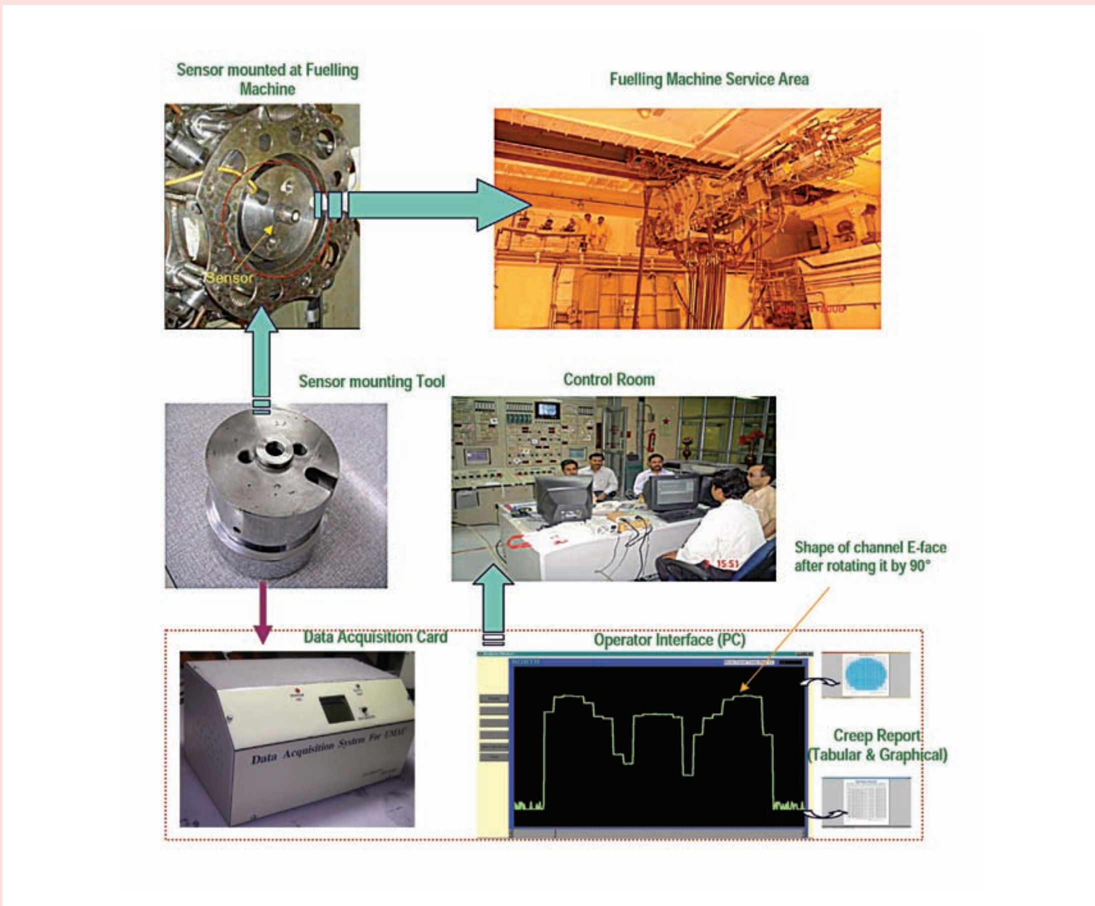
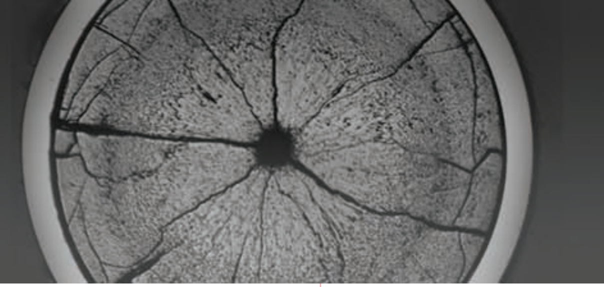


Fig 3: Schematic block diagram of UMAC system



Non-linearity of the sensor was minimized by adopting a lookup table type calibration process.

4.3 UMAC- Sensor Mounting Tool

The sensor is mounted in fuelling machine using an indigenously developed mounting tool. Sensor mounting tool has been designed, as shown in Fig. 4, to carry the ultrasonic sensor. This tool is compatible with Fuelling Machine. The sensor is mounted on the tool and each tool with sensor is clamped in the Fuelling Machine snout. The tool has an arrangement to adjust the gap between the sensor face and E-face of the channel. This ensures distance of the sensor from the E-face within its operating range.

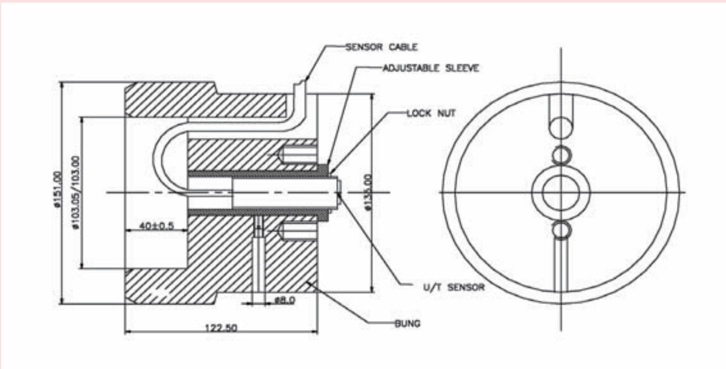


Fig 4: Sensor with Mounting Tool

4.4 UMAC - Data Acquisition System

The sensor controller generates standard signal output proportional to the distance of target surface (channel face). The signal is transmitted to the control room through FM junction box and is acquired in an in-house developed Data Acquisition System (DAS). Data Acquisition System of UMAC is designed as a standalone system and communicates to the personnel computer (PC) through RS232 port. The circuit mainly consists of the following four parts - Signal Conditioning module, Data Acquisition module, Power Supply module and Onboard Display module. The current signal is first converted into voltage signal compatible with the data acquisition module and passed through filtering circuit. A microcontroller chip with in-built Analogue to Digital Conversion (ADC), having 12 bit resolution, circuit is used for data acquisition. The power supply module generates DC regulated supply for ultrasonic sensors, as well as, for its internal requirement. The system also displays measurement parameter at its local display with proper identification. A special algorithm, for microcontroller program, was developed to download calibration table from PC database so that measurement parameter can be displayed with desired accuracy level.

4.5 UMAC – Operator Interface Program

A PC based operator interface program has been developed to perform measurement, evaluation and reporting of creep data through UMAC. The window based software was designed to display graphical profile of channel during measurement and evaluation process. The software facilitates following operation:

4.5.1 Calibration Generation and Loading

The system requires two ultrasonic sensors to be used for measurement of gap between FM and channel face on both sides during each measurement. A lookup table type calibration process is implemented for the system. The software facilitates generation and loading of calibration table for each sensor before measurement. A 2-axis Sensor Calibration Manipulator as shown in Fig. 5 designed in-house is used for the purpose.

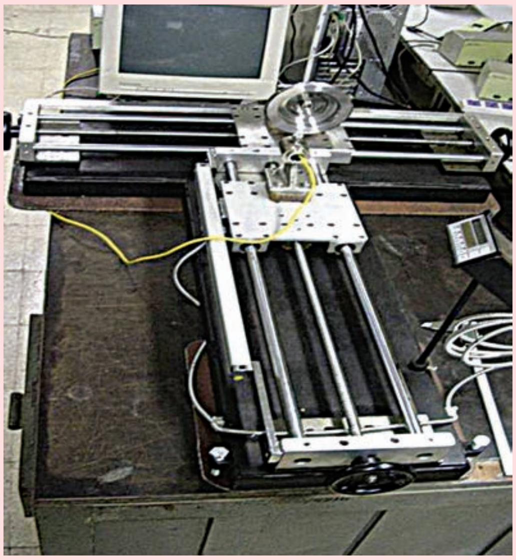


Fig 5: Sensor Calibration Manipulator

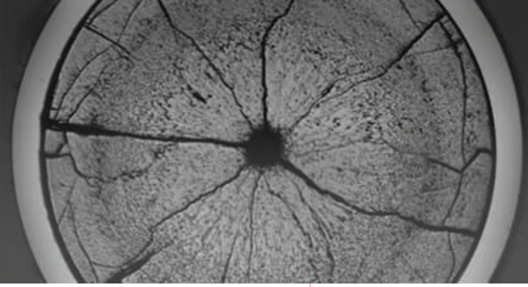
4.5.2 System Test & Repeatability Check Module

It is mandatory to check the health of the system before carrying out measurement or acquiring the data profile. This process assures accuracy of measurement data within its designed level. Testing of each side is carried out during standstill condition of FM contrary to measurement function where both sides are measured simultaneously. The process detects any anomaly in measurement condition such as electrical noise, calibration data, machine conditions etc.

4.5.3 Measurement & Evaluation Module

After successfully passing repeatability and calibration check, the measurement process is initiated. The measurement window, as shown in Fig. 6 facilitates acquisition, display, storage and evaluation of channel data profile [3].

Fig 6: Measurement & Evaluation of channel profile



After scanning and storing the raw profile, the data is processed in order to filter out relevant E-face data of all channels with proper identification. The average of both E-face data of particular channels will be taken to evaluate gap between sensor face and channel face. Gaps in North side and South side are added to evaluate total gap and then appropriate temperature correction is applied. A special algorithm based on channel profile of different plants was designed to perform the evaluation. The evaluation can be performed in three modes such as Auto Evaluation, Semi Auto Evaluation and Manual Evaluation. Evaluated data are stored in system database and processed further to generate reports in desired formats.

4.6 UMAC-System Evaluation & Testing

Performance of the system was evaluated using both analytical and statistical approach. Evaluation through analytical technique was carried out as per guidelines [5] from National Institute of Standard and Technology (NIST). The approach required indentifying the uncertainty component of the system and its probability distribution curve followed by evaluating *standard uncertainty* as per the distribution characteristic. The standard uncertainty was combined as per root mean square law to evaluate combined uncertainty. A coverage factor of 2 (normally used for industrial application and amounting 95% confidence level) was used to evaluate expanded uncertainty (expanded uncertainty=combined uncertainty x coverage factor). Final value of expanded uncertainty for UMAC system thus evaluated was ±0.67mm.

In the statistical approach [6], a set of data (measurement value by UMAC – measurement value by TMAC) of RAPS-4 was analyzed. A $\div^2$ (CHI SQUARE) test was conducted and found following normal distribution. The data value within ±2s (94.6% probability) was determined and found to be ±0.70mm.

Hence it was observed that despite using two different methods of estimating system uncertainty evaluation the results match very closely. The system was also thoroughly tested at Integrated Thermal Facility (ITF), Engg Hall-7, BARC by simulating the measurement condition. After successful testing at BARC, the system was used at different reactors (RAPS-2, RAPS-3, RAPS-4, KGS-2, KGS-3, TAPS-3 & TAPS-4) and the result was compared with measurement carried out by the existing TMAC technique. The results obtained were in good agreement with obtained of TMAC. Hence this technique was qualified for reactor use independently. Subsequently as per an MoU between BARC & NPCIL the UMAC was delivered to nine operating stations of NPCIL. Plant persons were trained and certified for operating the system before handing over to them.

5.0 Conclusion

Creep measurement is an important task to be performed during bi-annual shutdown of Indian PHWRs. Previously Optical Technique was in use. This was a manual technique and hence required considerable time as well as man rem expenditure. Development of TMAC at Refuelling Technology Division, BARC has helped in reducing the measurement time to approximately 16 hours compared to one week time taken by Optical Technique. Further man rem consumption was also reduced significantly. TMAC is currently in use satisfactorily by all plants since two decades on a routine basis. UMAC is an improvised version of the creep measurement technique which uses non-contact type ultrasonic sensor for the measurement. The system has been recently developed and qualified based on field trials at number of operating plants. The system has been supplied to all operating stations of NPCIL under an MoU. UMAC can successfully complete the measurement of all coolant channels of the PHWRs in just 4 hours. The system is also used to establish free expansion of coolant channels when reactor is brought back to operation after bi-annual shutdown as stipulated by regulatory authority.

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Forthcoming Symposium

Nuclear and Radiochemistry Symposium (NUCAR2011)

The tenth biennial symposium on 'Nuclear and Radiochemistry (NUCAR -2011) is being organised by Ihe Board ot Research in Nuclear Sciences (BRNS), Department of Atomic Energy, Government of India, in association with the GITAM Institute ot Science Visakhapatnam and Indian Association ot Nuclear Chemists and Allied Scientists (IANCAS). Mumbai, during February 22-26. 2011 at GITAM University. Visakhapatnam.

This conference will be dedicated to nuclear chemistry, chemistry of actimdes and fission products and various aspects of radiochemistry. The scope includes

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C Spectroscopy of actinides
D Chemistry of fission and activation products
E Radioanalytical chemistry
F Radioisotope applications
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Automation System for Transfer of Spent Fuel for Nuclear Reprocessing Plants

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Abstract

The Division of Remote Handling and Robotics (DRHR) has been working on design and development of various remote handling tools and automation system for handling active radioisotopes/spent fuel for various process systems. This article brings out first-of-its-kind advanced automation system designed for transfer of spent fuel bundles (pressurized heavy water reactors) for nuclear reprocessing plants. Introduction of this automation system for reprocessing plant is aimed at transferring the fuel bundles directly from fuel handling area (FHA) of storage pool to the dissolver cell in an automated way, without the necessity of using charging cask. This also contributes in eliminating dependency on skilled man-power and reduction of man-rem consumption. System design is such that it can easily be adopted to handle fuel from 220 MWe PHWR as well as 540 MWe/700 MWe PHWRs with minimum changes. Provision has also been kept for manual changing of spent fuel in case of non-availability of automation system.

1. Introduction

The spent fuel bundles from nuclear power reactors (this article is mainly concerned with pressurized heavy water reactors) are stored underwater at reactor site. After allowing it to cool-down for given period, spent fuel bundles from reactor site are transferred to underwater storage facility at the nuclear fuel reprocessing plant site. The spent fuel bundles are stored in an array of trays from ease of handling consideration. Presently, spent fuel bundles from storage pool are transferred to the reprocessing plant manually. Manual operation includes: Lowering of cask (through EOT); Transfer of fuel bundles (11 bundles weighing about 200 Kgs.) from storage tray to the charging cask using manually operated single/multiple underwater gripper assembly; Lifting of cask out of the pool and its alignment to shielded transfer port of the chopper cell (through EOT); Thereafter, fuel bundles are pushed (total pushing stroke of about 7m) manually in stages one after the other to the chopper cell. This operation requires dependency and availability of trained and skilled manpower. During handling of fuel bundle from pool to the chopper unit (through charging cask) also results in spillage of contaminated water all around on the floor. The manual operation also results in man-rem consumption. In order to resolve these issues, it was thought of replacing this manual process by an automated system.

The automation system is designed to transfer spent fuel bundles directly from storage pool to the chopper cell through an underwater tunnel, eliminating handling of charging cask. The system utilizes electro-mechanical wire rope driven conveyor system.

Fig. 1 gives plan view of automation system inside the hot-cell and Fig. 2 shows pool side view.

2. Design Criterion

A simple system is designed from ease of manufacture and assembly considerations. An electromechanical wire-rope driven system is

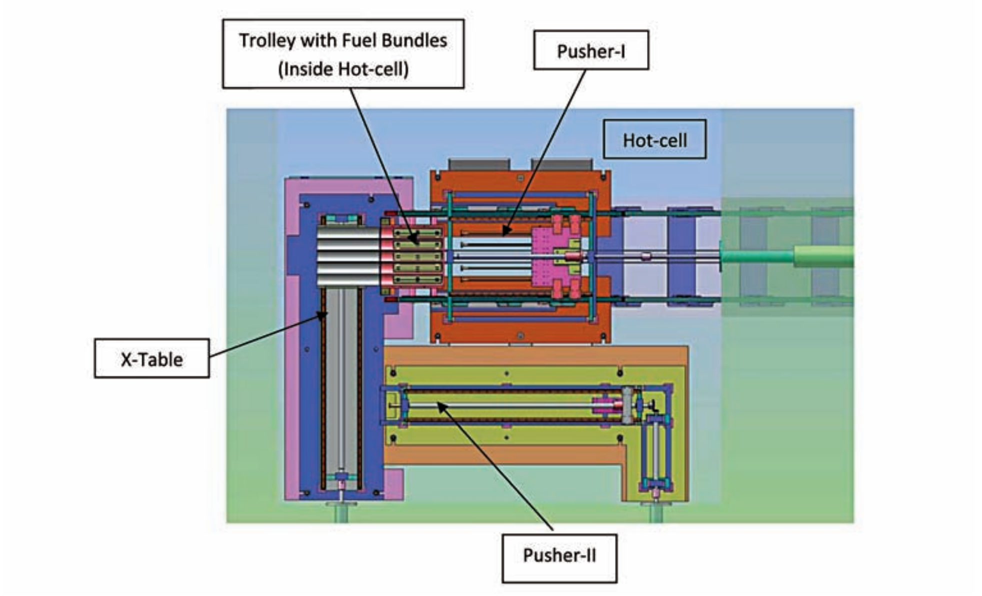


Fig.1: Plan view of Automation System (Inside the Hot-cell)

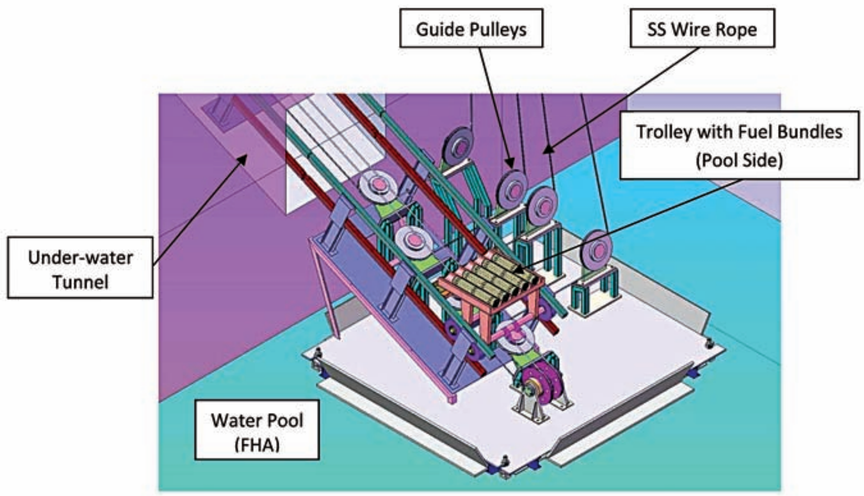
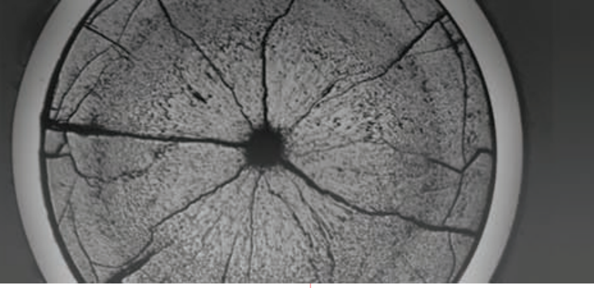


Fig.2: Pool Side View of Automation System



selected for this purpose. The system layout is designed such that components requiring maintenance/replacement are placed outside the hot- cell/water pool. Major components of the system are selected such that it requires minimum maintenance. System components are designed with adequate safety margin. Duplicated wire ropes are used for driving the trolley. Duplicated sensors are used for generating various process interlocks for system operation. All the electrical drives are provided with in-built protection scheme.

Though the system components are designed with adequate safety margin, provision is also made to remotely access the components and replace the same for the purpose of maintenance, if required. Critical components of the system are designed with sufficient factor of safety, giving desired service life. Material selection is done to ensure compatibility to work reliably in the prevailing ambient conditions.

3. System Features

Electro-mechanical wire rope driven trolley system (friction drive through counter-weight assembly) is used to transfer fuel bundles. System is designed to handle fuel bundles of 220 MWe PHWRs as well as fuel bundles of 540 MWe/700 MWe PHWRs with minimum changes. System design has modular construction. System can transfer five fuel bundles in 18 minutes i.e., 1.36 Te in one shift. However, provision is kept to reduce the cycle time to increase throughput. Stainless steel ball screw drives are used for linear movement of fuel bundles inside the hot-cell. Stainless steel pneumatic actuators are used for locking Trolley and X-table (at two positions). Pneumatic actuator is also used for direct sensing mechanism. Provision has been kept for remote replacement of all the sub-assemblies inside the hot-cell as well as inside the water pool.

Duplicated wire ropes are used for trolley movement for high reliability. Wire ropes are held under tension using external counter weight assembly. Failure of wire rope, in case of any, is detected by sensing the position of counter weight assembly. Components are designed with high design safety margin giving long service life. Safety aspects are covered in the system design. All the electrical drives are placed outside the hot-cell/water pool, for ease of maintenance/replacement. However, provision also exists for manual cranking of all the electrical drives, in case of its failure. Remotely operable pneumatic/ electrical connectors are used inside hot-cell. System health monitoring is done through various duplicated sensors and process timers. Provision also exists for manual charging of fuel bundles, as at present, in case of non-availability of the automated system.

4. System Description

This automation system comprises of two major sub-systems namely Mechanical System and the Electrical System.

4.1 Mechanical System

The mechanical system consists of Trolley and its driving unit sub-assembly, Trolley locking/ unlocking & front cover opening sub-assembly, Pusher-I (from trolley to X-table) sub-assembly, Sensing sub-assembly for the bundle on the X- table, X-Table sub-assembly and Pusher-II (from X-table to chopper) sub-assembly.

Trolley and its driving unit sub-assembly

The trolley carries five fuel bundles at a time (about 16 kgs. per fuel bundle). The trolley has the fuel bundles spacing (pitch) of 117.4 mm, which is same as that of the trays for 11 fuel bundles (inside the water pool) in case of fuel of 220 MWe PHWRs. Trolley has four wheels and it moves onto the rails. Two guide rails (one each side) are also provided at the top of the wheels to prevent trolley from toppling over. The assembly is moved by the rope and pulley driving system. One end of rope end is joined to front axle while other end of the wire rope is joined to rear axle of the trolley sub-assembly.

The driving system of trolley consists of a wire rope, guide pulleys and a driving motor. Two wire ropes are used from redundancy considerations. The driving ropes are kept under tension by two independent floating pulleys and counter weight assembly, ensuring system operation as friction drive system. SS 316 having 10 mm diameter (8x19 construction IWRC; Breaking strength of about 6000 Kgs.) wire rope is used. The trolley is provided with a spring-loaded stopper on the cell side and a fixed stopper on the pool-side to prevent the falling of fuel bundles.

