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BULK HYDROGEN ANALYSIS,

USING NEUTRONS

Final Report of the First Research Co-ordination Meeting of the above Co-ordinated Research Programme

IAEA HQ, Vienna
15-18 July 1997

30 - 13

1 Introduction

The main purpose of this Research Co-ordination Meeting (RCM) was to review the work programmes of the participants of the Co-ordinated Research Programme (CRP) to ensure that the overall scheme is coordinated and that individual participants are not duplicating the same research. The technical background to the CRP is described in the 'Information Sheet' for the meeting, which is given here at Appendix 6.1.

The list of participants is given at Appendix 6.2 and the meeting agenda at Appendix 6.3. At the meeting, Prof. Brooks was elected to be Chairman of the RCM and Mr Millen was elected to be Rapporteur. The Scientific Secretary for the meeting was R L Walsh, Physics Section, RIPC, IAEA.

After presentations from the participants on the work of their programmes, a sub-committee was formed to establish a procedure for review of the individual work programmes. The sub-committee consisted of:

Brooks (RCM chairman)
Millen (RCM rapporteur)
Bartle (coordinator - area 2.1)
Lanza (coordinator - area 2.2)
Shaikh (coordinator - area 2.3)
Csikai (coordinator - area 2.4)
Walsh (IAEA, scientific secretary of the RCM)

Each coordinator was responsible for the review of the projects in his area. Brooks indicated that while the review was aimed at assessing the work programmes, it was essential that the RCM promoted the following points:

- mechanism for information exchange between participants
- promote interaction
- stimulate communication
- encourage collaboration

Walsh expressed his desire that any specific collaborations between participants fostered by the meeting should be mentioned in the meeting report.

2 Project titles

These are given in Appendix 6.4

3 Discussion of Research Proposals. Specific Conclusions and Recommendations

Bartle prefaced the review of projects in the four research areas. He stressed the key to the coordinated research effort was establishing "relationships" between the participants in all areas. He indicated that the coordinators would act as mentors or coaches for the participants in their respective areas. He advised that the coordinators' previous experience in their areas would help participants. He encouraged the participants to contact the coordinators if a problem arose with their work. The coordinators indicated that they would undertake to assess the problems of participants and advise.

Bartle also felt strongly that all participants should consider a 're-orientation' of their thinking. Traditionally, scientists have tended to concentrate on their equipment and techniques, with the justifiable aim of developing good methodology. He felt that participants should in parallel consider the problem they are trying to solve and focus on the needs of their customer, whether it be industry or otherwise. Early in your work the benefits of using neutron techniques and other options must be considered. Participants should consider placing a list of other participants and their objectives in a prominent place. Bartle indicated that visualising the end use of your gauge or analysis method was a useful personal aid to the success of your work.

3.1 Neutron transmission, scattering and activation techniques (NTSA) (area 2.1)

Note the original name of this area was "Fast Neutron/Gamma Transmission Technique (FNGT). The participants indicated that this title did not cover the full scope of the projects in area 2.1. It was proposed and agreed that the name of this research area was changed to "Neutron Transmission, Scattering and Activation Techniques (NTSA)." (see recommendation X.X) to cover all the projects in this research area. (This includes the FNGT technique).

In addition to Bartle, ten other participants expressed interest in area 2.1. Participants were asked to comments on possible alternations and collaborations that could occur with other participants. The following suggestions were made:

- Padron Diaz (Cuba)- His applications in Fast Neutron and Gamma Transmission (FNGT) similar to work already performed by Bartle and Millen. He would like information on their experience. He would like to receive relevant papers covering this work.

- Cywicka-Jakiel (Poland) - Involved on moisture measurement in coke. The project is aimed at developing FNGT gauge to replace thermal neutron gauges in Polish steel plants. Cywicka-Jakiel is keen to continue collaboration with Millen and Bartle. She has already spent 3 months in Australia on IAEA sponsored training course. Cywicka-Jakiel indicated the difficulties of obtaining industry funding despite their interest in project. Hussein indicated that he would assist Cywicka-Jakiel in the modelling component of project. Csikai will help in comparison of various experimental geometries and calculated data. Cywicka-Jakiel is also concerned about stability for pulse shape discrimination (PSD)work. Bartle can advise as his group have much experience in this area.