Trolley locking/ unlocking & front cover opening sub-assembly

The trolley is locked in its end position in the cell, before pushing bundles from trolley to the X-table. The spring loaded stopper plate on the cell side of the trolley is opened to enable the transfer. Trolley locking (inside the cell) and movement of spring loaded stopper plate are performed by two pneumatic cylinders. Trolley locking also results in actuation of a two sets of duplicated limit switch (one on each side). Limit switch contacts are used for generating the process interlock.

Pusher-I (from trolley to X- table) sub-assembly

Pusher-I pushes fuel bundles from trolley onto the X-table. It consists of five pushers, LM rails, LM guide blocks, ball screw assembly and the driving motor. Drive motor is kept outside the cell from ease of maintenance considerations. All the five pushers are connected to a bracket, which is connected to the nut of ball screw assembly. Both ends of the screw are supported through bearings. Screw is coupled to the motor shaft. Two sets of limit switches are provided for end limits. Provision is kept for manual cranking of the driving motor. This is used to bring back the pusher mechanism to its home position, in case of motor failure.

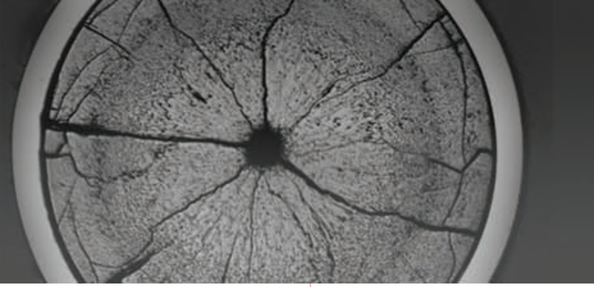
Sensing sub-assembly for the bundle on the X-table

Pusher-I transfers fuel bundles from trolley onto the X-table. Each fuel bundle is sensed directly on the X-table by this mechanism. It consists of a bracket, limit switches and a pneumatic cylinder. A set of five limit switches are used to directly sense the fuel bundles and additional two limit switches are used to sense the stroke of the cylinder. Five limit switches are mounted on the bracket and the bracket is fixed to the piston rod.

Cylinder is actuated, when all the bundles are transferred onto the X-table. The bracket with five sensors senses all the bundles individually on X-table and comes back to its home position, before X-table starts moving towards chopper (process interlock).

X-table sub-assembly

X-table receives fuel bundles from trolley at tunnel location and carries these fuel bundles to chopper location. It consists of a table, four guide blocks, two LM (Linear motion) rails, one ball screw and a driving motor. Motor is kept outside the cell. The table is mounted on four guide blocks. These guide blocks slide over the two LM rails. Rails are fixed to the structure. Ball screw is used to move the table over the rails. Nut of the ball screw is fixed to the bottom of the table. Both ends of the screw are supported through bearings. One end of the screw is coupled with motor shaft.



Pusher-II (X-table to chopper) sub-assembly

Pusher-II pushes all the bundles one by one into the chopper from X-table. It consists of pusher, guide blocks, LM rail, ball screw, bevel gears and motor. Motor is kept outside the cell. The X-table motor at Pusher-II location stops, using its encoder signal. However, alignment of X-table at Pusher-II location is ensured through actuation of pneumatic cylinder and a set of limit switch. Once, the X-table position is aligned with chopper cell centre-line, Pusher-II is actuated to transfer the fuel bundles one by one. Initial stroke for transfer of first four fuel bundles is 700 mm, while the last bundle is pushed by about 1.85 m stroke (1.2 m inside chopper). The X-table moves back to its home position after pushing operation is over. Fig. 3 shows 3-D drawing of some of the important sub-assemblies of the automation system.

4.2 Electrical System

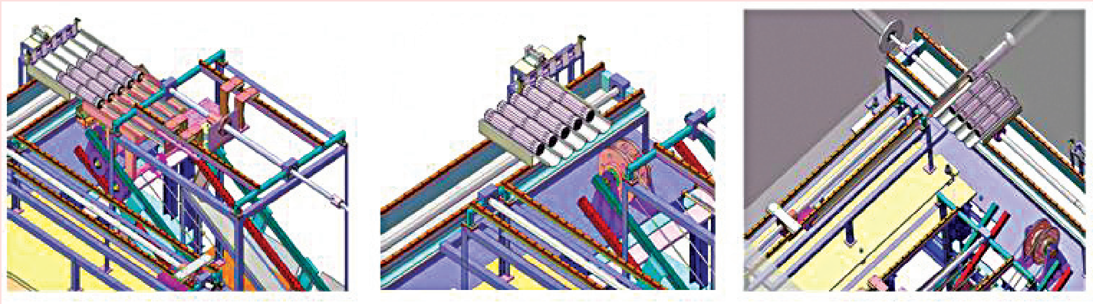
Electrical system consists of motors, feedback devices, sensors, controller, human-machine-interface (HMI) and the safety interlocks for the direct fuel transfer automation system.

Conventional 3-phase, 415 Volts, 50 Hz induction motors of given rating are used for all the drives. Appropriate feedback devices, located outside the cell, are used to provide the position feedback information for the trolley movement, X-table movement and Pusher-I&II movement. 'Fail-safe' brake is incorporated to ensure safety. Electromechanical limit switches are used in the cell to sense sequencing and other operations. PLC based controller is used, with touch screen panel and/or SCADA Panel. All the drive motors are fed through VFD's with soft start/speed, acceleration/deceleration and torque control feature. Indirect continuous and end-limit position information is used for display and generating process interlocks. The control panel displays real time parameters for the operator information. Manual cranking arrangement is provided with all the electrical drives, to bring the respective connected load to its home position, in case of non-availability of that drive.

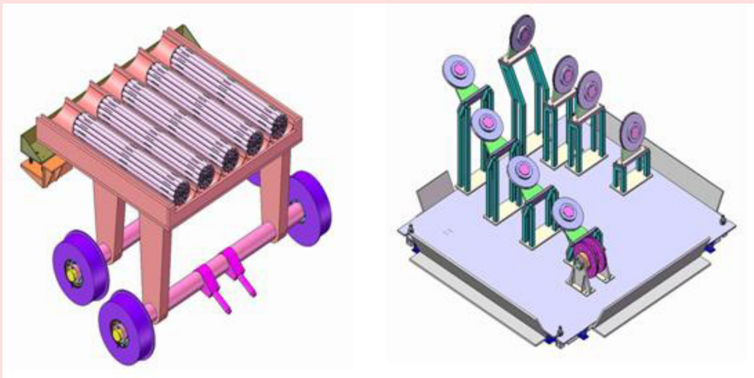
5. System Operation

Before operating the system, it is ensured that spent fuel bundle inventory is available in the storage pool and the chopper unit is in healthy condition. Further, availability of 3-phase power supply, class-I supply and pneumatic supply is ensured. Thereafter, fuel bundles are transferred onto the trolley using remotely operated under-water multi-grappler (trolley has provision of loading five bundles weighing 83 Kgs. of 220 MWe PHWRs). Then, trolley is moved to the dissolver cell through under-water tunnel. Bundles are transferred to the X-table using Pusher-I assembly. Subsequently, trolley moves back to its home position (storage pool) to accept another batch of fuel bundles and X-table moves (from tunnel location) to the chopper location. Bundles are pushed into the chopper unit one-by-one using Pusher-II assembly. X-table moves to the home position (tunnel location) to receive another batch. At every stage, activities are performed only after satisfying the process interlocks. Fig. 4 shows sequence of operation indicating time duration for each activity. This has been derived assuming two minutes as chopping time. System operation and cycle timings can be optimized to reduce the cycle time and hence giving increased throughput.

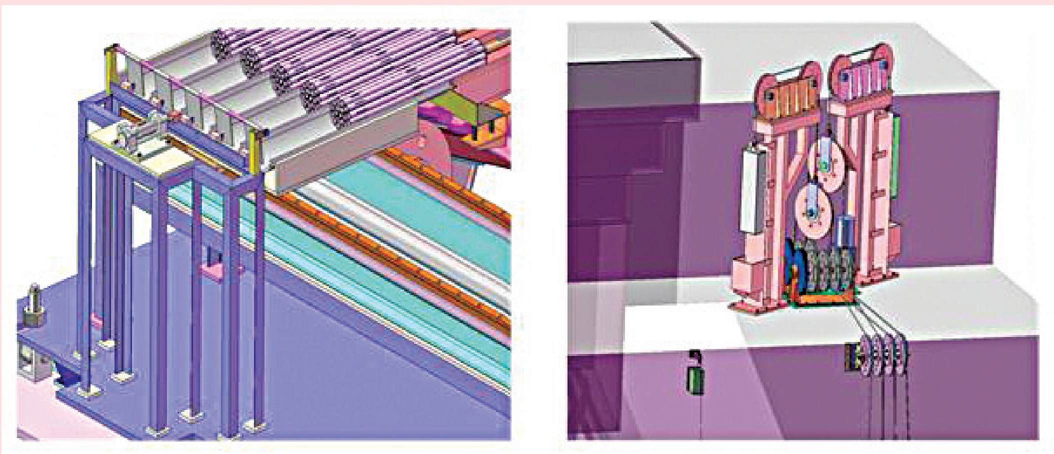
From safety considerations, system operation under postulated failure conditions has been taken into considerations. This includes: power failure, failure of electrical/pneumatic actuators, failure of PLC/control system, failure of wire rope, trolley in jammed condition and failure of other critical mechanical components.



(a): Pusher-I Sub-assembly (b) X-Table Sub-assembly (c) Pusher-II Sub-assembly



(d) Trolley Sub-assembly (e) Guide Pulleys (Pool Side)



(f) Direct Sensing of Fuel Bundles on X-Table (g) Counter Weight Arrangement

Fig. 3: Some important sub-assemblies of the automation system.

Sr. No.	Activity	0-3			4-6			7-9			10-12			13-15			16-18			
	1. Sub-cycle 1 (Trolley)																			
1.	Loading of five bundles on trolley	■	■																	
2.	Movement of trolley from pool to cell and locking of trolley			■	■	■	■	■	■	■	■									
3.	Pushing of bundles to X-table & return back of pushers											■	■							
4.	Return of trolley from cell to pool													■	■	■	■	■	■	
	2. Sub-cycle 2 (X-table)																			
1.	Pushing of bundles to X-table & return back of pushers											■	■							
2.	Direct Sensing of fuel bundles on the X-table.													■						
3.	Movement of X-table from pusher I to pusher II														■	■				
4.	Indexing & pushing of bundles into the chopper.(five fuel bundles)	■	■	■	■	■											■	■	■	
5.	Return of X-table from pusher II to the pusher I						■	■												
	3. Sub-cycle 3 (Chopper)																			
1.	Indexing & pushing of bundles into the chopper.(five fuel bundles)	■	■	■	■	■											■	■	■	
2.	Chopping of five bundles						■	■	■	■	■	■	■	■	■	■				

Process cycle activities and time taken

Note: This cycle time has been worked out considering chopping of one fuel bundle in two minutes (batch of five bundles in ten minutes).

Fig. 4: Sequence of operation indicating time duration for each activity.

6. Conclusion

This automation system is first-of-its-kind and being proposed for the first time for nuclear reprocessing plants. Design basis report (DBR) and Preliminary safety analysis report (PSAR) have been reviewed

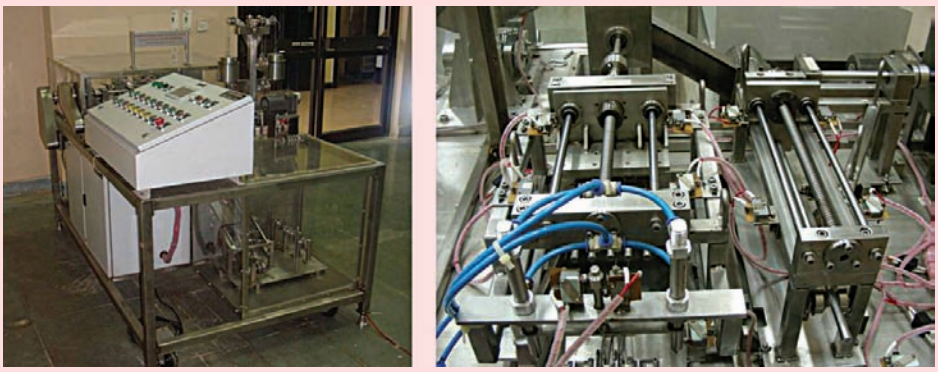


Fig. 5: Table-top working model commissioned at BARC

and approved by the working group of BARC safety council. System operation and remote maintenance aspects have been demonstrated through a scaled-down table-top size working model. Fig. 5 shows photograph of table-top working model commissioned at BARC. It is planned to build full-scale dry mock-up facility for process optimization and operator's training.

Acknowledgement

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Forthcoming Conference

Second International Conference on Advances in Nuclear Materials (ANM 2011)

The 2nd international conference on Advances in Nuclear Materials (ANM-2011) with "Materials Challenges for Future Reactors" as the theme, is being organized in Mumbai during February 9-11, 2011. The conference will be jointly organized by Bhabha Atomic Research Centre (BARC), Board of Research in Nuclear Sciences (BRNS) and Indian Institute of Metals (IIM), Mumbai Chapter. This conference aims to provide an opportunity for mutual interactions among materials scientists and technologists working on the development of materials for future reactors.

The proposed conference will cover a wide range of subjects with strong emphasis on advances in the field of material development for current and future generation nuclear reactors including work on development of materials for fusion reactors. The scope will include materials used for nuclear fuels, in-core and out-of-core components in the current operating thermal and fast reactors, advanced reactors and future generation reactors including fusion reactors. Advances made in the field of manufacturing technology, quality control and characterization, component fabrication and testing, performance evaluation through in-pile and out of pile testing, microstructural studies of materials and modelling of radiation damage and simulation of materials behaviour during irradiation will be part of the deliberations. Presentation will be in the form of plenary talks, invited talks and contributed papers. A poster session is also planned. Contributions are invited on the advances in the following topics:

1. Nuclear Fuels
2. Structural Materials for thermal & fast reactors
3. Materials for Fusion Reactors
4. Materials for HTR and accelerator driven systems
5. Effect of irradiation on fuels and structural materials
6. Simulation & Modelling

Important Dates

Abstract Submission	Oct.31,2010
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Registration	Dec. 15, 2010
Submission of full text	Jan. 05,2011

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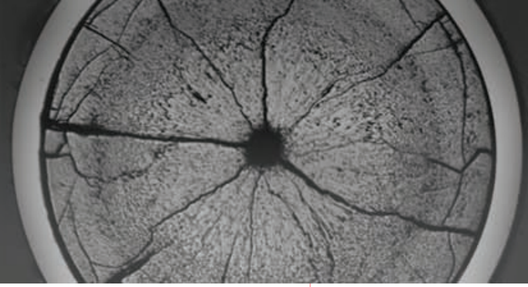

Hydrogen as an Alternate Energy Carrier for Transport Applications: Role of Nuclear Energy

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Abstract

The rapidly growing Indian transport sector, our indigenously available meagre crude oil resources, an increasing import bill for petroleum products and environmental concerns due to burning of fossil fuels, has led developers to find suitable alternatives. Hydrogen has emerged as an attractive energy carrier for transport applications. These issues, along with hydrogen production technologies and the suitable nuclear reactor concepts required for large scale production of hydrogen have been briefly discussed in the article.

1. Introduction

The transport sector forms about 6% of the Indian Gross Domestic Product (GDP), of which road transport contributes almost 70% [1]. There has been an almost explosive growth in the total number of vehicles in India. While there were about 21.4 million vehicles in 1991, the number more than doubled to about 55 million vehicles in 2001. Most recent estimates peg the number of vehicles in India at about 89.6 million (based on 2006 data). Thus, in the period 1991-2006, the road transport sector has grown at a compounded annual growth rate of 10%. Indian transport sector is mainly dependent on petroleum-based products. The Indian domestic reserves [2] of crude oil is rather meagre and is estimated to be 769 million tonnes. The current annual domestic production of crude oil is 33.51 million tonne while the current consumption is 160.77 million tonnes, i.e. almost 80% of the crude oil consumed in the country is imported. It can be anticipated that the road transport sector would continue to grow with current rate, if not more, in the coming years, resulting in larger crude oil imports and increased burden on our economy. Due to depletion in world reserves of petroleum and the increasing trend of their prices, it has become inevitable that India find an alternative energy provider for transport applications. Moreover, being carbon-based, the impact of use of fossil fuels on the environment and health is adverse due to the production of air pollutants such as SO_2, NOx, suspended particulate matter (SPM), particulate matter of micron sizes (PM_{10}, $PM_{2.5}$), CO and CO_2 [3] Due to these pollutants, effects are observed at three levels – local (e.g., smoke affecting visibility, ambient air, noise etc.), regional (such as smog, acidification) and global (i.e., global warming). Thus, continued, and increasing, dependence on fossil fuels is not desirable from economic, environmental, and sustainability viewpoints. Therefore, finding alternate long term and sustainable energy carrier for this sector is of immense importance. Hydrogen has emerged as an attractive alternate energy carrier that could provide a non-polluting solution, but is not available freely in nature and needs to be separated out either from a suitable hydrocarbon or water. The separation processes are highly energy intensive and require a source of primary energy. Nuclear energy is ideally suited as a primary energy source for large scale hydrogen production. Development of hydrogen production processes along with suitable nuclear reactors forms a part of the extended 3rd stage of the Indian nuclear power programme [4].

2. Energy consumption as an indicator of growth

Human development index (HDI) is an internationally well-accepted development indicator. It is strongly related to Per Capita Electricity Consumption (PCEC), as shown in Fig. 1. India has been progressively moving up along the correlation curve. A country with HDI range of 0.85-0.9 can be considered as a reasonably developed country. Based on the correlation curve, we can deduce the per capita electricity requirement, from HDI considerations. The other important measure of human development is Per Capita Oil Consumption (PCOC). The PCOC and PCEC correlate with each other linearly as shown in Figure 2. Thus, for the goal of reaching HDI of 0.85-0.9, the PCEC and PCOC requirements are in the range of 3815-5435 kWh/capita/year and 1115-1620 kg/capita/year respectively. An appropriate choice of targets from within these ranges could be e.g. a PCEC of 5000 kWh/capita/year and PCOC of 1500 kg/capita/year. The current PCEC and PCOC in India are about 618 kWhr/capita/year [5] and 130 kg/capita/year. The time scale for achieving these targets would depend upon the availability of resources and by appropriately meeting the technological challenges.

As a modest target, it can be conceived that of both the above requirements, 25% may be fulfilled by nuclear energy. Thus, besides electricity generation, nuclear reactors solely for the purpose of meeting the additional non-electricity energy requirement (predominantly transport) need to be developed, designed and deployed.

3. Hydrogen as an alternate energy carrier

Hydrogen is a clean and efficient energy carrier. The properties of hydrogen as compared to other conventional fuels are given in Table 1. Hydrogen is high in energy content (120.7 MJ/kg), which is the highest for any known fuel. However, due to its lower density, its energy content per unit volume is rather low. This poses challenges with regard to its storage when compared to other liquid fossil

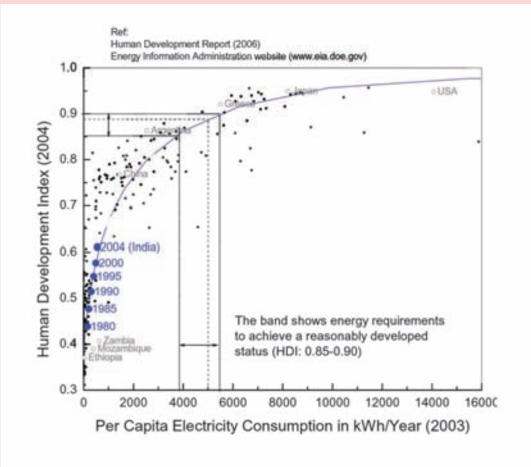


Fig. 1: Variation of HDI with PCEC

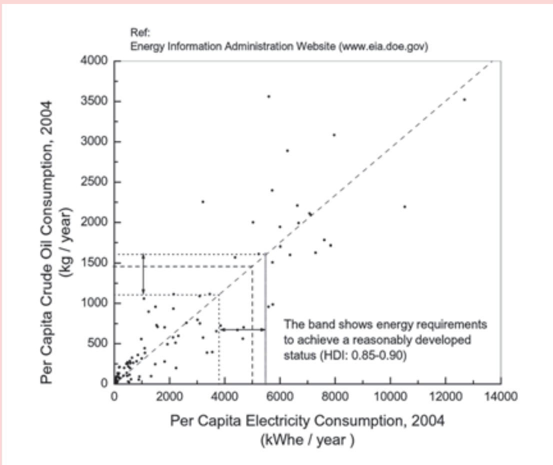


Fig. 2: Variation of PCOC with PCEC

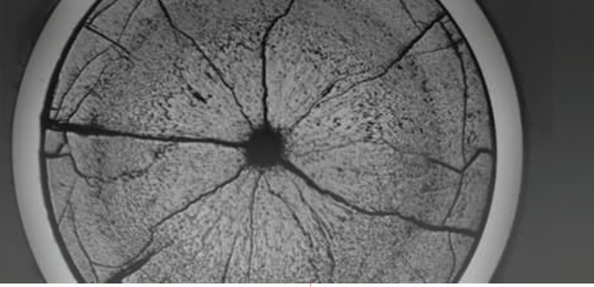


Table 1: Properties of Hydrogen vs. other conventional fuels [7]

Fuel/property	Hydrogen	Natural Gas	Petrol	LPG	Diesel
Lower heating value (MJ/kg)	120.7	49.54	41.87-44.19	46.05	42.6
Higher heating value (MJ/kg)	141.89	54.89	43.73-47.45	50.24	45.6
Density at standard conditions (kg/m^3)	0.08	0.6	720–780	510	850
Phase at standard conditions	Gas	Gas	Liquid	Liquid	Liquid

fuels. When burnt, hydrogen produces water as a by-product and is, therefore, environmentally benign. Although CO_2, etc. are not produced if hydrogen is burnt in air, NOx may still be formed at high temperatures. Hydrogen as energy carrier can be either used directly in internal combustion (IC) engines, it can be used in fuel cells to produce electricity to run hybrid vehicles (which use electricity as well as petrol) or in full electric vehicles. Fuel cells are not subject to the same thermodynamic limits as in fuel-cell driven engines, because they are not heat engines but electrochemical devices. A hydrogen fuel-cell based car can therefore convert hydrogen energy into motion about 2–3 times as efficiently as a normal car converts oil energy into motion. A good fuel-cell system, based on hydrogen to electricity conversion, is around 70% efficient [6], while a typical efficiency of a car engine from oil to output shaft averages only about 15–17%. Both systems then incur further minor losses to drive the wheels.

Besides the direct use of hydrogen as energy carrier, the option of producing a synthetic fuel, which can be directly used as fuel in IC engines, is also being evaluated. The production of synthetic fluid fuel would utilise hydrogen produced using nuclear energy along with a source of carbon such as biomass. The common issues related to hydrogen storage, its transport, and its utilisation, which could affect overall efficiency, safety and economics are remedied by the suggested solutions of using biomass/coal along with hydrogen to produce a synthetic fuel. The use of biomass for such a production would lead to no net CO_2 burden on atmosphere. Conventional oil pipelines can be used for transportation of this synthetic fuel. Vehicle engines would be similar to conventional and existing engines. These aspects of synthetic fuel would result in large economic savings. Thus, for example, a synthetic fluid fuel like methanol would be easy to produce, transport, and utilise in IC engines.

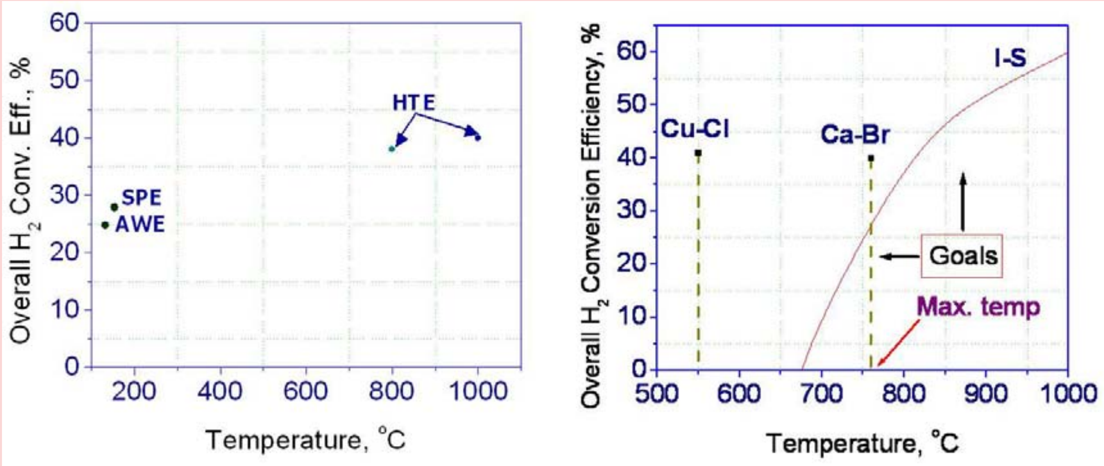
4. Hydrogen production options and Role of Nuclear Energy

As we know, hydrogen is not found in elemental form. The richest source of hydrogen is water. The other major sources include natural gas, coal, and biomass. Hydrogen production technologies, in commercial use today, employ catalytic steam reforming of natural gas, naphtha and other hydrocarbons, partial oxidation of hydrocarbons, gasification of coal and electrolysis of water. Newer methods based on biological, photo-biological, photochemical, and electrochemical processes are also being developed in laboratories all over the world. Currently, however, from among all these processes, the largest contribution is of the steam reforming of natural gas. In India, the fertilizer and petroleum refining industries produce hydrogen on a large scale, based on the steam reforming process. Hydrogen is also produced as a by-product in the chemical industry. However, in a situation envisaged earlier, the amount of hydrogen produced, as a by-product will not be sufficient. Depending upon requirement of hydrogen at a particular location, all these processes can be further classified as production methods for distributed applications where hydrogen is produced at the point of distribution or large size centralised plants with a distribution network up to the point of dispensing. Electrolysis, renewable energy, biomass and biological route based technologies are expected to play a significant role in the production of hydrogen for distributed applications. Coal gasification and nuclear energy based water splitting on the other hand can play a significant role in centralised hydrogen production. At any given time, depending upon the status of R & D of a particular process, several commercial methods for hydrogen production need to work together so as not to overburden a particular resource and to maintain a diversity of supply.

The Ministry of New & Renewable Energy (MNRE) has prepared a National Hydrogen Energy (NHE) Road Map [7]. DAE, and in particular BARC, has played a key role in the formulation of the road map specifically for hydrogen production. The DAE hydrogen energy programme also contributes to the NHE road map. The contribution will be in the form of planning for production of nuclear hydrogen in large volumes for long-term supplies. During the interim period it is proposed to produce hydrogen by other methods.

Nuclear energy based hydrogen production envisages hydrogen production by splitting of water. The processes for efficiently producing hydrogen from water, both by electrolysis and thermo-chemical splitting, are highly energy intensive and require process heat and/or electricity at temperatures generally exceeding 550 °C. The efficiencies for these hydrogen-producing processes increase at higher temperatures. Electrolysis process provides an option of utilising the electricity from grid during off-peak hours and provide load balancing as a bonus. Electrolysis is more efficient, if carried out at high temperatures. Thermo-chemical splitting of water to produce hydrogen has a very high reported efficiency (40-57%) [8], but needs process heat at 550 - 850°C. In essence, high quality process heat is required to be provided as input for producing hydrogen.

High temperature nuclear reactors, designed to supply process heat at such temperatures, have a large potential for sustainably supplying energy for these hydrogen production processes. Fig. 3 shows the temperature requirements and related efficiencies reported for a few electrolysis and thermo-chemical processes. However, it must be noted that efficiency alone at the cost of lower productivity due to technological challenges in achieving high capacity factors need to be carefully considered while selecting a process for large scale deployment.



Electrolysis Processes:
AW: Alkali Water
SP: Solid Polymer, HT: High Temperature

Thermo-chemical Processes:
Cu-Cl: Copper - Chlorine, Ca-Br: Calcium-Bromine,
I-S: Iodine-Sulfur Process

Fig. 3: Variation of hydrogen production efficiencies with respect to temperatures for electrolysis and thermo-chemical based processes

4.1. Electrolysis of water

Electrolysis currently comprises about 4% of world's current hydrogen production and is used mainly in areas with very cheap electricity. Special applications requiring high purity hydrogen such as semiconductor manufacturing utilise the electrolysis process. Different electrolysis methods exist depending upon the type of electrolytes used. Typical cell voltages are 1.85V-2.05V. The effective electricity consumption, depending on the nature of electrolyte, is approximately 3-4.5 kWh/Nm^3 [6] at standard conditions. Cell efficiencies for different electrolytes vary between 70-90 %. Overall energy efficiency of the process depends on both cell efficiency as well as electricity generation efficiency. Water required is of the order of 1 litre/Nm^3 of hydrogen produced. The major factor in the electrolysis route of hydrogen production is the availability and cost of electricity. New techniques such as high temperature steam electrolysis are being developed to reduce electricity requirement in the process. The following electrolysis based processes are either being extensively used or are in advanced stage of development:

4.1.1. Alkaline water electrolysis

Hydrogen generation at lower temperatures (70°C) utilises NaOH, KOH or NaCl as electrolytes. The key factors favouring the alkaline electrolyser are that it eliminates the need for expensive platinum-based catalysts, it is well proven at large scale, and it usually has a lower unit cost than other electrolysers. Compact alkaline electrolysers have been designed and demonstrated in Chemical Engineering Group (ChEG), BARC [9]. BARC has developed water electrolysers with high current density based on indigenously developed advanced electrolytic modules incorporating porous nickel electrodes. This includes a portable electrolyser of 1.5 Nm^3/hr capacity and electrolyser based systems of 10 Nm^3/hour and 30 Nm^3/hr capacity.

4.1.2. Solid Polymer Electrolyte (SPE) water electrolysis

The SPE water electrolysis is used at intermediate temperatures of around 120°C. It can operate at high current densities and has a compact cell. It contains a proton conducting membrane as the electrolyte material. These membranes exhibit high chemical stability both in strong oxidising and reducing conditions up to 125 °C. Much of the technological development, which is currently going on for proton exchange membrane based fuel cells, can be transferred to this type of electrolyser. Development of such an electrolyser is also in progress at BARC.

4.1.3. **High Temperature Steam Electrolysis (HTSE)**

High temperature electrolysis splits steam at a temperature above 800°C. This process uses calcium and yttrium stabilised zirconium oxide (YSZ) membranes. Operation of the cell at high temperatures (900 – 1000 °C) reduces the amount of electricity needed to produce a kilogram of hydrogen, by about 30% [6] as compared to electrolysis process at room temperature. Electricity consumed is about 2.6-3.5 kWh/Nm^3 of hydrogen produced [6]. Nuclear reactors operating in the same temperature range are ideally suited for this purpose. Since the reactor is operating at high temperatures, the efficiency of electricity production is much higher (above 45%). The combination of these effects could result in an overall efficiency of hydrogen production of about 40-45%. In essence HTSE utilises a Solid Oxide Fuel Cells (SOFC) in reverse direction. BARC has a roadmap for development of SOFC. R & D activities are being pursued for a tubular type SOFC along with steam electrolysis sub-systems. Development of 1 kW and 5 kW SOFCs working with reformed fuel and air is in progress mainly in ChEG and Materials Group (MG) in BARC. The methods and materials currently under development in BARC for SOFC power packs, could be utilised for the development of the SOEC system. A HTSE system with 1 Nm^3/hr hydrogen production capacity is being targeted for the design validation of the tubular cell type construction and technology demonstration purposes.

4.2. High temperature thermo-chemical splitting of water

Direct thermolysis of water requires a temperature greater than 2500 °C. In thermo-chemical processes, water splitting is subdivided into different partial reactions, each occurring at a different temperature. A thermo-chemical process is a sequence of thermally driven chemical reaction in which water and heat are the inputs, hydrogen and oxygen are the outputs and the chemicals and reagents are recycled in a closed cycle. A large number of thermo chemical cycles have been studied worldwide [8]. Three promising processes representing high, medium and relatively lower temperature regimes are the Iodine-Sulphur (I-S), Calcium - Bromine (Ca-Br) and Copper- Chlorine (Cu-Cl) processes. Presently R & D has been initiated for the more challenging I-S process at BARC. Other options will also be considered before a large-scale deployment is planned so as to have an optimum mix of the technologies. High temperature nuclear reactors are well suited for supplying heat to endothermic reactions involved in this process. Apart from feasibility of the process, efficiency, stability of close loop operation, safety, suitable materials, and integration aspects with a high temperature nuclear reactor are the key issues. These issues are being addressed at BARC in the initial developmental effort. The initial R & D on Copper-Chlorine thermo chemical process also has been initiated at BARC. The Iodine –Sulphur and Copper-Chlorine processes have been described briefly.

4.2.1. **Iodine-Sulfur (I-S) Process**

The I-S process is a three-step process involving formation and decomposition of hydriodic acid (HI)and sulphuric acid (H_2SO_4). This process is an all-fluid process and has been well studied and fully flow sheeted in laboratories in USA, France and Japan. The thermal decomposition of sulphuric acid and hydroiodic acid is endothermic. The I-S cycle requires process heat at around 850 °C and offers high thermal energy to hydrogen conversion efficiency. Thus, economics of scale are favourable for large-scale production of hydrogen from nuclear power. This process has the highest reported efficiency (57%), generating hydrogen at high pressure (50 atmospheres). There are various R & D issues that have to be addressed in order to produce hydrogen using this process. These are evaluation and simulation of the process, studies on different reactions & phase equilibrium [10, 11], development of materials, equipment & instruments, closed loop process operation & control scheme, integration with nuclear reactor, lab scale, pilot scale and finally plant scale demonstration of the process. R & D is being carried out in Chemistry Group (CG), ChEG, Chemical Technology Group (ChTG), MG and Reactor Design and Development Group (RDDG) in BARC. After carrying out initial R & D, future activities involve lab scale and pilot plant scale demonstrations.

4.2.2. **Copper – Chlorine (Cu-Cl) Process**

The main attractiveness of the Copper-Chlorine process is that it requires process heat at a relatively lower temperature of around 550 °C. This process and other potential processes that operate at lower temperatures have two major advantages – lower demand for material development and greater flexibility in heat sources. In this process, hydrogen is generated at 475°C and oxygen at 530°C. The combination of lower process temperatures and relatively inexpensive process chemicals make this process highly attractive. For development of this process, laboratory level experiments have been initiated in BARC.

As mentioned earlier, wide ranges of pathways are being developed for producing hydrogen using nuclear energy. A comparison from the economics perspective is necessary to evaluate various hydrogen-producing technologies. RDDG, BARC has developed a software tool "Hydrogen Economic Evaluation Programme (HEEP)" for this purpose for the International Atomic Energy Agency [12].

5. Nuclear hydrogen – options for nuclear energy systems

While considering the options for nuclear energy assisted hydrogen production, there is a need to find out ways for an optimum utilisation of raw material especially related to nuclear materials. To meet such large demands in a sustainable way, India has plans to employ a closed nuclear fuel cycle with large-scale thorium utilisation [13]. The magnitude of the demand, will call for nuclear reactors with advanced designs, incorporating inherent and passive safety features and systems that can be located close to population centres, and will have no impact in public domain, arising out of any normal or accident conditions prevailing in the nuclear plant. The other specifications for the suitable nuclear reactor for hydrogen generation would obviously depend on the process selected for hydrogen production. The reactor and associated plant will also need to meet the advanced objectives and requirements, which will be relevant for future innovative nuclear energy systems deployable on a very large scale. Some of the basic requirements for such a high temperature reactor, are listed below:

a) Capability to supply process heat at high temperature.

b) Large heat capacity of the core so as to have slow rise of core temperature in case of abnormal conditions: Ceramic core components like beryllia/graphite.

c) High temperature, high burn-up TRISO coated particle-based fuel.

d) Long life fuel/On-line refuelling to reduce downtime: e.g. Pebble based fuel configuration.

e) Reduced downtime in replacement of core components: Pebble based fuel configuration as compared to prismatic blocks.

f) Low enthalpy - low pressure cooling system: Molten lead and its alloys or molten salt based coolant.

g) Natural circulation of coolant for core heat removal.

h) Additional safety features for integrated operation of reactor with hydrogen production plant by providing an intermediate loop.

i) Incorporation of highly reliable and redundant passive safety features.

Considering these aspects, India has prepared a roadmap [4] for development of reactors for generating nuclear hydrogen. Keeping in focus the long-term objective, the current R&D activities in BARC target challenging technologies for high temperature nuclear reactors, capable of supplying process heat at 1000 °C. A lower temperature option, if developed in future, can be easily supported. Accordingly, technologies for high temperature nuclear reactors using thorium-based fuel are being developed. Considering anticipated demands and deployment of such reactors in large numbers, an emphasis has been put on inclusion of inherently safe design features and development of passive design options so as to ensure increased safety margins.

6. Indian High Temperature Reactor Programme

Under the high temperature reactor programme, BARC is currently developing a Compact High Temperature Reactor (CHTR) as a technology demonstrator for associated technologies. The CHTR is a molten heavy metal cooled 100 kWth reactor, with core outlet temperature of 1000 °C, will use ^{233}U-Th based particle type fuel, and incorporate several advanced passive safety features [14]. At present, a detailed design of the CHTR has been established after completing the conceptual design of the reactor and associated systems. Experimental facilities are under various stages of development to carry out a wide array of studies related to liquid metals, passive safety and heat removal systems. The manufacturing capabilities for BeO, carbon components, and TRISO coating based particle fuel have been demonstrated. Subsequent to the manufacture of fuel, materials and other systems, a critical facility for CHTR would be set up.

In order to generate hydrogen on a large-scale using high temperature thermo-chemical processes (>850 °C), design options for a relatively larger power reactor (600 MWth) are currently being investigated. One of the options being considered envisages a pebble bed type molten lead/ molten salt cooled reactor with several inherent and passive safety features. Typically a high temperature reactor of 600 MWth capacity supplying heat at 1000°C, would be able to produce 80000 Nm^3/hr of hydrogen besides generating electricity and producing potable water from saline water. Detailed physics and thermal hydraulic design for the 600 MWth reactor is also being carried out. Developmental activities for these two reactors are being carried out under XI-XII plan projects with the associated R & D being carried out mainly in RDDG, MG, Design Manufacture and Automation Group (DMAG) and Nuclear Fuels Group (NFG) in BARC. Material development work has also been initiated at Nuclear Fuel Complex (NFC).

such dependence is undesirable. This dependence on fossil fuels could be reduced, if not avoided, by

7. Concluding Remarks

India has a transport sector that is growing very rapidly, particularly the fossil fuel dependent road transport sector. This directly implies a continuing dependence on imported crude and an exposure of the economy to the fluctuations in crude oil prices in the international markets. From an energy security, environment and economic point of view, a gradual yet certain transition to hydrogen as alternate energy carrier. As a preliminary goal, we could target 25% of our fossil fuel requirement to be met through the use of hydrogen. To meet such a target, hydrogen generation requires a source of primary energy, which is abundant and sustainable. Among possible alternatives, nuclear energy, which has a very small carbon footprint, emerges as an attractive primary energy sources. Towards this end, R&D activities in BARC are at various stages of development in the fields of hydrogen production, high temperature reactor design and integration of these systems.

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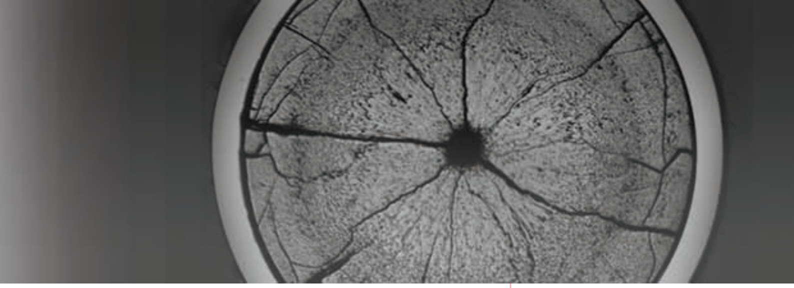

Development of ^{90}Sr-^{90}Y Generator Systems for Radio Therapeutic Applications

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Abstract

^{90}Y in carrier-free form is a potential therapeutic radioisotope due to its several desirable nuclear properties. It is a pure beta emitter with 64.1h half life and 2.28 MeV energy formed by the decay of ^{90}Sr. ^{90}Sr is available in good yield during the fission of heavy nuclides and can be recovered in large quantities from high level liquid waste originating from PUREX process used in spent fuel reprocessing and is an ideal source for generator applications due to its long half life. A number of generator systems based on solvent extraction, ion exchange, extraction chromatography, electrochemical etc. are reported in literature, but none of them satisfy the requirement of an ideal system for use in radiopharmaceutical centers. Purity of the product and ease in handling of the system are the two major requirements. This has prompted to develop a generator system for routine application. Feed ^{90}Sr and solvents used in these studies are of indigenous origin. The techniques used have been progressively changed from extraction chromatography through single membrane cell to the current two membrane cell configuration. The present paper describes the step by step evolution of the generator system based on supported liquid membrane technique to its current status. The system is currently configured at an ideal level of 100 mCi for routine use and can be multiplied with additional units as per demand. During the course of generator development, a simple and novel quality control technique based on extraction paper chromatography was also perfected for the first time.

Yttrium-90, a therapeutic radioisotope of enormous interest [1-4] is a pure â- emitter ($T_{1/2}$ = 64.1 h, $E_{\beta max.}$ = 2.28 MeV) formed by the decay of ^{90}Sr. To separate this radionuclide in carrier-free form from parent ^{90}Sr many techniques have been proposed and only a few of them are being actually used [5-8]. The most important issue that needs to be addressed in the development of this generator system is product purity i.e. the activity due to ^{90}Sr should be <0.001%. A convenient generator system which can ensure continuous supply of pure ^{90}Y for commercial radiotherapeutic applications is yet to be realised.

With this background Fuel Reprocessing Division in collaboration with Radiopharmaceuticals Divisions of BARC initiated studies on the development of a generator system for the production of carrier-free ^{90}Y from ^{90}Sr way back in 1995 [9]. First and foremost requirement in this development is to get ^{90}Sr in mCi levels in purest form. High Level Liquid Waste (HLLW) originating from spent fuel reprocessing by PUREX process contain large amounts of ^{90}Sr along with many other fission products and actinides. To separate ^{90}Sr from HLLW many processes have been reported [10-14]. In the initial stage of the generator development a secondary stream containing ^{90}Sr obtained after partitioning of actinide from HLLW carried out earlier [15] was used as feed for the separation of carrier-free ^{90}Y [9]. Later, multi-step methods were developed [16, 17] and used for the separation and purification of ^{90}Sr from PUREX-HLLW which was used as feed for separation of ^{90}Y. A short description on the development of various generator systems and the status of the current system is outlined below.

1. Extraction Chromatography based column Generator

A generator system employing extraction chromatographic column comprised of sorbent KSMC, obtained by impregnating an acidic organophosphorous reagent. 2-ethylhexyl 2-ethylhexyl phosphonic acid (KSM-17), synthesised indigenously [18], with an inert support chromosorb 102 (supplied by Johns Manville, USA, 100-120 mesh size) was used. Impregnation of chromosorb 102 with KSM-17 was carried out (in 1:3 w/w ratio of chromosorb 102 and KSM-17) in 100% methanol [19]. The final material was washed with 20% methanol and air dried.