- Hussein (Canada) indicated he would like advice on neutron detectors. His challenge is to measure slow neutrons in the presence of a fast neutron flux.

- Millen (Australia) is interested in other ways of detecting neutrons instead of ^{6}Li detectors and gaining information on the use of neutron generators. Brooks can advise on detectors and Mikerov on neutron generators.

- Chim-Oye (Thailand) and Jonah (Nigeria) are setting up laboratory facilities to allow the determination of hydrogen in mineral and industrial samples. They can collaborate and compare their accuracies. Csikai indicated that they can compare their neutron reflections methods and thermal neutron capture methods.
- Ishikawa (Japan) indicated that he will provide more detail in work program. He is looking at moisture determination in brick and metal. He will collaborate with Tominaga (Japan) well known for his development of the FNGT technique for use in coke and other materials He is interested improving detector sensitivity.

- Brooks (South Africa) has taken note of the comments on problems of multiple neutron scattering for elemental bulk analysis. He indicated that his technique will be compared with the pulsed fast neutron analysis method (PFNA) of elemental identification.

- Erduran (Turkey) is keen to collaborate with Brooks due to interest in similar applications. Design and construction of the neutron collimator and shielding has been executed. He is keen to learn about portable neutron generators. Mikerov can advise

- Balasko (Hungary) is interested in the neutron methods for measuring the flow of hydrogen in closed systems. He would like to maintain close links with the participants in this area and those using radiography techniques.

- Csikai (Hungary) has used the neutron reflection technique for the determination of hydrogen and the (carbon+oxygen)/hydrogen ratio in various oil samples. He proposed the upgrading of the 'Betatron' equipment developed in Debrecen for this purpose. In addition to his specified work program, Csikai will commence improvement of methods used for the determination of the flux density spectra of neutrons inside bulk samples.

Bartle asked the participants in this area to establish immediate email communication with himself and Millen, and between themselves, on their return to their respective countries

3.2 Digital neutron imaging (area 2.2)

Four participants expressed an interest in this area: Balasko (Hungary), Lanza (USA), Mikerov (Russia) and Shaikh (India).

Balasko is interested in studies of two phase flow and is currently doing dynamic imaging using an intensified Vidicon with an 8 bit frame grabber. Some concerns about the dynamic range of such a system (256 levels) were raised but Balasko indicated that it seemed sufficient for his present work. He also is investigating Fuji photo-stimulated luminescence (PSL) imaging plates as another possible imaging system. They have excellent spatial resolution, but at present he does not have the required laser reader for the plates and thus must drive them to Ljubljana, a six hour trip. The plates cost approximately US$200 each but multiple plates will be required to allow for multiple images to be made and to allow for those plates currently in transit. Balasko is primarily interested in digital imaging as a user rather than as a developer of such devices.

Mikerov is developing a portable charge coupled device(CCD) based fast neutron imaging system. Fast neutrons were selected rather than thermal in order to have sufficient penetration for large objects. Applications are envisaged in areas such as nuclear power plant inspection, where the components to be inspected are large. He is also working on a 14 MeV deuterium-tritium (D-T) tube source with a small (5 mm) spot size appropriate for projection imaging. The detection system uses a thick (20 mm) plastic scintillator which is imaged by a lens-coupled cooled CCD. He was interested in collaborating with Lanza on the development of lower cost imaging sensors and associated electronics and with others interested in neutron sources.

Lanza has been investigating the possibility of using complementary metal oxide semiconductor (CMOS) based imaging sensors as a replacement for CCD technology. It is believed that such sensors could be substantially less expensive than CCDs and in addition may offer the ability to readout a pixel by pixel basis rather than serially as required for CCDs. This could be very useful for scattering experiment or for imaging where only one part of the image is to be read out in order to have high frame rates. He expressed an interest in collaboration with Mikerov.

Shaikh is currently using both film imaging and electronic imaging. He would like to use digital methods in both static and dynamic imaging for two phase flow and also to add tomographic capability for inspection of fuel bundles. The HYSEN method (hydrogen sensitive epithermal neutron radiography) was also mentioned but currently takes several hours to produce an image and thus may not be fast enough for practical use. The reactor produces approximately 10^6 n/cm^2/s at the sample position and concerns were raised as to whether this was sufficient for using the HYSEN method although there was agreement that it was sufficient for use with cooled CCD technology. Collaboration with both Lanza and Mikerov would be useful.