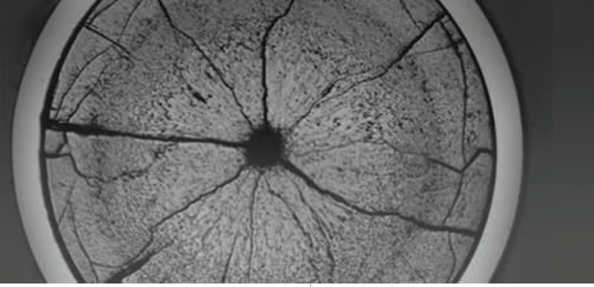
Solvent extraction and extraction chromatographic [19, 20] studies carried out for various metal ions of interest showed that KSM-17 does not extract mono- and divalent ions from nitric acid medium. Glass columns packed with 0.5 to 1.0 g of KSMC were used for separation of ^{90}Y from solutions containing equilibrium mixtures of ^{90}Sr-^{90}Y in HNO_3 (at pH = 2).The ^{90}Sr-^{90}Y equilibrium mixture was obtained from a byproduct of HLLW subjected to actinide partitioning procedure followed by removal of ^{137}Cs using granulated ammonium molybdophosphate (AMP) [15]. The feed contained traces of Cs and Ru. During the loading, Y^{3+} gets absorbed on the column, while ^{90}Sr followed effluents. Column was washed with 0.01M nitric acid to remove all the strontium and associated impurities completely. Finally, carrier-free ^{90}Y was eluted with 0.5M HNO_3. The radiochemical purity of the product was determined radiometrically by following the decay of ^{90}Y activity as a function of time. This generator was used for low-level separation of ^{90}Y (<5 mCi), with decontamination factor of $>10^5$ from ^{90}Sr. The ^{90}Y product was found suitable for radiopharmaceutical application. The decontamination of ^{90}Y from ^{90}Sr in loading and washing step is most important step for obtaining ^{90}Y product of desired purity. Also, during loading and washing the source volume of ^{90}Sr increased, which served as feed for milking ^{90}Y in the next cycle. This necessitated a pretreatment step for ^{90}Sr feed solution in the subsequent cycle. In view of these drawbacks, further studies on extraction chromatographic generator system were discontinued.

2. Supported Liquid Membrane (SLM) based ^{90}Sr-^{90}Y Generator System

Detailed study using supported liquid membrane (SLM) technique, in flat sheet configuration was carried out to asses the feasibility of the method for efficient separation of ^{90}Y from ^{90}Sr. The SLM system consisted of, a metal-specific ligand (carrier) impregnated in the pores of a flat sheet support that separates the two phases *viz.* source and receiver phase. Under optimized conditions, desired separations can be achieved. Two indigenously synthesized ligands *viz.* 2-ethylhexyl 2-ethylhexyl phosphonic acid (KSM-17) and octyl phenyl-N, N-diisobutyl carbamoyl methyl phosphine oxide (CMPO) were used as carriers. ^{90}Sr isolated from high level liquid waste was used for ^{90}Y separation.

2.1 Single Stage SLM Generator

Initially, a single stage membrane based generator system employing 2 ethylhexyl 2-ethylhexyl phosphonic acid (KSM-17) carrier, supported on a polytetrafluoro ethylene (PTFE) membrane was



developed. Schematic diagram of the generator is shown in Fig. 1. The parameters influencing the transport of ^{90}Y across the membrane, such as, transport time, acidity in the feed as well as receiver compartment, nature of the feed/receiver phase and concentration of the radionuclide were studied to optimize the transport to obtain ^{90}Y of high purity. Detailed description of the studies is given elsewhere [21]. The system when operated for ~3-4 h yielded pure ^{90}Y in nitric or hydrochloric acid medium.

This system was used to separate ~10-20 mCi lots of ^{90}Y almost on weekly basis. Under optimised conditions, ^{90}Y obtained from this generator system was free from ^{90}Sr activity as ascertained radiometrically by following the activity-decay (almost complete decay of β-activity after about 26 days) as well as by paper chromatography and paper electrophoresis [22]. However, under recommended conditions, the separation yield for ^{90}Y was found to be only ~40%, which could be enhanced (>90%) by changing the acidity of the feed/receiver phase appropriately or by increasing the transport period. Invariably, higher yield of ^{90}Y also enhanced the ^{90}Sr contamination in the product making it unsuitable for radiotherapeutic use. Therefore further studies were carried out to explore the possibility of getting pure ^{90}Y in higher yield. Additionally, an attempt to obtain ^{90}Y in acetate form was also made, since acetate medium is preferred over nitrate and chloride in radiolabeling of biomolecules.

2.2. Two Stage SLM Generator

To overcome the above limitations, a two-stage SLM based generator system was developed which is principally based on the solvent extraction properties of two ligands, namely KSM-17 and CMPO under optimum conditions. The system was operated in two ways *viz.* in simultaneous and sequential modes. Brief description of these systems is given below.

2.2.1 Two Stage SLM Generator system in simultaneous mode

In this two stage SLM generator system, glass cell assembly having three chambers of capacity 5 mL each was used. Mixture of ^{90}Sr and ^{90}Y adjusted to pH 1-2 was placed in the first chamber (feed chamber). The second chamber also called intermediate compartment contained 4M HNO_3 and the third chamber (receiver chamber) contained 1M CH_3COOH. KSM-17 based SLM was inserted between the feed and intermediate chamber, whereas CMPO based SLM was placed between intermediate and receiver chamber. Under these conditions selective transport of ^{90}Y from feed chamber is carried out to aqueous phase containing acetic acid via 4M HNO_3. The detailed description of the studies is reported elsewhere [23]. Schematic diagram of the generator is shown in Fig. 2.

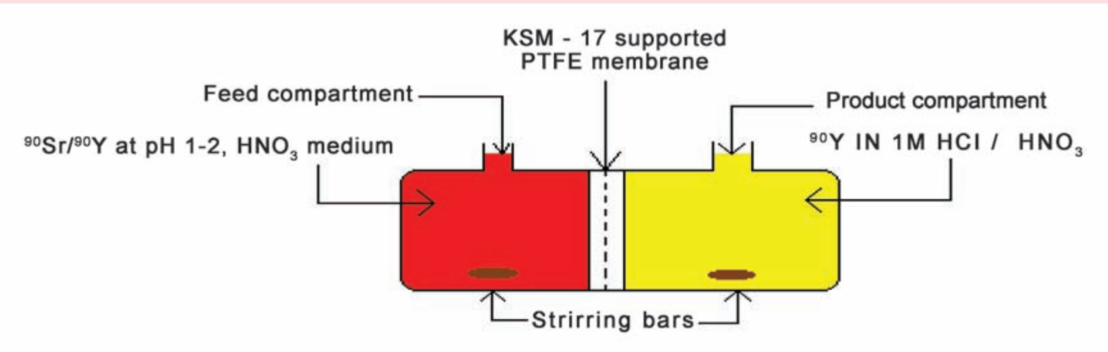


Fig. 1: Single Stage SLM Generator

The passage of ^{90}Y as monitored by changes in the β-activities of each chamber as a function of time at about 10 mCi level is given in Fig. 3. The observation on the transport pattern of ^{90}Y from feed chamber in the first stage indicated that quantitative transport to the intermediate chamber takes about three hours. There was gradual increase in the level of beta activity in the intermediate chamber up to 3 h duration, which diminishes subsequently due to its transport into the final product chamber. In the final product chamber, it was observed that >85% transport was obtained in a period of ~ 10 h.

This system was used for milking ^{90}Y in ~10-20 mCi lots in acetic acid medium for radiopharmaceutical applications. In an alternate approach the generator system was tested in sequential mode which is described below.

2.2.1 Two Stage SLM Generator in Sequential mode

Here, the system is a glass cell with two compartments similar to that used in single stage. The generator is operated in two separate steps. In the first step, the mixture of ^{90}Sr and ^{90}Y adjusted to pH 1-2 is used in the feed chamber and the receiver chamber contains 3-4 M HNO_3. KSM-17 based SLM is used for the transport of major amount of ^{90}Y to the receiver phase at 4M HNO_3 in about 4 h. The product from this first step is taken out and placed in the feed chamber in the second stage, whereas the ^{90}Y depleted lean ^{90}Sr left out in the feed compartment of the first stage is transferred back in the feed reservoir for next cycle. In this second stage, 1M acetic acid is used as receiver phase. This step generally lasts for ~4 h to get highly pure ^{90}Y in acetate form amenable for easy labeling in >90% yield.

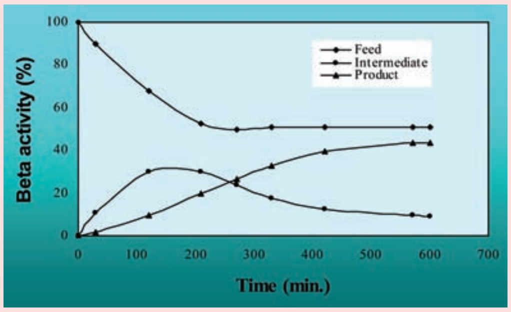


Fig. 3: Separation of ^{90}Y from $^{90}Sr/^{90}Y$ mixture using a two stage SLM system

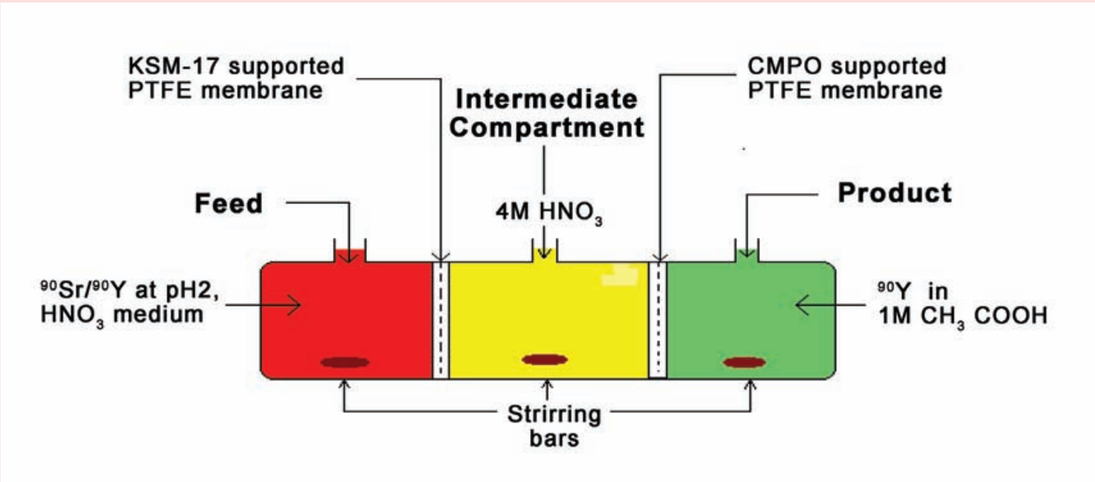


Fig. 2: Two stage Membrane Cell operated in simultaneous mode

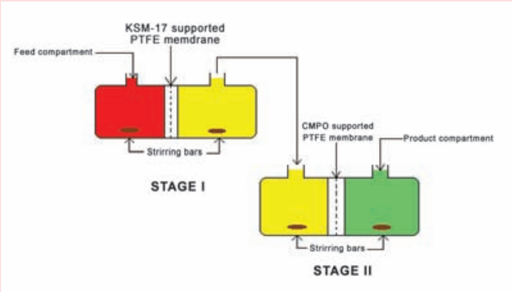


Fig. 4: Two stage Membrane Cell operated in sequential mode

The generator system operated in this mode has greater convenience and is being used for generation of carrier free ^{90}Y on regular basis.

2.1 Development of a Quality Control Procedure Based on Extraction Paper Chromatography (EPC) for Estimation of ^{90}Sr in ^{90}Y

A simple, quick, real-time quality control method based on extraction paper chromatography (EPC), for accurately estimating ^{90}Sr levels in ^{90}Y, with sensitivity better than 10^{-4}%, was developed (24). The method involves appropriate and accurate dilution of the test solution to a concentration of 1.0 mCi/mL using 0.5M ammonium acetate. A known aliquot (20-50 μL) of this test solution is applied on the paper, where a spot is impregnated with KSM-17. The paper is developed in saline. The KSM-17 retains Y^{3+} tightly at the point of application (R_f =0) and Sr^{2+} migrates with solvent front, resulting in neat sharp separation. The separated block of the paper after drying is cut and subjected to radiometric analysis in a liquid scintillation counter. Thus we estimate the amounts of radioactivity in Sr and Y regions. Since the sensitivity of this method is very high even at trace levels of ^{90}Sr in ^{90}Y, it facilitates real-time quality control (QC) of the ^{90}Y obtained from the generator, before actual use of ^{90}Y labeled product for therapeutic applications.-This is the first report on a real-time QC analysis of ^{90}Y and hence named as "*BARC Method for Quality Control of ^{90}Y*". All the ^{90}Y product samples separated by the generators are being tested regularly for its quality by this method. The contamination of ^{90}Sr in the ^{90}Y product is always found to be <0.001%, which is far below the permissible level.

2.1.1 Upgradation of the ^{90}Sr-^{90}Y generator system at 100 mCi level

Studies were further continued to upgrade the generator system to generate ^{90}Y at ~100 mCi level for routine application in radiopharmaceutical centers. Owing to operational simplicity, sequential mode was preferred for upgradation. The generator system operated in this mode showed a separation yield of 92 ± 3% from five independent operations. The data on the activity transport in first and second stage are given in Fig. 5 a & b.

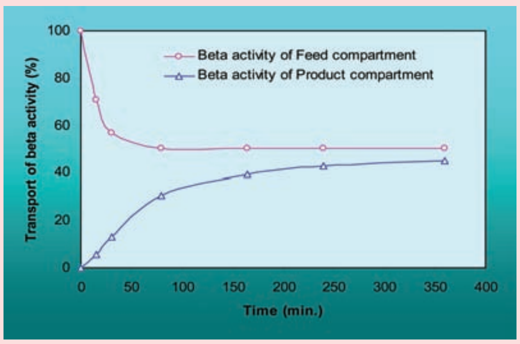


Fig. 5a: Transport of ^{90}Y in 1st Stage at 100 mCi Level

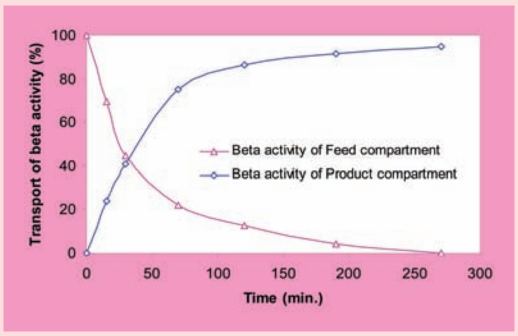


Fig. 5b: Transport of ^{90}Y in 2nd Stage at 100 mCi Level

The quality control of the ^{90}Y product was carried out by the EPC method described above. The level of ^{90}Sr in all the ^{90}Y products was found to be less than 0.001%. A typical extraction paper chromatogram is shown in Fig. 6.

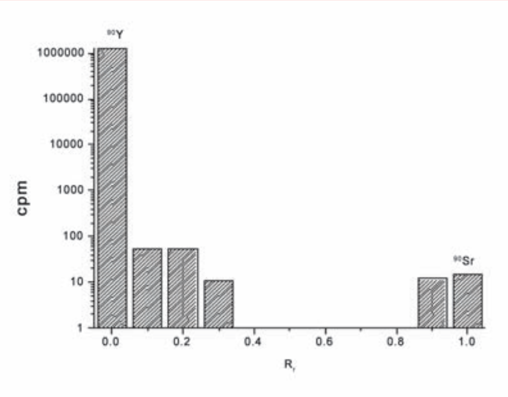


Fig. 6: EPC of a sample of ^{90}Y from SLM generator

CONCLUSION

Supported Liquid Membranes based ^{90}Sr-^{90}Y generators can be used for the clean separation of ^{90}Y from ^{90}Sr suitable for radiopharmaceutical applications. Yield exceeding 90% is achievable under optimized operating conditions. The purity of the ^{90}Y product can be checked by simple and reliable quality control procedure based on extraction chromatography with sensitivity better than 10^{-4} %.

ACKNOWLEDGEMENTS

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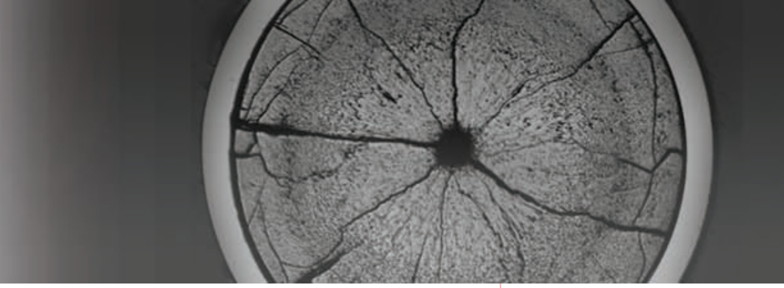

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Post Irradiation Examination of Thermal Reactor Fuels

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Abstract

The Post Irradiation Examination (PIE) facility at Bhabha Atomic Research Centre, Trombay, over the past thirty years, has been used for examination of different types of experimental as well as power reactor fuels and for validation of fuel modeling codes. This article describes the facility and brings out the results of some of the examinations carried out on irradiated experimental MOX fuels and fuels of PHWRs.

Introduction

The fuels used in nuclear power plants are fabricated under stringent quality control. The fuel operates in a hostile environment of high temperature, steep thermal gradient, high energy charged particles, fission fragments and fast neutron flux. The fuels are designed to withstand the normal operating conditions and other envisaged accidental scenarios, for the smooth running of a nuclear plant. The performance of the fuel is crucial for the plant performance, which has a large bearing on economics of nuclear power and radiation safety. Towards the monitoring of performance and also to get to the root causes of fuel failures, detailed PIE is carried out on selected fuels discharged from

Fig.1 The Post Irradiation Examination facility at PIED, BARC

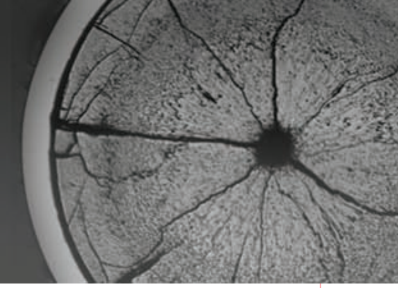


Table 1: List of fuels examined at the PIE facility

Sl. No.	Fuel pins/bundles	Reactor
1	Experimental UO_2 Fuel pins (9 pins)	PWL, CIRUS
2	BWR (18 fuel pins)	TAPS, units 1 and 2
3	Experimental UO_2-PuO_2 fuel clusters (15 fuel pins)	PWL, CIRUS
4	PHWR UO_2 (14 bundles)	Various power plants
5	PHWR ThO_2	KAPS#2
6	Experimental ThO_2-4%PuO_2 (5 pins)	PWL, CIRUS
7	Experimental ThO_2-6.75%PuO_2 (2 pins)	PWL, CIRUS
8	Experimental UO_2-3%PuO_2 (2pins)	PWL, CIRUS
9	Experimental ThO_2 (2pins)	PWL, CIRUS

power reactors. This examination generates information which is useful for fuel designers, fuel fabricators and reactor operators to bring about changes for optimizing the performance of fuels.

Central to the PIE activities are the six concrete shielded hot cells, capable of handling radioactivity varying from 10^2 Curies to 10^5 Curies of 1.3MeV gamma radiation and are shown in Fig.1. The cells are equipped with radiation shielding windows, master slave manipulators, periscopes, service plugs, external transfer drawers, inter cell transfer drawers, personnel entry doors, roof plugs, in-cell lighting and operate at a negative pressure with respect to the surrounding areas. The cells are provided with elaborate ventilation, waste disposal and radiation monitoring systems to enable safe working of the operating personnel. The irradiated fuel is brought from the research reactors located in Trombay and from power reactors in shielded casks and introduced into the hot cells through fuel transfer port without compromising the radiation shielding.

The list of fuels examined in the facility is given in Table.1. The experimental fuels were manufactured at the Radiometallurgy Division, BARC and irradiated in the Pressurized Water Loop (PWL) of CIRUS research reactor. The design of the experimental fuels and their irradiations were co-ordinated by the Reactor Engineering Division, BARC. In addition to these fuels, a large number of fuels from DHRUVA reactor were examined both in the initial stages of fuel development and also during the course of its operation.

FACILITIES AVAILABLE FOR PIE

PHWR fuel bundle dismantling machine

PHWR fuel is in the form of a bundle, as shown in Fig. 2a. This bundle is dismantled by cutting the end plates with a remotely operated bundle dismantling machine. The cutting is carried out using Nd-YAG laser beam guided into the cell using an optical fibre. The movement of the laser head is computerised and is numerically controlled. This machine was developed jointly with the Division of Remote Handling and Robotics, the Atomic Fuels Division and the Raja Ramanna Centre for Advanced Technology, Indore. Fig. 2b shows the laser based

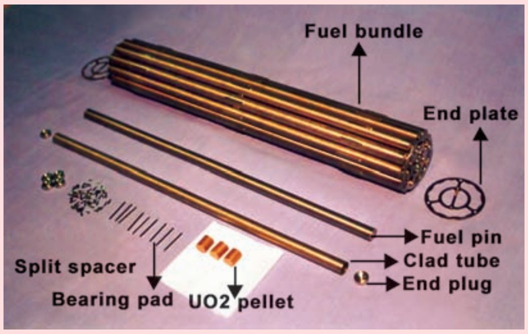


Fig. 2a: Components of a 19-element PHWR fuel bundle

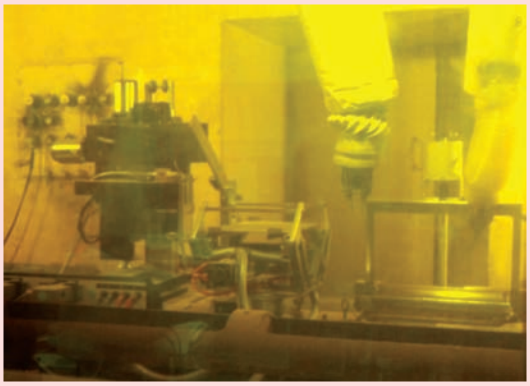


Fig. 2b: PHWR fuel bundle dismantling machine inside the hot cell

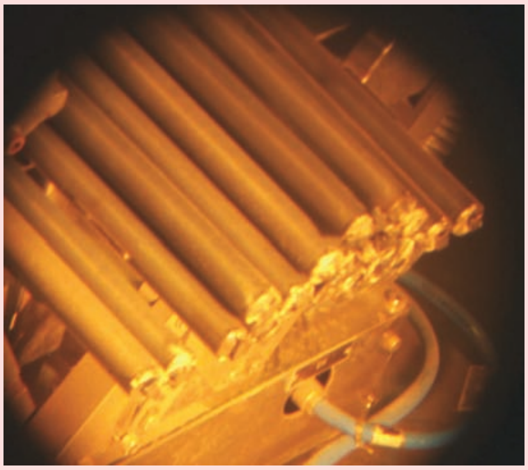


Fig. 2c: Elements separated after dismantling

fuel bundle dismantling machine inside hot cells and Fig. 2c shows separated fuel pins after the dismantling.