Lanza indicated that the followings developments would greatly enhance digital imaging:

- low cost electronics
- low noise and wide dynamic range detectors
- fast neutron imaging method for inspection of large objects
- improved scintillation screens, especially for fast neutron imaging
- source developments, especially those with small spot size would be useful.

3.3 Hydrogen detection by epithermal neutrons (area 2.3)

Four participants expressed interest in this research area, Balasko (Hungary), Brooks (South Africa),. Ishikawa (Japan) and Shaikh (India).

Balasko would like to establish the HYSEN method using the Indium foil on one of the beam tubes available and study the hydrogenous sample. He would also like to establish a filtered beam facility with various filters to vary the neutron beam energy, and use an imaging plate (in parallel to the film method) to record the radiographs as the image plates have a few more orders sensitivity than the usual X-ray film.
Brooks would like to establish a facility using monoenergetic eV neutron source based on resonance scattering and make a feasibility study of detecting neutrons scattered from hydrogen sample, by means of the kinematic energy loss in scattering.

Shaikh is interested in establishing HYSEN technique using the reactor neutron source based on Cadmium + Indium filter and Indium foil detector. The technique will be used in studying the hydrogen concentration in zirconium and aluminum compounds. He has also proposed to set up an epithermal neutron facility using an iron filter, to detect hydrogen in heavy elements.

Ishikawa (Japan) also expressed interest in establishing the HYSEN method.

HYSEN and other resonance filter techniques are important in investigating hydrogen in materials. It would be appropriate to improve the speed of the techniques by using electronic cameras instead of photographic films. Progress of the work and results obtained on the different materials could be exchanged with mutual interest. Csikai suggested that Chim-Oye and Jonah should use epithermal neutrons for characterizing various types of geological samples to check possible high absorbing elements.

3.4 Microscopic behavior of hydrogen in bulk materials (area 2.4)

Three CRP participants, Ishikawa (Japan), Shaikh (India), and Csikai (Hungary) were interested in the investigations of microscopic behaviour of hydrogen in bulk materials. Ishikawa has initiated a co-operation between JAERI and the Musashi Institute of Technology, Tokyo for the determination of hydrogen in metals and alloys by using a sensitive neutron radiography technique.

Shaikh has applied the neutron diffraction method for the determination of the concentration of hydrogen and the phase identification of zirconium hydride in zirconium matrices (zircaloy strips). It is planned to apply the quasi elastic neutron scattering for the study of the diffusion in intermetallic compounds.

Csikai's group has measured the accumulation of deuterons in metals, alloys, semiconductors and metallic glasses using accelerated D^+ ions in the 60-180 keV energy range. Kinetics of the retention has been monitored by the detection of protons and neutrons produced in the $^2H(d,n)$ and $^2H(d,p)$ reactions. Retention probability, saturation yields, concentration profiles were determined for a number of samples.

Deuterons were considered as a tracer for hydrogen to study the changes of some physical parameters of solids caused by the high hydrogen concentrations.
Further, Csikai recommended the following :

1. Addition of a new point, 2.5, to the research areas with the title "Depth profile analysis by deuteron induced reactions".

2. Development of a stable measuring system based on coincidence between the neutron induced recoil proton and the ^3He particle produced in the $^2H(d,n)$ reaction.

3. Use of neutron diffraction, inelastic and quasi-inelastic neutron scattering to study hydrogenous materials, eg ZrH_2 (zirconium hydrides) and some intermetallic compounds.
4. Development of a sensitive neutron radiography system for industrial applications in the fields of civil engineering, steel industry, etc.

5. Investigations on the advantages and limitations of depth profiles analysis of deuterons in solids using deuteron induced reactions.

Further, co-operation with I. Padron Diaz has been initiated via an expert mission under TC project CUB/1/007.