NON DESTRUCTIVE EXAMINATIONS

Visual Examination

After dismantling, the individual pins are visually examined using wall-mounted periscopes at magnification of 2X and 10X for the integrity of all the welded appendages, presence of surface defects like cracks, corrosion, discoloration, fretting, ridging etc. Fig. 3a shows a scanning wall periscope being used for visual examination and Figs. 3b to 3f show the periscopic view of failures identified during the visual examination of PHWR fuel bundles received from power reactors.

Fig. 3a: Wall periscope for visual examination in hot cells facility.

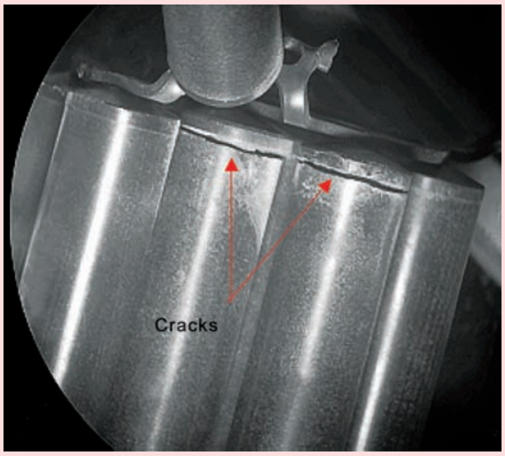


Fig. 3b End cap weld cracks observed in PHWR fuel bundle no. 54505.

Fig. 3c: Cracked endplate of a PHWR fuel bundle.

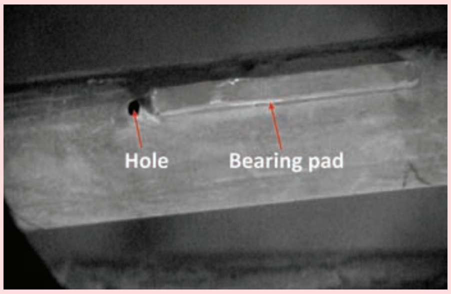


Fig. 3d: Pinhole due to damaged bearing pad from bundle no. 102653

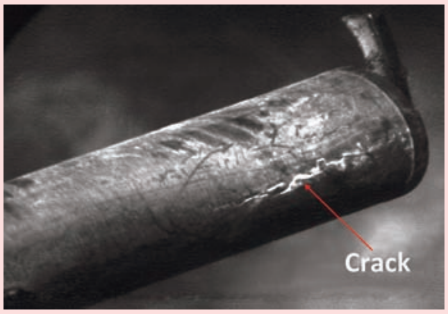


Fig. 3e : Crack on the cladding of an outer fuel pin from bundle no. 108305

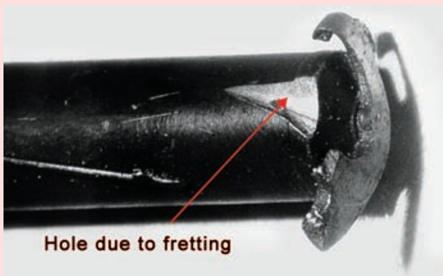


Fig. 3f: Fretting failures seen during the early stages reactor operation

Liquid nitrogen-alcohol leak test on fuel pins

All seemingly intact fuel elements are subjected to leak tests inside the hot cells. The cleaned fuel pin is dipped in liquid nitrogen for about five minutes. In case of a leaky fuel element, the internal cavity of the fuel element would get filled up with liquid nitrogen. The fuel pin is then transferred to an alcohol bath at room temperature. Any entrapped liquid nitrogen will bubble out through the leak on expansion in the warmer alcohol bath, thus enabling the identification of the leak site. The nitrogen bubbles emanating out of one such leak are shown in Fig. 4a and a close-up of the leak area is shown in Fig. 4b.

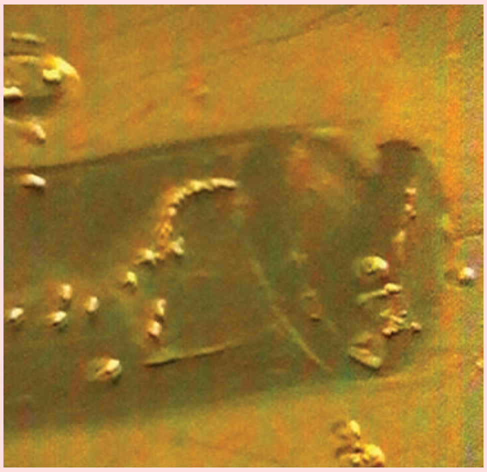


Fig. 4a: Nitrogen gas bubbles coming out of the leak in the end cap weld.

Fig. 4b: White patch around the zone containing leak near the weld.

Ultrasonic testing of end cap welds in fuel pins

Remote immersion ultrasonic testing has been developed and used inside the hot cell to inspect end cap weld region of PHWR fuel elements, as end cap region could be one of the primary sources of defects. Fig. 5a gives the principle employed in detection of partial fusion and root crack in the end cap welds and Fig. 5b shows the arrangement used inside the hot cell for testing these welds. The signals obtained from a sound weld and a defective weld is shown in Figs. 5c and 5d.

Ultrasonic testing of fuel element cladding

Ultrasonic testing is carried out to detect incipient sub-surface, part through-wall cracks that might be present in the fuel cladding, which are otherwise are not discernible during visual examination and also cannot be revealed by leak testing. The arrangement for remote immersion ultrasonic scanning of PHWR fuel cladding is shown in Fig. 6. The set-up has arrangement for both longitudinal and circumferential scanning of the fuel cladding.

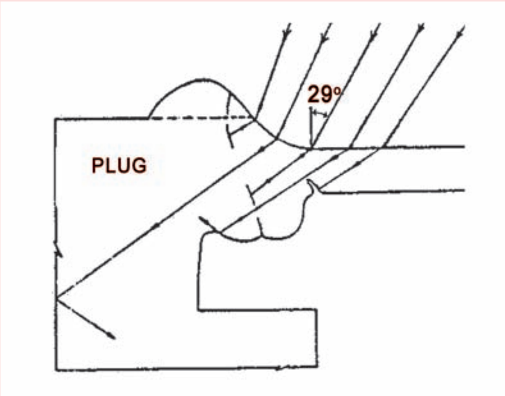


Fig. 5a: Ultrasonic testing of end cap welds for lack of fusion and root cracks.

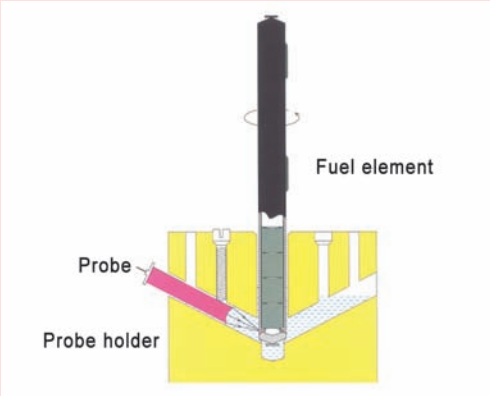


Fig. 5b: Fuel pin in the probe holder unit.

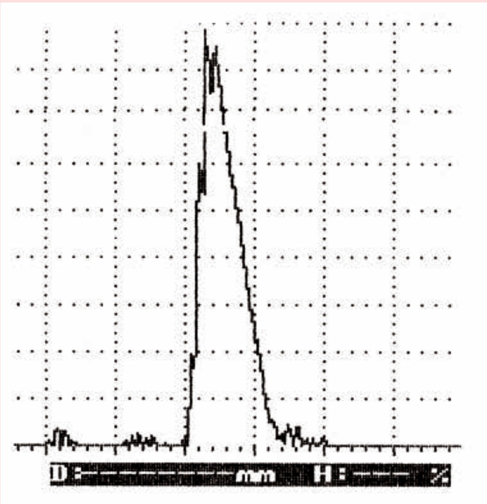


Fig. 5c: Weld step signal from a sound end cap weld

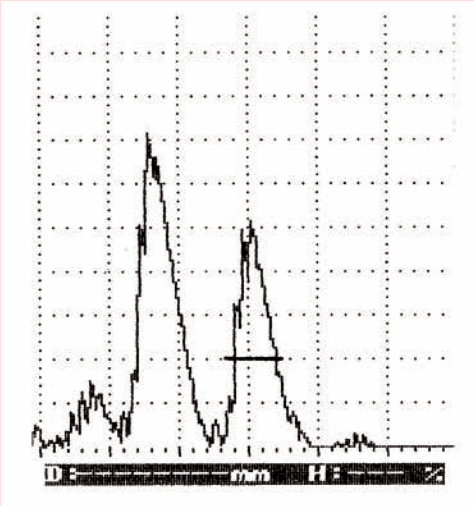
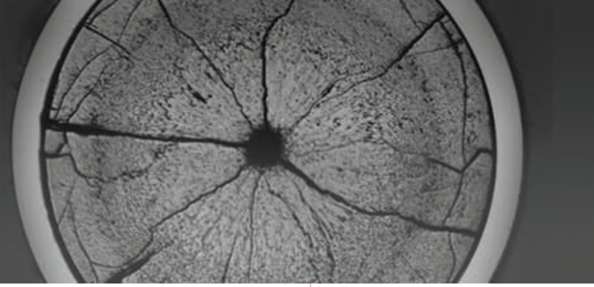


Fig. 5d: Signal from a defective weld with partial fusion



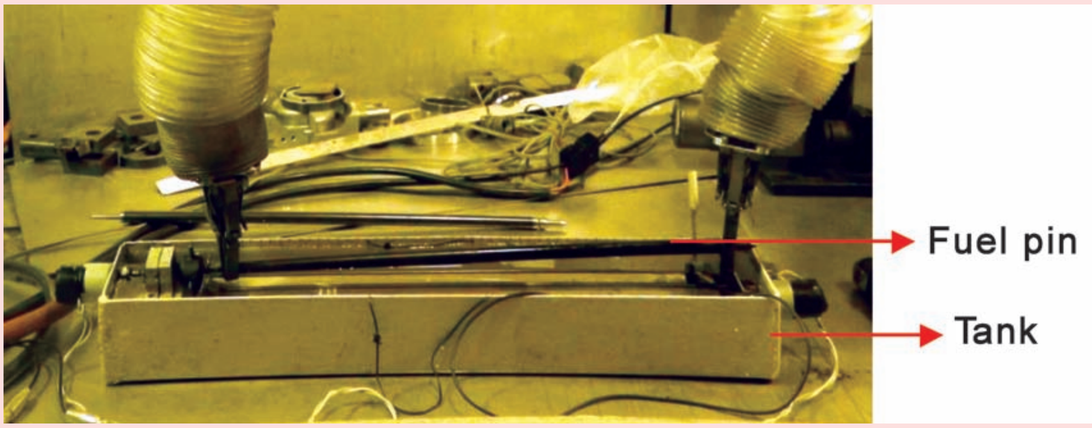
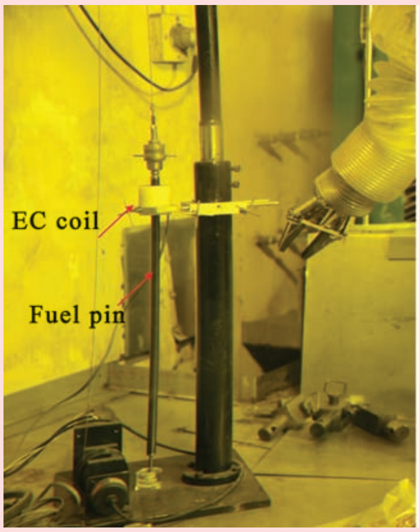


Fig. 6 : Ultrasonic immersion scanner for PHWR fuel pins. Motors fitted on both ends of the tank are used to translate the ultrasonic probe along the length of the fuel element and also to rotate the fuel to enable helical scanning of the fuel element cladding. The system can also be used for the ultrasonic inspection of end plug welds.

Eddy current testing

Eddy Current Testing (ECT) with an encircling coil is a sensitive test for detecting, localized dimensional variations like ridging at pellet interface and fretting wear point defects in the fuel cladding. ECT is also used to measure oxide layer thickness and detection of hydriding in the zirconium alloy cladding of the irradiated fuel elements. Fig. 7a shows the eddy current testing set up inside the hot cell used for of irradiated fuel pins and Fig. 7b shows the signal obtained from a defect in the cladding from of a fuel element from AC-6 cluster irradiated in PWL, CIRUS.



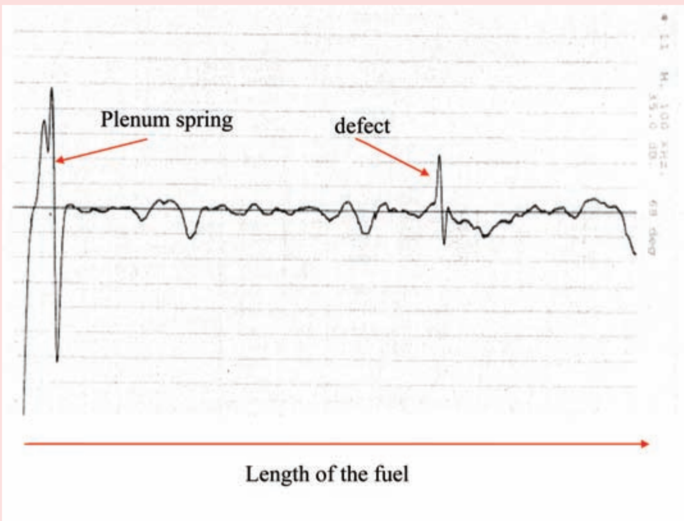


Fig. 7a Eddy current test set up.

Fig. 7b: Signal obtained from a defect in the fuel cladding.

Gamma scanning

Gamma scanning of irradiated fuel is carried out by translating it in front of a collimator of a radiation counter. The counting is performed using a NaI(Tl) detector or a HPGe detector coupled with a multichannel analyser. The output gives an idea regarding the burn-up profile along the length of the fuel element, distribution of specific fission products, enrichment mix-up, loss of fissile material and widening of inter pellet gap. Generally the variation of gamma activity due to Cs^{137} isotope is monitored in gamma scanning.

DESTRUCTIVE EXAMINATIONS

Released fission gas analysis

As a part of destructive examination, fuel elements are punctured for the measurement of the amount of released fission gases. Volume of the released fission gas and the void volume in the fuel pin are measured to arrive at the pressure inside the fuel pin. A dual column gas chromatograph and a quadrupole mass spectrometer are used to analyse the respective chemical and isotopic composition of the collected gases. The entire analysis is carried at sub ambient pressures from safety point of view.

Fig. 8a shows the fission gas puncture chamber, used for puncturing fuel elements, installed inside the hot cells and Fig. 8b the analysis part of the set up installed in the operating area.

Microstructural Examination

The regions of interest from the fuel element are sectioned using remotely-operated low-speed precision cutting wheels. The irradiated fuel in the cut section is held in place by a cold setting resin that is sucked into the fuel by applying suction vacuum from the other end of the fuel pin section. The set section is further cut, mounted and prepared for metallographic examination using a set of remotely operated grinders and polishers, one of which is shown in Fig. 9a. The prepared section is examined using a remotely operated, shielded metallograph, Fig. 9b. The microstructure of the irradiated fuel provides the information on the performance of the fuel and also the root cause of failure. β–γ autoradiography on the metallographic samples is carried out to study the distribution of fission product (Cs) across the cross section. α–autoradiography is carried out to analyse the distribution of plutonium in the fuel cross section.

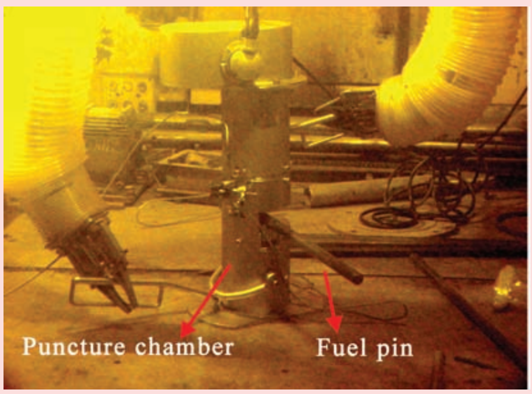


Fig. 8a :A low dead volume puncture chamber used for measurement of volume of released fission gases.

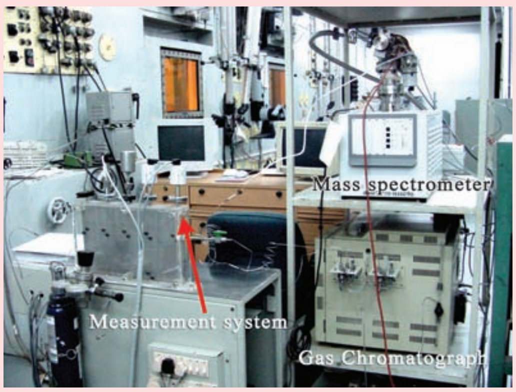
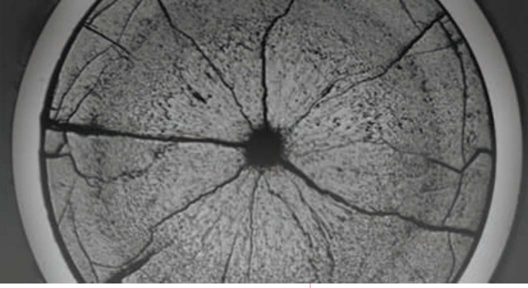


Fig. 8b The analysis part of the set up comprising of gas chromotograph and a quadrupole mass spectrometer.



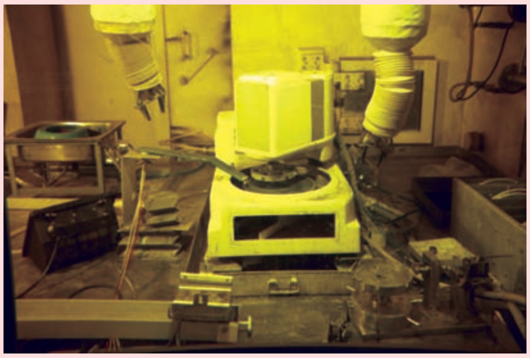


Fig. 9a: Metallographic preparation set up inside the hot cell.

Fig. 9b: Remotised- shielded metallograph with radiation resistant optics used to examine samples from irradiated fuels

Mechanical testing

Tension tests are carried out on rings cut from the irradiated fuel element cladding using a remotely operated universal testing machine kept inside the hot cells (Fig. 10). The fuel is removed from the cladding before mechanical testing. The controls and data acquisition system are kept in the operating area. The tests are carried out up to a temperature of 300ºC to assess the irradiation induced changes in the mechanical properties. The results from the ring tension tests and the deformation behaviour of the clads are shown in Fig. 11 and 12 respectively.

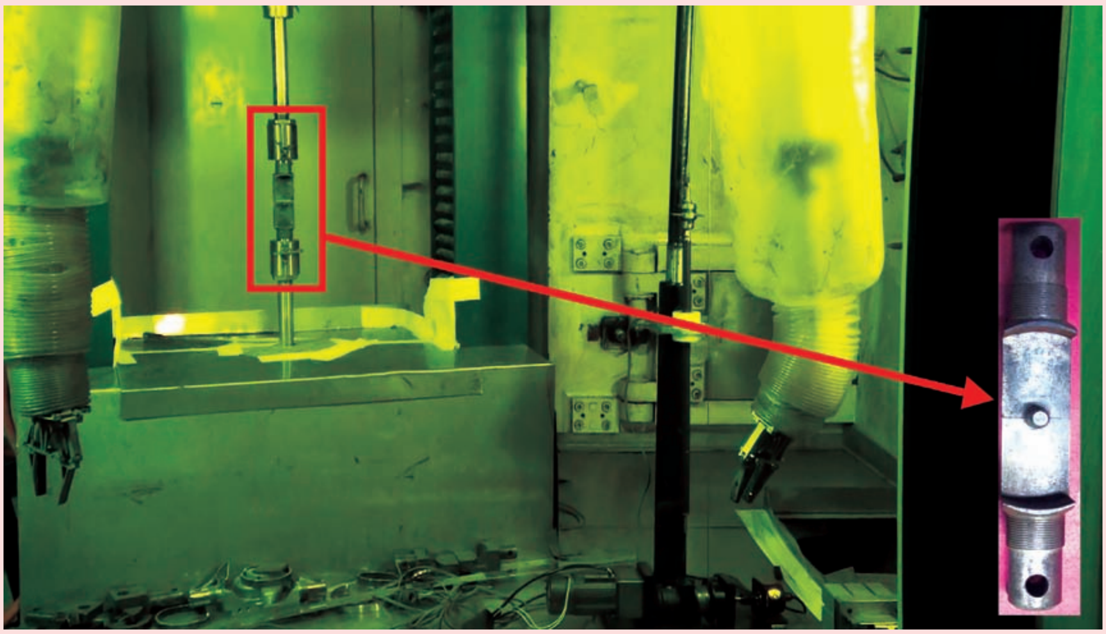


Fig. 10: Screw driven universal testing machine inside the hot cell and the ring tension test grip set (right inset).

Ring tension tests (RTT) were carried out using around 3.5 mm wide rings cut from the clad tubes. These rings were pulled along the hoop direction using two split semi-circular mandrels with a curvature that fitted into the inner diameter of the rings, having effective specimen gauge length of 5.2 mm. The tests at 583 K were carried out in an electrically heated environment chamber.

At ambient temperature, the failure in the irradiated fuel claddings occurred with formation of shear bands and the fracture surface was inclined at about 45° to the tensile loading axis resulting in limited ductility levels. Tests near reactor operating temperature (~583K) of the clad tubes showed a large increase in the ductility levels for the low as well as high burnup fuel clad tubes. At reactor operating temperature all claddings showed significant levels of gross deformation before failure combined with irradiation induced hardening. Defective fuel clads, having high hydride density, were found to be severely embrittled at ambient test temperature but its ductility also improved significantly near the reactor operating temperature. Presence of a large density of hydride platelets, accompanied by irradiation induced shear band formation, at the test temperature had a dominant role in reduction of clad ductility.

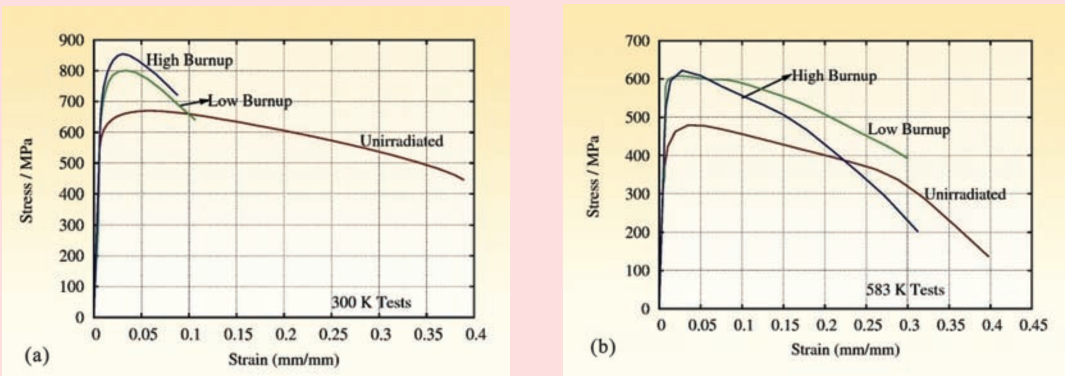


Fig. 11: Circumferential tensile deformation behaviour of low and high burnup fuel pin claddings, (a) at ambient temperature (300 K) showing irradiation hardening and reduction in clad ductility and (b) at 583 K showing significant increase in clad ductility at elevated temperature.

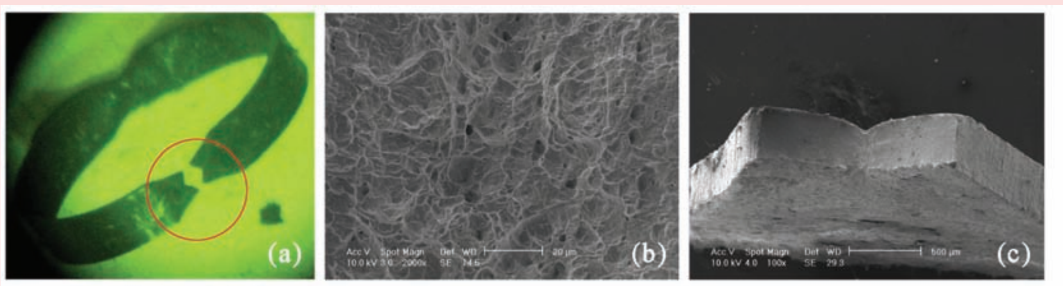
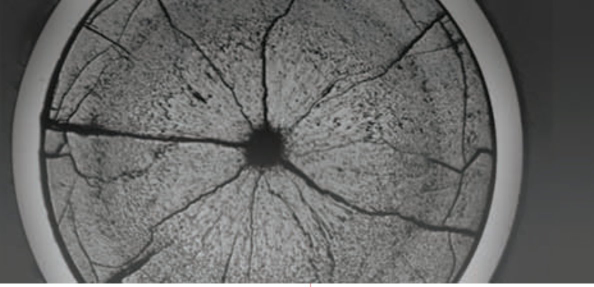


Fig. 12: Deformation behaviour of clad after burnup level of above 15000 MWd/tU at 583 K showing (a) significant level of ductility (b) failure by void formation in the central portion of specimen followed by (c) localized shearing at 45° to the loading direction.



Fuel pin ballooning experiments

There is an interest to study the effect of a sudden increase in temperature of the irradiated fuel for analyzing its behavior under loss of coolant accident conditions. To simulate such effects, a furnace is available in hot cells where a part of the fuel element can be heated to temperatures up to 1300°C and this is shown in Fig. 13a and 13b. Such studies have been carried out on PHWR fuel elements having different burn ups. The mechanism of clad deformation at such temperatures has been established metallographically. The clad creep rate has also been established at the temperature for Zircaloy-2. Few ballooned fuel pins and the microstructure near the failed region of the cladding are shown in Figs. 13c and 13d respectively.

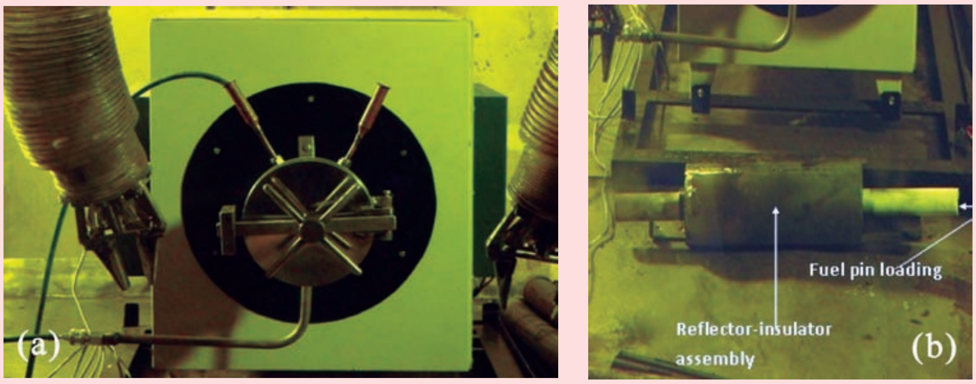


Fig. 13: Furnace used for ballooning studies on irradiated fuel

Fig. 13c: Some of the ballooned fuel elements are shown.

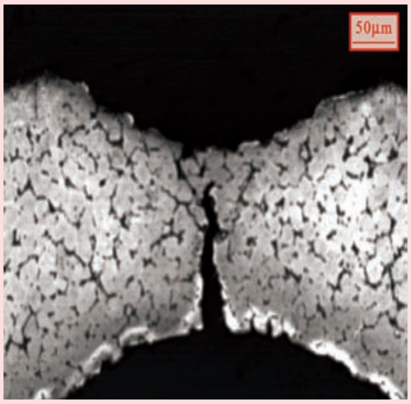


Fig. 13d Metallographic section through the failed region of the cladding. The grain boundary cavities indicate that the primary cause for failure is thermal creep.

The fuel pins had internal fission gas pressures of 2.4MPa and 0.55 Mpa. A part of the fuel was introduced into the region of the furnace that was kept at temperatures ranging from 700°C to 1300°C, thus simulating a sudden heating up of the cladding envisaged during a LOCA. The temperatures were held for about 10-15 minutes. While lower temperatures did not lead to failure of the fuel cladding, the cladding failed at higher temperatures with a diamteral deformation of around 37%.

SOME OF THE FUELS EXAMINED

MOX fuels

In a programme to assess the performance of (U,Pu)O_2 MOX fuel, prior to its introduction in commercial reactors, three experimental MOX fuel clusters fabricated at RMD were irradiated in the Pressurized Water Loop (PWL) of CIRUS. The detail of such fuels is given in Table.2. A typical experimental MOX fuel pin is shown in Fig.14.

No abnormal corrosion, deformation or ridging was observed during visual examination and profilometry of the irradiated MOX fuel pins. Leak testing confirmed that all the fuel pins were intact. The microstructure did not indicate any abnormality thus paving the way for the introduction of such fuel in TAPS BWR. The microstructural features of fuel pin sections taken from AC-2 and AC-4 cluster are shown in Fig.15 and Fig.16 respectively.

Table 2: Details of the experimental fuels irradiated in PWL, CIRUS:

Cluster designa tion	Fuel composition	Number of fuel pins	Cladding type	Burn up (MWd/Te)	Peak liner heat rating, kW/m
PWL-P1	UO_2-1.5% PuO_2	Single element	Collapsible	400	
AC-2	UO_2-4% PuO_2	Six	Free standing	16,265	41.4
AC-3	UO_2-4%PuO_2 Chamfered pellets, Controlled porosity pellets included	Six element cluster— (3 MOX, 3 He filled)	Free standing	16,000	49.0
AC-4	UO_2-4%PuO_2 Solid pellets, annular pellets, higher grain size pellets, low temperature sintered pellets and varying pellet clad gap.	12 element cluster. Six with fuel and the other six with He	Free standing	2,000	49.0
AC-6	ThO_2-4%PuO_2	5+1He filled	Free standing	18,500	39.5
BC-8	ThO_2-6.75% PuO_2	Two	Collapsible	10,300	42.5
	UO_2-3% PuO_2	Two			
	UO_2	Two			
	ThO_2	Six			

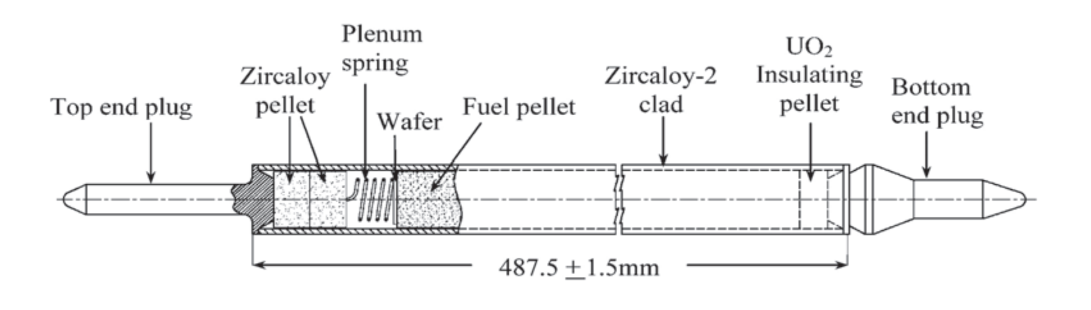


Fig. 14: A typical experimental fuel pin for MOX irradiation

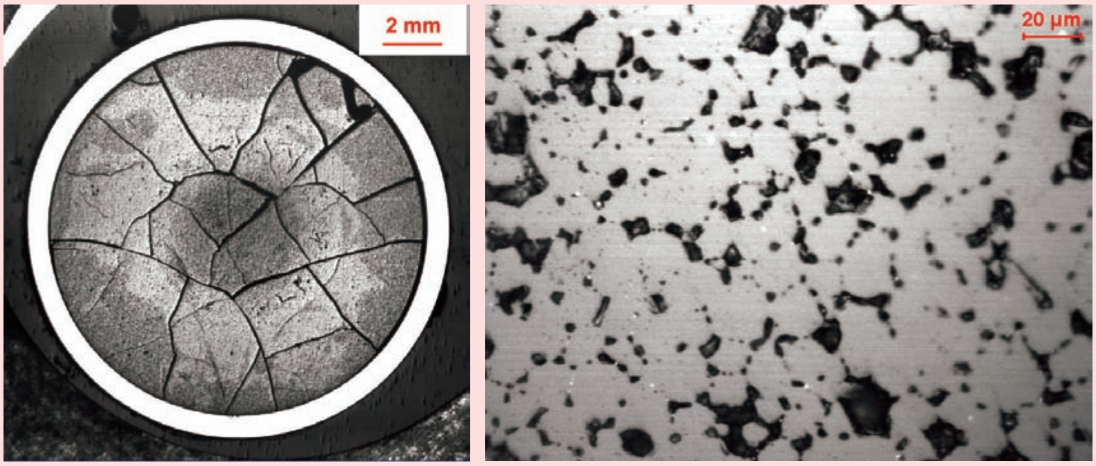


Fig. 15: Examination of metallographic samples of a pin from the AC-2 cluster revealed a central dark porous region as shown in the figure. The centre of the fuel revealed grain growth and interconnected pores at the grain boundaries as shown on the right. Such a microstructure is indicative of normal performance of a fuel.

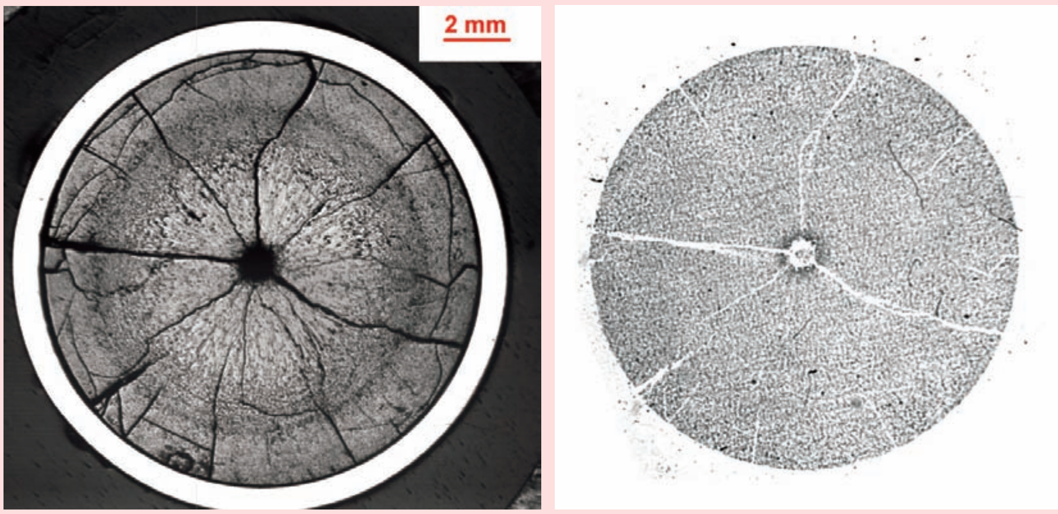


Fig. 16: Microstructural examination of pin M-11 of AC-4 cluster revealed restructuring of fuel with formation of a central void, columnar grain region and equiaxed grain growth region in the transverse fuel section. The figure on the left shows the photomicrograph revealing restructuring in the fuel and figure on the right shows the α-autoradiograph of the fuel section revealing a dark region near the central void due to Pu migration and accumulation. Puncture tests carried out on this fuel pin indicated presence of carbon monoxide in the pin. Pre-irradiation documentation of the pellets indicated a higher impurity level of carbon in the pellets compared to the pellets in other pins, though well within the specifications. It appears that the CO formed during early stages of sintering (as low temperature oxidative sintering route was used in the manufacture of the pellets used in this fuel element) had got trapped in the pores. The trapped CO might have got released during irradiation thereby reducing the thermal conductivity of the filler gas helium resulting in a rise in the fuel central temperature and consequent restructuring.

PHWR FUELS

PHWR fuel of 15,000MWD/tU burnup

Results from PIE of one of the two high burn up fuel bundles are discussed in this section. The linear power rating of the fuel pins in the outer ring is around 20% higher than that of the pins in the intermediate ring and the central element. The examined fuel bundle had attained an average burnup of 15,000MWd/tU, which is more than twice the design discharge burnup of 7,000 MWd/tU. Visual examination and leak testing showed that all the 19 fuel pins were intact, without any evidence of deterioration, demonstrating that PHWR fuel pins can be operated to such high burnup, without failure. There were no signs of pellet-clad interaction or crevice corrosion at the weld between the clad and the bearing pad in the fuel cross sections examined. Results of fission gas release measurement and microstructural data generated on the fuel pins from bundle no. 56504 are summarised in Table 3. Fig. 17 explains the microstructural variation in the fuel cross sections taken from different pins of bundle no. 56504.

Table 3: Summary of PIE results on 15,000MWD/tU burnup PHWR fuel bundle

Parameter	Outer pin	Intermediate pin	Central pin
Fission gas release, %	20	2	0.7
Fission gas pressure, kg/cm^2 (Ambient temperature)	28	4.3	3.2
Estimated fuel central temperature, ºC	1700	1250	1170
Grain size, µ	33	19	15
Pellet-clad gap, µ	32	27	16
Oxide layer thickness on the inner surface of the fuel cladding, µ	5	Thin and discontinuous	0
Oxide layer thickness on the outer surface of the fuel cladding, µ	2.7	2.4	2.4
Oxide layer thickness on the bearing pad	3.7	—	—

Fuel Bundle No. 56504

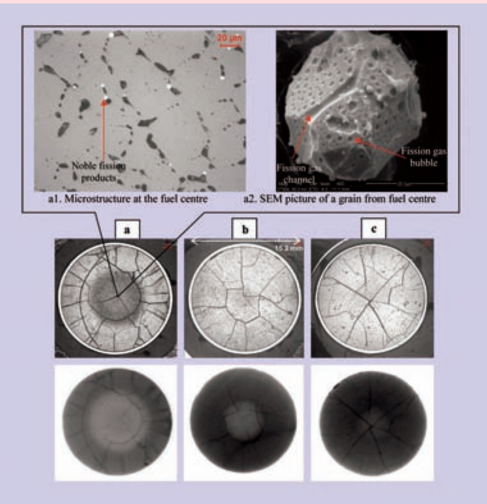


Fig. 17 Microstructure & β–γ autoradiographs of high burnup PHWR fuel

The results of the metallographic examination of the transverse sections taken from different outer, intermediate and central elements are shown. The as-manufactured microstructure of the fuel had undergone changes during irradiation in the reactor due to the intense heat generated by nuclear fission. The extent of this change decreased from the outer element to the central element and is governed by the linear heat rating of the pins in the fuel bundle. The size of the dark porous region at the fuel centre is the highest for the outer element (a) and is quite small for the other two fuel elements (b and c). The corresponding β–γ autoradiographs of the outer, intermediate and central fuel pins are also given in the figure. The central bright region in the autoradiographs indicates that the volatile radioactive fission products have migrated from the central region to the periphery of the fuel section. Observation of the dark porous region at higher magnification revealed interconnected bubbles on the grain boundaries (a1). The scanning electron micrograph of a grain of UO_2 (a2) from the central region shows precipitated fission gas bubbles on the face of the grain which subsequently gets inter-linked to form channels on the grain edges.

MICROSTRUCTURE EVOLUTION IN FAILED FUELS

Fuel failure leads to alteration of the microstructure of the fuel. Fig. 18 and Fig. 19 describe the evolution in microstructure of fuel and cladding in failed fuel pin from bundle no. 108305 and 82505 respectively.

Fuel Bundle No. 108305

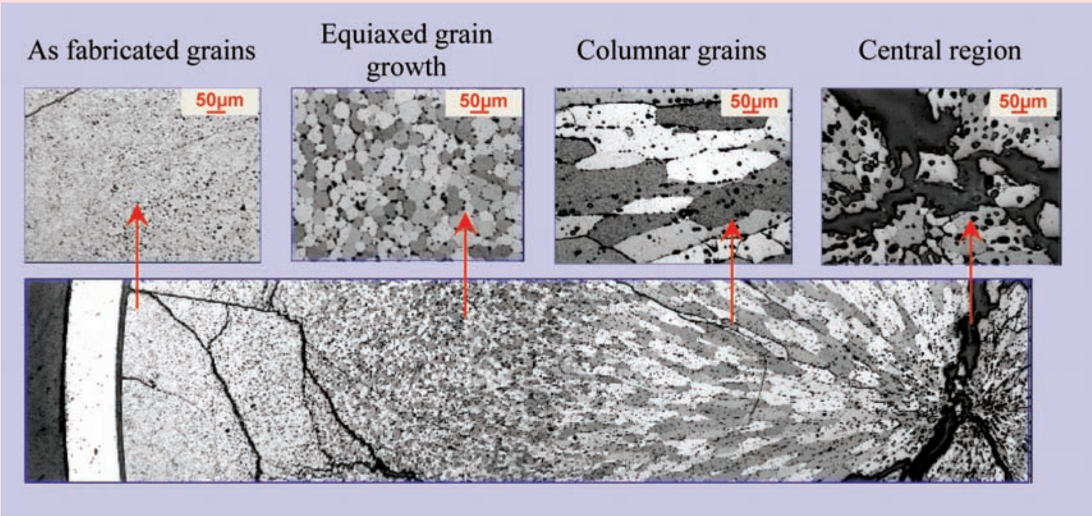


Fig. 18 Restructuring in fuel occurs due to a steep temperature gradient from the centre to the periphery of the fuel. Boundaries of the microstructural regions in an irradiated UO_2 fuel can be used as markers for estimation of fuel centre temperature attained during operation.

- Up to 1150ºC as-sintered microstructure is retained.
- Above 1150ºC the grain boundaries act as a sink for the fission gases which diffuse and form pores at the grain boundaries.
- Above 1300ºC there is equiaxed grain growth.
- Above 1700ºC the vapour pressure of UO_2 becomes high and under the severe radial temperature gradient causes -
  - o Migration of pores up the temperature gradient, towards the fuel centre, due to evaporation of UO_2 from the hotter side of the pore followed by condensation of UO_2 on the colder side of the pore leading to the formation of columnar grains
  - o The porosity accumulates at the fuel centre forming a central void.

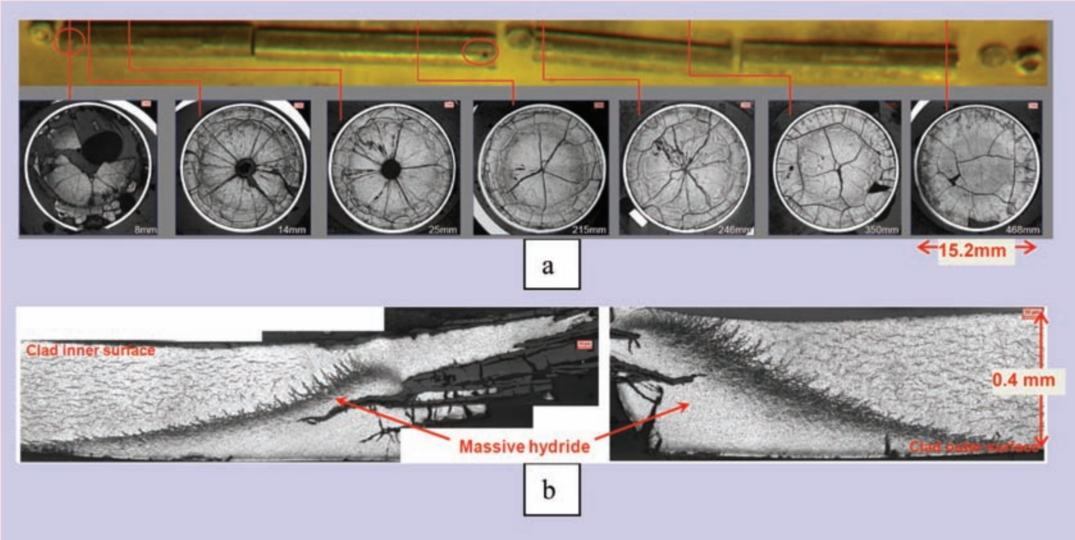


Fig. 19a: A fuel pin with a defective end plug weld operated in the reactor for a period of 710 days and accumulated a burnup of 4400 MWd/tU. Metallographic cross sections from different regions of the fuel pin are shown.

Fig. 19b : Section thorough a massive hydride blister in the fuel cladding from the same fuel pin.

a. The defective end plug is located on the left hand side of the photograph of the fuel pin. Water entered inside the fuel pin through this defect and flashed into steam and filled the fuel-clad gap. Presence of steam inside the fuel-clad gap reduced the gap conductance, oxidized the fuel and cladding, reducing the thermal conductivity, of the fuel causing an increase in the fuel central temperature. Extent of restructuring observed in the fuel is shown in the series of macrographs revealing central void in the fuel at one end and grain growth at the other end.

b. The oxidation of fuel and cladding produce hydrogen/deuterium which gets picked up at vulnerable sites on the inner surface of the clad. Local massive hydriding at these locations lead to “sunburst” type of blister formation resulting in holes in the fuel element cladding. Such holes seen in the fuel element during the visual examination are shown below.

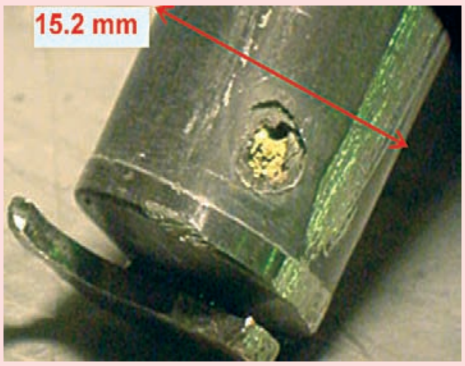


Fig. 19c: A pin-hole near the end plug weld of the fuel element. The UO_2 had got oxidized by the steam generated due to ingress of water in the pin.

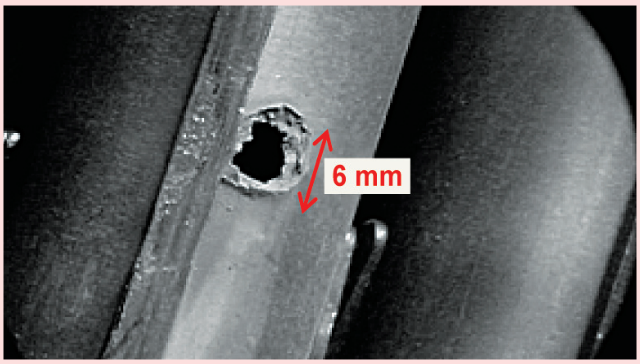
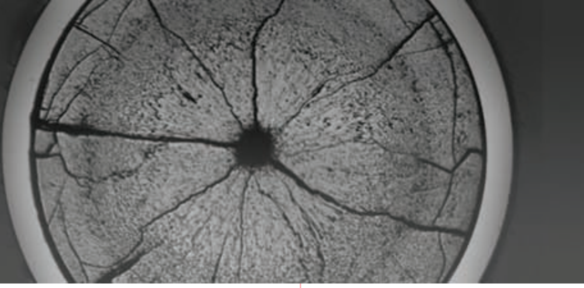


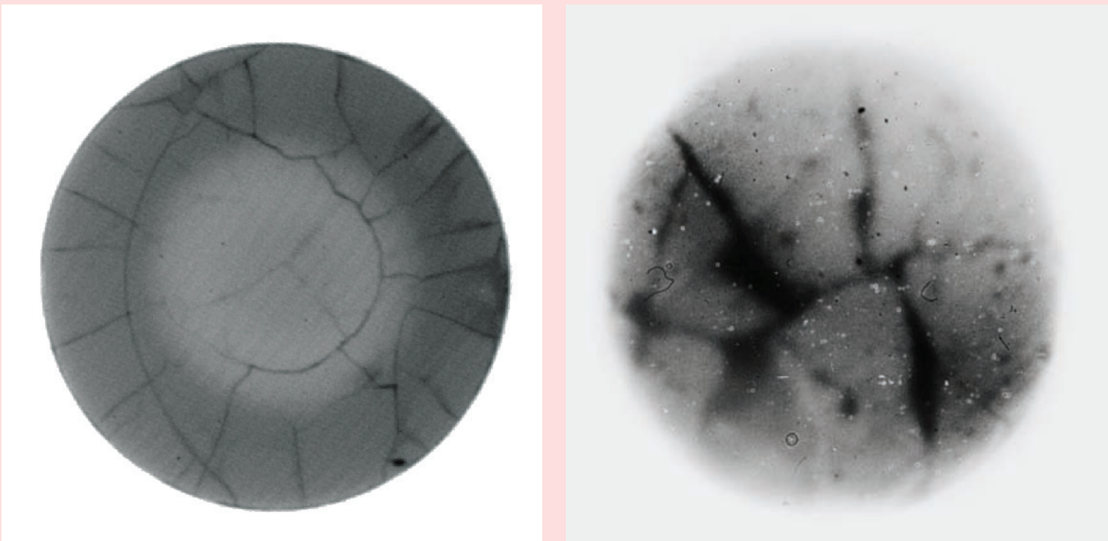
Fig. 19d: Another hole due to hydride blister is seen in the same fuel pin clad near middle bearing pad.



PHWR Thoria fuel bundle

The ThO_2 fuel bundle irradiated in KAPS to a burnup of 11,000 MWd/t(Th) did not show any defect or aberration, as revealed by the results from leak test and visual examination of the individual pins after bundle dismantling. Puncture tests carried out on the pins did not indicate any fission gas release. The β–γ-autoradiographs of outer elements of UO_2 and ThO_2 fuel bundle having similar burnup are compared in Fig. 20.

Post irradiation examination of experimental thoria fuel and thoria based MOX fuel assemblies showed excellent performance of these fuels with minimal discernible changes in the fuel microstructure and negligible release of fission gases under steady state conditions. However, the capacity of these fuels to withstand the repeated power ramp, multiple cycle irradiations during its service in power reactors will have to be investigated further.



β–γ–autoradiograph of UO_2 β–γ–autoradiograph of ThO_2

Fig. 20 The β–γ–autoradiographs of outer elements of UO_2 and ThO_2 fuel bundle having similar burnup are shown. β–γ–autoradiography indicates presence of Cs in the fuel cracks (darker regions) and the cracking in ThO_2 is not as extensive as observed in a UO_2 fuel section. The uniform presence of Cs across the cross section of the thoria indicates that the thermal gradients in thoria pellet were not sufficiently high to cause any migration of fission products

SUMMARY

The facilities available for PIE of thermal reactor fuels and the examinations carried out on some of them have been given in the article. The causes of some of the failures of PHWR fuel elements have been explained. The evolution of fuel microstructure of due to irradiation of PHWR fuel elements to higher burnup is brought out. The nature of fuel restructuring in cases of fuel clad rupture is also described.

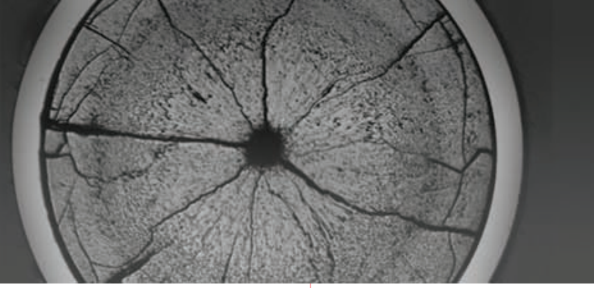
Though the examination of PHWR fuels with extended burnups, throws light on the performance of the fuel under normal operating conditions, its behavior under envisaged off-normal conditions has to be arrived at by modeling or by simulation like the fuel pin ballooning experiments, a glimpse of which has been presented.

'InDA–APDA Conference (InDACON-2010) on Desalination & Water Purification': A Report

A Three-day conference on 'Desalination and Water Purification' was organized at Chennai (India) from March 10–12, 2010 under the auspices of the Board of Research in Nuclear Sciences (BRNS) in association with the Indian Desalination Association (InDA) and the Asia Pacific Desalination Association (APDA). This was to bring together the stakeholders in desalination & water purification technologies to exchange information, identify the gaps in technology and implementation of related programmes and to assess possible techno-economic solutions to fulfill the societal objective of providing purified water. About 225 delegates from Australia, Austria, Brazil, Germany, India, Israel, Italy, Japan, Singapore, South Africa, Spain, Sweden, USA etc. participated in the deliberations. Representatives from industries such as Befesa Spain, SWS Italy, Outo Compo Sweden, Gerindtec Germany, Hyflux Singapore, IDE Israel, V.A. Tech Wabag, Ion Exchange (I), M/s ROCHEM (I) and many others took active part in the event.

Mr. B. Bhattacharjee Hon'ble Member National Disaster Management Authority (Government of India) inaugurated the conference in the presence of Ms. Patricia A. Burke Secretary General International Desalination Association (IDA) and Mr. Neil Palmer Vice President Asia Pacific Desalination Association. Mr. Bhattacharjee emphasized the need for safe drinking water for all. He stated that India

At the inaugural function (from left to right): Dr. P.K. Tewari Head, Desalination Division(BARC), Mr. Neil Palmer Vice President Asia Pacific Desalination Association (APDA), Mr. B. Bhattacharjee Hon'ble Member National Disaster Management Authority (Government of India), Ms. Patricia A. Burke Secretary General International Desalination Association (IDA), Mr. S.K. Ghosh, Director Chemical Engineering Group (BARC) and Dr. S. Prabhakar Organizing Secretary.



requires smaller size desalination and water purification units for domestic use (Litres/ Day capacity), small size units for community level (kilo-Litres/ Day capacity), medium size units for industrial requirements (Million Litres/ Day capacity) and large size units for the cities. The market for all sizes and requirements is ever expanding. Earlier, Dr. P.K. Tewari, while welcoming the invitees and delegates, spoke about the role of the Indian Desalination Association (InDA) in the field of desalination and water purification in India. InDA presently has a strength of more than 270 members including corporate members. Total water market in India is estimated at US$ 14 billion for municipal, industrial, residential and other requirements. It is growing at a fast rate. Water recovery and reuse is followed in several industries and has successfully demonstrated its usefulness. Industrial water market is about US$ 3.5 billion. Gross wastewater generation is more than 30 000 Million Litres per Day (MLD) at present and estimated to be more than 80 000 MLD by 2050. Indian Industries need to gear up for water recycling and zero discharge in a big way. Mr. S.K. Ghosh, Director, Chemical Engineering Group (BARC) delivered introductory remarks about the conference. He stated that the conference would cover the entire spectrum of desalination & water purification technologies, starting from integrated water resource management to nanotechnology, for water purification. Mr. Neil Palmer, Vice President Asia Pacific Desalination Association, talked about the activities of Asia Pacific Desalination Association (APDA). Indian Desalination Association is one of the board members of APDA. Ms. Patricia A. Burke Secretary General International Desalination Association (IDA) briefed about the importance of IDA and its activities. InDA is an association affiliate member of IDA. Dr. Prabhakar (Organizing Secretary) gave vote of thanks.

An overview on the programme on Desalination in Australia, China, India and Singapore indicated the increasing role of desalination in meeting public water supply demand. Membrane desalination has been found to play a critical role. At the same time, the advantages of implementing thermal desalination systems particularly linked to waste heat sources and nuclear plants was also highlighted. Recent advances in thermal desalination and membrane technologies were also presented and discussed. Nano-technology for desalination and water treatment had a good response from South Africa and Brazil besides India. The technology being futuristic in nature, the papers were research oriented, some of them related to preparation of nano-materials and nano-membranes and the remaining on applications for water purification at laboratory level. Membrane Development session featured papers pertaining to the development of reverse osmosis (RO), nano-filtration (NF), charged NF and ultrafiltration (UF)membranes. It was felt that membrane development was the key to improve economics and eco-friendly separations. The key areas identified include development of nano-composite membranes, antifouling membranes, proton exchange membranes (PEMFC) for fuel cells and bipolar membranes for water salt splitting. The financing and social aspects included informative lectures from IDBI regarding lending for water sector, Inclusive integrated management of local needs through AKRUTI (an experience of BARC), reject management and the challenges in the implementation of safe drinking water programme.

On the last day, a technical visit was organized to the Nuclear Desalination Demonstration Plant (Kalpakkam) and Reverse Osmosis Plant at CPCL (Chennai) for interested delegates and invitees.

National Symposium on Nuclear Instrumentation (NSNI 2010): A Report

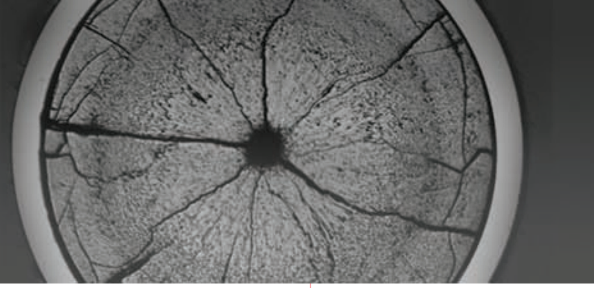
The National Symposium on Nuclear Instrumentation (NSNI 2010), sponsored by BRNS (DAE), was held at theMultipurpose Hall, Training School Hostel, Anushaktinagar, Mumbai during 24-26, February 2010. Over four hundred delegates from DAE laboratories and other scientific, academic and industrial organizations from India and two experts, one each from Switzerland and Italy, participated in this national symposium. The response to the symposium was overwhelming in terms of contributed papers too. Over one hundred and sixty technical papers were accepted for presentation in the symposium. Among them, forty-three papers were arranged for oral presentation in ten technical sessions and the others were presented in three poster sessions with one such session held on each day of the symposium.

A salient feature of the symposium was the invited lectures. Fifteen invited lectures from eminent experts in the field were arranged in the technical sessions.

The inaugural session of this symposium was held at NPCIL Auditorium at Nabhikeeya Urja Bhavan, Anushaktinagar, Mumbai on 24th February 2010. Mr. R K Patil, Associate Director (C), E&I Group welcomed all the delegates. Dr. S.K. Jain, C&MD, NPCIL, presided over the function and delivered presidential address. In his detailed presentation, Dr. Jain highlighted the role of Nuclear Instrumentation and Radiation Detectors & sensors in the current and upcoming power reactors and appealed to the scientific and engineering community in the field, to carry out innovative research & development keeping in view future requirements. Mr. G. Govindarajan (former Director, E&I Group, BARC) delivered the keynote address. He reviewed the growth of nuclear instrumentation and associated radiation detectors and sensors at BARC, for various application areas such as Nuclear Physics experiments, Accelerators and others. Mr. G.P. Srivastava, Director, E&I Group, BARC gave an overview of the Symposium and indicated future areas of R&D in Nuclear Instrumentation at BARC. Proceedings of the symposium in both, printed as well as CD forms were then released during the inaugural session, which was concluded with the vote of thanks proposed by the convener Mr. V.M. Joshi, Head, EISD, BARC.

All the subsequent events and technical sessions were held at the Multipurpose Hall, Training School Hostel.

On the first day, three technical sessions were held. A poster session followed the third technical session. In Technical Session - I, Dr. P. Swaminathan, (IGCAR, Kalpakkam) delivered an invited talk on “Sensor Networks for Supervision & Control of Prototype Fast Breeder Reactor (PFBR)”. He emphasized the need for incorporating safety measures right from the early design stage and explained various safety measures built into the design of instrumentation for PFBR. By providing redundancy in sensors, one could ensure that safety does not depend only on the functioning of a single sensor. Diversity and physical separation can be provided to alleviate simultaneous loss of system. While highlighting the merits of computer-based systems, he also cautioned about the associated potential threats such as loss of confidentiality, integrity and reliability due either to malfunctioning of such systems or due to access by unauthorized persons. This talk was followed by six oral presentations mainly dealing with the hardware and software aspects of Nuclear Instrumentation for power reactors.



The Technical session - II dwelt upon the development of Nuclear Instrumentation for Accelerators, Nuclear Physics experiments and related application areas. This session started with an invited lecture on "Future challenges in Control & Instrumentation for Nuclear Plants – ECIL's roadmap" delivered by Mr. Y.S. Mayya, (ECIL, Hyderabad) and subsequently seven contributed papers were presented.

Technical Session-III began with an invited talk by Dr. R. Bhowmick (IUAC, New Delhi) on "Development of Nuclear Instrumentation at IUAC". He provided a historical overview of the development of nuclear instrumentation at IUAC. He described the proposed roadmap for future developments and outlined the overall strategy such as usage of low cost and more easily available components to combat obsolescence, careful analysis of circuit failures for achieving robust design and adoption of multiple design strategy followed by choosing the best option. He emphasized the need for paying attention to issues such as improving the long-term stability, guarding against obsolescence and others. In the other invited talk, Dr. Prabhakara Rao (BEL, Bengaluru) presented an overview of various radiation detectors developed at Bharat Electronics Ltd., Bengaluru. He highlighted the success story wherein the silicon-based detectors developed at BEL, in collaboration with Electronics Division of BARC, were fruitfully deployed for CMS experiments at CERN. He then described other types of detectors such as micro strip detectors, PIN diodes and Si-PIN photodiodes developed at BEL for various nuclear physics experiments. He provided an overview of the facilities available at BEL, Bengaluru for fabrication and testing of solid-state radiation detectors, that could be useful to the scientists and engineers for various applications. Thirty-seven poster papers related to Nuclear Instrumentation for Accelerators, Physics experiments and Health and Environmental Monitoring were then presented and discussed in Poster Session (I).

On the second day of the conference four technical sessions were held. In Technical session IV, there were two invited talks on topics of very, vital importance in today's perspective viz. 'remote detection of nuclear materials'. Dr. V. Venugopal (BARC, Mumbai) delivered the first talk on "Nuclear Forensics". He indicated the need for detectors and advanced instrumentation, suitable for remote detection and characterization of nuclear materials and also for tracing probable origin thereof. Prof. G. Viesti (Dept. of Physics, University of Padova, Italy) delivered the next invited talk on "Neutron induced Non Destructive Assays of Large Objects". The Rest of the session saw oral presentations of four contributed papers, dealing with robot based instrumentation / systems for radiation monitoring & hot cell environments, instrumentation for neutron based landmine detection and that for mapping lunar chemistry. In Technical Session - V, Dr. (Ms.) Madhuri Joshi (COEP, Pune) delivered an invited lecture on "Image Processing for Security ". Following this, two contributed papers related to verification/qualification of hardware and software relevant to FPGA-based nuclear instrumentation were presented. Technical Session - VI dwelt upon the development of Detectors, ASICs, FPGAs and MEMs for nuclear and allied instrumentation. Dr. Stefan Ritt (Paul Scherrer Institute, Switzerland) gave an invited lecture on "Development of high speed waveform sampling ASICs" where he highlighted the application of such devices for astrophysical experiments. Subsequently the poster session (II) was held in which forty contributed papers were presented in the form of posters and the summary of these papers was presented to the delegates. Technical Session - VII also dwelt upon the development of detectors, ASICs & MEMs for Nuclear Instrumentation. The session began with an invited lecture by Prof. N.K. Mondal (TIFR, Mumbai) who talked about the Indian Neutrino Observation (INO) Detector systems. This lecture also indicated some new areas of development for nuclear instrumentation. Subsequently, three contributed papers related to detector & ASIC developments were presented.

The third and final day of the Symposium began with Technical Session -VIII that concentrated on development of nuclear instrumentation for Accelerators, RF Electronics and Physics experiments. Dr. Pitambar Singh (BARC, Mumbai) delivered an invited lecture on "Accelerator Developments: ADS program". Following this, five contributed papers were presented. Technical Session - IX was devoted to development of Nuclear Instrumentation for Reactors. First invited talk was delivered by Mr. A.K. Chandra (NPCIL, Mumbai) in which he discussed about "Modernization of Control & Instrumentation for Power Plants". Mr. B.B. Biswas (BARC, Mumbai) then gave an invited talk on the topic "Programmable Logic Controllers for Safety Systems". Subsequently six contributed papers were presented. Technical Session X, which was the last technical session, concentrated mainly on the development of Biomedical Instrumentation. The session began with an invited talk by Mr. N. Ravindaran (L&T Medical Systems, Mysore) who talked about "Development of Medical Instruments; Indian Scenario". Prof. Dinesh Sharma (IIT, Powai Mumbai), in his second invited talk, spoke on the "Emerging trends in FPGA architectures. Subsequently, six contributed papers, mainly related to biomedical and Health and Environmental monitoring instrumentation, were presented. This was followed by Poster Session III where almost forty contributed papers were presented in the form of posters. A summary of these papers was presented and questions were addressed to authors of respective papers for clarification.

A short concluding session was held, wherein the feedback from the delegates and participants was invited. The general opinion of the participants was that the symposium was fruitful and all the invited and many of the contributed papers were highly informative. The first main suggestion was that the symposium on Nuclear Instrumentation should be held once in every two years so that R&D activities in this field in the DAE family as well as at other laboratories can be discussed and debated more frequently. Secondly, the participants expressed that though the concept of poster sessions was necessary and acceptable, some strategy needed to be adopted, so that the authors of the papers slotted for poster sessions could also interact — even if for a brief period — with the entire audience rather than only the select interested individuals. The organizers assured them that both these suggestions would be noted and appropriate actions would be taken up while organizing future symposia on Nuclear Instrumentation.

Fluid Power Technology: Introduction of a new course for students

N. L. Soni
Head, Fluid Power & Tribology Section, Refuelling Technology Division

Fluid power is widely used in industries where requirements exist for high force/torque along with precise position and speed control, stall load conditions, sudden change in direction, small system volume (overall size and weight) and intermediate stopping positions, less heating requirement etc. Fluid Power & Tribology Section (FPTS) of the Refuelling Technology Division is involved in development of various types of hydraulic valves and various actuators for oil as well as water hydraulic applications, design and development of various types of hydraulic systems, selection, testing and repair of the hydraulic components, static and dynamic analysis of the hydraulic control systems etc. FPTS has attained expertise in the development of special hydraulic components like rotary actuators, friction-less hydraulic actuator and special purpose valves etc. FPTS is also using servo valves, proportional valves, integrated circuit valves, accumulators etc. FPTS is regularly updating knowledge on the latest trends and developments in fluid powersystems and valve technology i.e. proportional, servo valves and integrated hydraulic circuits etc.

The Fluid Power Laboratory (FPL) has the infrastructure for testing servo valves, pressure control valves, flow control valves, hydraulic motors,

250P-150Q Power Pack

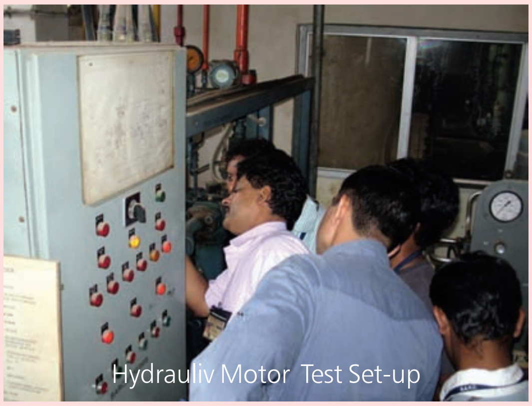
210P-30Q Power Pack

Dehydration unit

servo-hydraulic motors, hydraulic pumps, electro-hydraulic pumps, filters etc. It also has facilities like condition monitoring systems and particle counting system, to monitor healthiness of fluid power systems and hydraulic oil, ferrography system to trace back the sources of wear particles in the hydraulic systems available in FPL as well as other divisions of BARC, RPP Vashi and other DAE constituent units. Special test facilities for testing servo linear/rotary actuators, friction-less hydraulic linear actuators, special rotary actuators and endurance testing of valves. FPTS is actively involved in providing hydraulics/fluid power related solution to various divisions in BARC as well as NPCIL. Modifications in Spent Fuel Chopper hydraulic system, Dhruva fuelling machine, AHWR fuelling machine Z drive, weight balancing system of AHWR, ISOMED hydraulic circuit, Remotely Operated Hydraulic Trolley Along-with 6DOF Manipulator (ROHYTAM), Integrated Jack Loading system of IGCAR etc. are some of the examples of involvement of the FPTS.

Based on the expertise of FPTS, various divisions of BARC have requested FPTS to conduct beginners and Advanced level Hydraulic Control System courses and tailor made courses. One such tailor made course was conducted by FPTS for Radiation Processing Plant (RPP), Vashi personnel. Mr. N.L. Soni, Head Fluid Power & Tribology Section, is working as a visiting faculty to CITD for Advanced Hydraulic Control Systems for M.Tech and PG diploma students in Mechatronics. Based on the suggestions and requests received from several divisions, a new course on “Fluid Power Technology” was proposed by FPTS, for Trainee Scientific Officers (TSOs), HBNI M.Tech and PhD students, and BARC officers/ employees. The course was proposed this year and it was approved by HBNI.

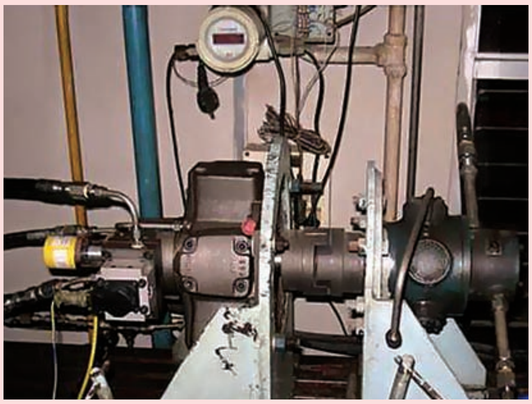
Hydraulic training courses are offered by several Indian and international fluid power and pneumatic component manufacturers. But their course contents are limited only to introduction, selection, application and troubleshooting of their own manufacturing range of components. Manufacturers who are not manufacturing precision integrated hydraulic circuit components are imparting training only to their stack components or standard valves. Our course is unique in that sense, since we have not restricted ourselves to any single vendor or supplier but a wide range of suppliers like Rexroth, Parker, Vickers, Eaton, Danfoss, and Kawasaki etc. Our course content covers all types of components being used in hydraulic systems and as per the latest trends in the fluid power industry including imported items from various countries like Italy, Japan, Sweden,



Hydrauliv Motor Test Set-up

Rotary Actuator Test Set-up

Dehydration unit

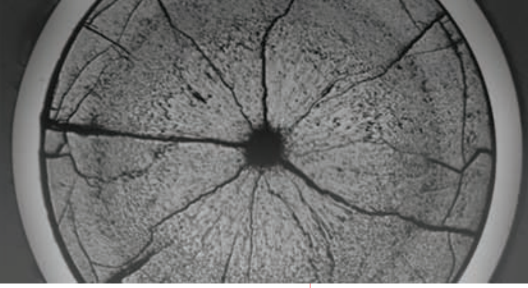


Students performing the experiments in the Fluid Power Lab, Hall-3

Germany, Denmark, France and other European countries. Integrated circuits, proportional valves, their varieties, servo valves, direct drive valves etc. The main aim of the course is to familiarize the students with the subject and various types of designs of same function performing components and analysis of hydraulic systems.

The course content was prepared keeping in mind the background knowledge to fluid mechanics. The course covers basics fluid power technology, hydraulic & pneumatic circuit design, sizing of hydraulic components, advanced hydraulic circuits & electro-hydraulic servo controls, water hydraulics, analysis of hydraulic circuits and 12 experiments in hydraulics and pneumatics etc. The power point lecture presentations with audio-visuals and animated pictures; lecture notes in form of e-books and experimental manuals were prepared and handed over to HBNI for students reference.

A total 30 lectures were delivered at HBNI and 12 experiments were conducted at the Fluid Power Lab, Hall-3. Officers from Fluid Power and Tribology Section delivered the lectures and guided the students for carrying the experiments.



School on Pulsed Power Technology (SPPT-2010): A Report

A School on Pulsed Power Technology (SPPT-2010) was organized under the auspices of the Power Beam Society of India (PSI), with full financial support from the Board of Research in Nuclear Sciences (BRNS), at the Multi-purpose Hall of Training School Hostel during 18-21 May 2010. This was the second school on pulsed power technology organized by the Power Beam Society of India. The first school was held during March 17 – 21, 2009. The present School, apart from covering fundamentals of Science, Technology and Engineering of Pulse Power Systems, also focussed on Pulsed Electron Beam Generation and their Application in Basic and in Strategic Areas. There was an overwhelming response from academic as well as R&D organizations from all over the country. More than a hundred participants applied for the school, out of which about 40 participants from DAE units and 40 from non DAE units including DRDO laboratories and academic institutions were shortlisted.

The inaugural program started with a welcome address by Dr. K. C. Mittal, Project Manager, EBC (Kharghar) and Treasurer of the society. He noted that the society was established in 2003 with a view to bring together the community working on laser and particle beam generation. Since Pulsed Power forms a basic requirement for such systems, the society decided to organize annual schools, beginning last year. Dr. A. K. Ray, Raja Ramanna Fellow and Director of the School, mentioned that the community was aware of the fact that though the applications of this technology in various strategic and nonstrategic industries are increasing and job opportunities for young scientists and engineers are opening up, no academic institution in our country offers a properly formulated course. Hence, the scientists and engineers joining DAE and DRDO laboratories are generally mentored in respective laboratories or are self taught. The society, therefore, felt the necessity of holding such schools for the young scientists and engineers at a regular intervals. This should help in cultivating necessary manpower in this important field. Dr. L. M. Gantayet, Director, BTD Group, BARC in his Presidential address, lauded the motive of the school and desired that number of participants be limited to that of a typical class room so that there could be more interaction between the participants and the lecturers. Mr. G.P. Srivastava, Director, E&I Group, BARC inaugurated the school. He noted that in recent times, pulsed power technology has emerged as a vital tool having applications both in societal needs, such as food preservation, sterilization and waste management as well as in strategic fields. He emphasized the need for knowledgeable manpower being available to meet the technological challenges in this important area of R&D of the country. Dr. T. C. Kaushik, Convenor of the School proposed the vote of thanks to all those directly and indirectly involved in organizing the school.

The scientific session started with the keynote address by Prof. G. R. Nagabhushana on "Capacitors for Pulsed Power" in which he discussed the basic elements of energy storage capacitors, their manufacture and characterization. He also discussed some of the basic types of capacitors and progress in the dielectric elements to enhance the energy density and thereby reduce the size. In the subsequent sessions, there were six lectures devoted to basics of breakdown mechanisms in various media under pulsed and DC field, energy storage systems, pulse conditioning systems, opening and closing switches and pulse modulators etc., related to general pulsed power systems. Focal theme of the school being the pulsed electron beams and its

Mr. G. P Srivastava, Director, E&I Group speaking at the inaugural function. Others on the dais (From Left) are Dr. K. C. Mittal, Treasurer, Power Beam Society of India, Dr. L. M. Gantayet, Director, Beam Technology Development Group, Dr. A. K. Ray, Director of the School, and Dr. T. C. Kaushik, Convener of the School.

applications, seven lectures were arranged on the science and technology of electron beam generation and their applications in societal as well as in strategic & defence fields. Four tutorials with typical examples of designing various pulsed power systems and electron beam systems were included in the school. There was an evening lecture on "Generation, Stable transport and Collection of Electron Beam for High Pulsed Power Microwave Tubes" by Dr. Vishnu Srivastava who brought out the latest scheme of sheet beam technology in microwave tubes. A poster session was held for presentation of works by the participants. A visit was arranged to the Electron Beam Centre, Kharghar for the benefit of the participants who got first hand knowledge of the working of a large electron beam accelerator facility.

"EXAFS studies on Actinides" : A Report

The DAE-BRNS Workshop on "EXAFS studies on Actinides" (EXAFS-2010) was co-organized by the Radiochemistry Division, BARC and the Raja Ramanna Centre for Advanced Technology, during March 8-9, 2010. Dr. S.K.Deb, Co-convener and Chairman, Local Organizing Committee, welcomed the delegates. Dr. V.K.Manchanda, Co-chairman EXAFS-2010 and Head, Radiochemistry Division, BARC gave the introductory remarks, wherein he explained the objective of the workshop and its genesis. He mentioned the expanding horizons of EXAFS-based structural studies and the need to investigate systems involving actinides by this technique at INDUS-2. Dr. P.D.Gupta in his inaugural address, informed the gathering that INDUS-2 had achieved more than 100 mA of beam current and was running round the clock. He mentioned about the important role of actinides research in the atomic energy programme and called upon the participants to propose experiments at INDUS-2, to unravel the mysteries of actinide speciation. Dr. P. Chaddah in his address, emphasized the role of universities in the utilization of national facilities in general and INDUS-1&2 in particular. He urged upon the need to involve universities in the effective utilization of INDUS synchrotron. Dr. B.S. Tomar, Convener of the workshop proposed a vote of thanks.

The two-day workshop had 9 invited lectures and two contributory paper presentations. There were seven faculty members and around 50 participants. The participants were drawn from DAE (BARC, RRCAT and IGCAR) and non-DAE (University of Goa and Indian Institute of Science, Bangalore) institutes.

The lectures included an overview of INDUS

(From left to right) :Dr. B.S.Tomar (Convener), Dr. P. Chaddah (Guest of Honour), Dr. P.D.Gupta (Chairman) Dr. V.K. Manchanda (Co-chairman) and Dr. S.K. Deb (Co-convener & Chairman, Local Organizing Committee) during the inaugural function of EXAFS 2010.

Participants of EXAFS 2010

Synchrotron by Dr. Gurnam Singh followed by the details of the EXAFS beam line (BL-8) by Dr. S.N. Jha. Dr. D. Bhattacharyya explained the theory of EXAFS and presented some of the work carried out by his group, at the European Synchrotron Radiation facility (ESRF) at Rosendrof. Dr. Steven Conradson from Los Alamos National Laboratory (LANL) and Dr. Melissa Denecke from the Institute of Nuclear Engineering, Karlsruhe, gave the details of the EXAFS facilities in USA and Europe respectively. Dr. Tapas Ganguli and Dr. Debdutta Lahiri explained the EXAFS data analysis methodology. There was a tour of INDUS 1&2 at the end of day 1, wherein the participants were shown the various beam lines for X-ray spectroscopy, vacuum UV and IR spectroscopy.

On the second of the workshop, day Dr. David Clark(Los Alamos National Laboratory), Melissa Denecke (INE, Karlsruhe) and Steven Conradson (LANL), delivered lectures on EXAFS studies on actinides, which was the theme of the workshop. Dr. Clark also delivered another lecture on sample preparation and the hutch for the EXAFS studies with radioactive samples. Mr. Sumit Kumar and Mrs. Aishwarya Kar presented their work on EXAFS studies on actinides, carried out at Elettra and INDUS Synchrotron facilities respectively. Later a two-hour 'hands on' training session on analysis of EXAFS data was held at the computer centre, which was conducted by Drs. D. Lahiri and T. Ganguli and was a huge success.

Thorium Technologies: A Special Display of Resources

The Scientific Information Resource Division, BARC organized an exhibithion on the theme 'Thorium Technologies' in the main hall of BARC Central Library. The exhibition was held from 17th of May, 2010 to 18th of June, 2010.

The exhibition displayed items under the following categories: Popular Newspaper articles and clips on Thorium; BARC Reports; books and conference proceedings and audiovisual short clips related to Thorium. These exhibits provided in depth information on recent trends and developments in the area of Thorium technology. In addition to the above, the exhibits also included development of Thorium as a Thorium based metallic fuel. A detailed metallurgical process flow chart of thorium alloys, prepared by the Uranium Extraction Division BARC, was also displayed.

As a run up to the exhibition, certain Scietometric Studies were done using the INIS Database, showing publication trends in India and the world over.

The Exhibition was well received and was visited by about 500 of our Scientists and Engineers.

From left to right: Dr. K. Bhanumuthy, Head SIRD, Dr. R.K. Sinha, Director BARC & Dr. S. Banerjee, Chairman, AEC at the display

National Fire Service Week at BARC

Every year 14th April is observed as National Fire Service Day. On this day in the year 1944, the fire service personnel displayed exemplary courage and devotion to duty as they fought the huge fire that had erupted following an explosion on a ship S.S. Fort Sticken berthed at the docks of Mumbai Port Trust. Many fire fighters lost their lives, leaving behind their names etched in the minds of Mumbaites forever.

Several programmes were organized by the Fire Service Section, BARC during the fire service week (April 14-20, 2010), to create fire safety awareness among the employees in BARC, Trombay and Anushaktinagar.

On behalf of BARC, Mr. A.K. Tandle, Chief Fire Officer placed a wreath on 14th April, 2010 at the memorial erected on the grounds of Mumbai Port Trust and at the headquarters of Mumbai Fire Brigade, Byculla.

On 15th April2010 Dr. S. Banerjee, Chairman, AEC and Director, BARC were offered pin flags to inaugurate the fire service week and to start the fund raising campaign. Dr. S. Banerjee emphasized the need to prepare ourselves for safety challenges thrown due to upcoming new research facilities and ensure fire safety, by updating fire fighting equipment and training of fire staff. Pin flags were also offered to Mr. N.D. Sharma, Controller, BARC and Mr. S.K. Ghosh, Director, Chem. Engg. Group and Mr. Hanmanth Rao, Head, ChED.

Mr. A.K.Tandle, CFO, BARC welcoming Dr. S.Banerjee,Chairman, AEC and Director, BARC on the occasion of “Fund Raising Campaign” in BARC

On 16th April, 2010 two crews from BARC Fire Service Section participated in the Tactical Medley Drill Competition organized by the Govt. of Maharashtra at Cross Maidan, Dhobi Talao, Mumbai. 13 teams belonging to various organizations viz. Mumbai Fire Brigade, BPCIL, Mumbai Port Trust, State Fire Training Centre participated in the competition. Team 'B' was awarded the 2nd prize and in individual ladder drill it won the 3rd prize.

On 17th April, 2010, live Fire Fighting and Rescue Demonstration was organized at Tapti Building Ground for the benefit of Anushaktinagar residents. Around 400 residents witnessed the programme. On 18th April, 2010 an arrangement was made to screen a film on "Preventing Accident in the Home" through cable network at Anushaktingar. 19th April, 2010, a programme on Fire Fighting Equipment Exhibition with fire fighting and rescue demonstration was organized at Hall-7. Mr. D. Saha, Head, RED in his welcome address, expressed his happiness in arranging programmes which would help improve fire safety awareness amongst the Hall No.7 officials. Mr. A.K. Tandle, CFO, briefed about observance of fire service week's various programme like fire drill competition at State and industrial level for fire professionals, fire safety awareness programme for BARC employees and resident of Anushaktingar. He requested all employees to go through fire order and know their duties in handling fire emergency successfully.

Mr. S.K. Ghosh, Director, ChEG congratulated Hall No.-7 authorities for allowing to conduct fire safety awareness programme at their place and the overwhelming participation of the employees. He appreciated their active role in ensuring fire safety at their work place.

Mr. R.K. Sinha, Director, RD & DG & DMAG noted that fire magnitude has increased with time. Hence timely action was required to avoid fires. He emphasized the need for maintenance and upkeep of fire prevention, fire detection and alarm system and minimum combustible material, to reduce fire losses.

On 20th April, 2010, Fire Service Week culminated with a ceremonial parade at Cross Maidan, Dhobi Talao, in which BARC's Fire Service personnel contingent participated along with Emergency Rescue Tender & Equipment. Hon'ble Mr. Bhaskar Jadhav, Minister of State, Urban Development chaired the concluding function. A film on fire safety "The Towering Inferno" was screened at the Central Complex Auditorium for BARC employees. A prize distribution function was arranged at Fire Station, BARC for the winners of various competitions conducted among BARC fire service personnel. Mr. S.K. Ghosh, Director, ChEG & Mr. Hanmanth Rao, Head, ChED distributed the prizes to the winners.

Kendriya Sachivalaya Hindi Parishad, (KSHP) BARC

Kendriya Sachivalaya Hindi Parishad (KSHP), BARC organized a special musical cultural programme in the Central Complex Auditorium on 28th October, 2009, to pay a unique tribute to Dr. Bhabha as part of the centenary year celebrations. The programme titled as "Dr. Bhabha aur Unke Sapnon Ka Bharat" was conceptualized and directed by Ms. Namrata Kadam, Secretary, KSHP and it featured the versatile personality of Dr. Bhabha and his outstanding contribution in the growth of the Indian Atomic Energy Programme. The event was chaired by Dr. Tulsi Mukherjee, President, KSHP. Director, RC&I Group and Controller, BARC were among the diginitaries present on the occasion. The programme was attended by a large gathering and ended with an emotional tribute to Dr. Bhabha.

Dr. V. Venugopal, Director RC & IG, Controller, BARC and
Dr. Tulsi Mukherjee, Director, Chemistry Group
at the C C auditorium along with the participants of the programme

Seventeenth National Symposium on Environment (NSE-17) : A Report

The Seventeenth National Symposium on Environment (NSE-17) was held at the Indian Institute of Technology, Kanpur during 13-15, May 2010. Prior to this, sixteen such symposia were held in various parts of the country. Considering the fact that environmental monitoring has to be strongly linked with modeling and validation of such models, the focal theme of the symposium was chosen as Advances in Environmental Monitoring and Modeling. Prof. Mukesh Sharma Convener NSE-17 and Co-ordinator, Centre for Environmental Science and Engineering outlined the programme of the symposium. Dr.(Ms.) G.G. Pandit, Head, EMAS, EAD, BARC talked about the theme of the symposium. Mr. V.D. Puranik, Head, EAD, BARC in his address, outlined the National Symposium on Enviornment series being conducted by EAD at different locations in India. Prof. Muralidhar, Dean R&D, IIT Kanpur in his address, highlighted the importance of forging alliances between academia and research institutes for national benefit. Mr. H.S. Kushwaha, Director Health Safety & Environment Group (HS&EG), BARC in his inaugural address, emphasized the importance of advanced monitoring and modeling techniques for environmental restoration and sustainable development.

National Symposium on Environment (NSE) series sponsored by BRNS / DAE was conceived in 1992, to provide a platform to researchers for exchanging ideas and emerging trends in the area of environmental monitoring and modeling. The symposia are held in various universities and research centres all over India, with a theme related to environment. For the present symposium there were 102 contributory papers (40 Oral and 62 Poster presentations) by various academic institutions and

At the inaugural function from left to right are : Dr.(Ms.) G.G. Pandit, Head, EMAS, EAD, BARC, Prof.K. Muralidhar, Dean R&D, IIT Kanpur, Dr.Debanik Roy, Programme Officer, BRNS, DAE, Prof.R.K. Thareja, IIT Kanpur, Mr. V.D. Puranik, Head, EAD, BARC, Dr.Mukesh Sharma, Co-ordinator, CESE, IIT Kanpur, Mr. H.S. Kushwaha, Director, HS&EG, BARC

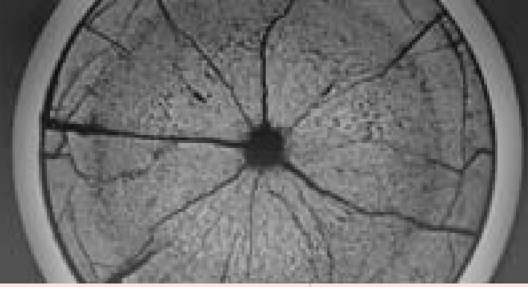
Delegates at the Symposium

research centres apart from DAE units. The invited speakers for the symposium included experts from various research institutions including IITs and DAE units. Forty five delegates participated from BARC in the symposium.

Mr. H.S. Kushwaha, Director, HS&EG, BARC gave the inaugural lecture on Safe and Green Nuclear Power on 13th May, 2010. He emphasized the role of nuclear power in building the nation.

A wide range of topics related to environmental science and technology were covered during the three-day symposium. It includes technologies for clean environment, monitoring & modeling of pollutants and their transport, mitigation strategies for pollutants, environmental radioactivity, regulatory aspects and environment, environmental awareness, education and other related areas. There was lively interaction between young researchers and experts during poster sessions.

In the concluding session experts provided their perspective about NSE 17 and on the future directions of the monitoring and modeling technologies. The prizes for best poster presentations were distributed by the organizers. A feedback session was also arranged to seek suggestions for future programmes.



BARC Scientists Honoured

Name of the Scientist : J.P. Mittal
DAE Raja Ramanna Fellow, Ex-Director, Chemistry & Isotope Group

Award : Distinguished Achievement Award

Awarded by the : Asian and Oceanian Photochemistry Association, Japan, in the general assembly during the Asian Photochemistry Conference 2010, held at Wellington, New Zealand, from Nov. 14-18, 2010.

Name of the Scientist : V.K. Srivastava
Head, TDS

Elected : Elected to the Council of the Indian Institute of Chemical Engineers (IIChE) for the period (2010-2012)

Elected at : Indian Chemical Engineering Congress (2009) held at Visakhapatnam during December 27-30, 2009.

Name of the Scientist : Chandra Bhanu Basak
Materials Science Division

Titel of the Poster : "Determination of Some Themophysical and Thermomechanical Properties of UO_2 and IC by Classical Molecular Dynamics Simulation"

Award : Best Poster Award

Awarded at the : "Joint ICTP-IAEA Advanced Workshop on Multi-Scale Modeling for Characterization and Basic Understanding of Radiation Damage Mechanisms in Materials" held at the Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy, during April 12-23, 2010.

Name of the Scientists : Joy Mittra, Nirupam Das, U.D. Kulkarni and G.K. Dey
Materials Science Division

Titel of the Poster : "TEM study of various dislocation-precipitate interactions in Alloy 625"

Award : Best Oral Presentation Award

Awarded at the : "International Conference on Advances in Electron Microscopy and Related Techniques & XXXI Annual Meeting of EMSI (EMSI-2010)" held at BARC, Mumbai during March 8-10, 2010.

Palm tree at BARC

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