4 General Discussions

As a group, the participants of the RCM possess a large body of expertise in the area of neutron analysis for hydrogen and moisture detection. Despite this it is clear that individual participants need and have requested assistance and advise on certain areas eg. detector selection, electronics and related issues such as maintaining gain stability. This RCM provides a good opportunity for participants to commence a network and obtain advice where they need it. This could help them overcome issues which have been problems in their individual laboratories. The general topics raised by participants were :

- neutron sources - relative merits of different neutron production for their application
- detectors - selection of detectors
- electronics - gain stability of particular interest
- other techniques - access to non-neutron techniques, to enable comparison of of participants techniques and other techniques
- modelling codes - advice on suitable code for participants applications
- data analysis - advice on analysis methods and possible collaboration.

- industry contact - advice on industry interaction eg how to approach or write a proposal to industry
- communications - establishment of list server and website. (See section 5.3)

- marketing - it was emphasised by several speakers eg Lanza and Bartle that work in the laboratory should run parallel with a consideration of how an analysis method is going to be used at completion of the project. Lanza suggested all participants should consider the following points at the start and should continually address throughout a project: (i) what is the problem to be solved ? (ii) how will it be solved ? (iii) why will we succeed where others have failed ? (iv) assuming success, who cares ? (iv) how long will the project take and how much will it cost ?

5 General Conclusions and Recommendations to the Agency

These concerned marketing of the CRP's products; the date of the next RCM; more electronic communication; and the structure of the final report.

5.1 Marketing

Marketing is the key to identifying and gaining the support of our customers. The aim of marketing is to ensure that products are being used. Communication with actual and potential customers should occur at all stages of the research and technical development.

The determination of the relationship between the scientific and industrial aspects of the market helps us to sell the product. This segmenting of the market is discussed in section 5.1.1.

There are important strategies which can be used in making presentations to industries. These include ensuring that the industry contact is able to follow each step and responds with an affirmative "yes" to key questions. Recommendations ('tips') for good marketing are given in section 5.1.2.

It is important to remember that gaining a commitment and funds from industry may be easier than first thought. Committed managers and engineers in industry dream of solutions to problems they encounter day by day. If the product matches the need then the commitment will follow.

Procedures suggested for advertising include an IAEA-based brochure on the market features of the CRP's products. This ensures that any marketing strategy by an individual can draw on resources of the group. It is also of value for individual areas of the CRP to develop advertising brochures. Marketing can also be an objective of internet site communications.

5.1.1 Segmenting of the market

The nature of the "market" for the industrial use of bulk hydrogen measurement using neutrons can be described as follows:

traditionally our scientific research may have met needs (e.g. in scientific journals) in one region - a region of high scientific interest but of low industrial interest. Conversely, the market focus for work in the CRP may satisfy needs in a region of somewhat lower scientific interest but of high industrial interest. However, the actual market opportunities themselves may eventuate in a third region, where industrial needs require lower scientific development and lower costs. It is necessary to realise that all regions are equally important if a customer need is being met.

5.1.2 Recommendations for good marketing

Try to approach people seen as key individuals in industry.

(i) In making a presentation about the need your instrument will meet for industry, try to get agreement at each stage. For example, if you ask the question: "This instrument will save your industry money, won't it?" .... you want a strong affirmative "yes". See a "yes" as a green light. At each stage don't proceed without it.

(ii) One-on-one presentations are best; remember it is hard to get a large group to agree (on anything).

(iii) If your presentation appears to have failed the following ideas can be followed:

(a) Ask the contact for a referral to others in his/her organization (or other organizations) who could be interested.

(b) Suggest a meeting with others as technology may be difficult to understand.

(c) Find out what the problem is and plan adjustments to your product - is it that there is no actual need for this instrument? Or is it the cost, or the shape of the package?

5.2 Date of next RCM

The meeting recommended that the next RCM should be held on 17-20 November 1998, in Vienna.

5.3 Electronic communication

A central goal of the IAEA is to maximize communication between researchers. In order to do this, we recommend that:

1. A list server should be established to facilitate rapid e-mail between the group as a whole and between individual researchers. Questions and discussions would be available to all. Hussein volunteered to host the list server, in collaboration with Lanza.

2. A website should be established for dissemination of technical information, meeting information and other information which may be useful to the researchers and also to industrial users.

3. Both the website and the list server should be established as soon as possible.

4. Researchers should be encouraged to make research reports and technical information available in electronic form whenever possible. Such reports could be sent as electronic mail or posted on the website.

5. The IAEA should use electronic forms to enable Member States to submit proposals and reports electronically.

5.4 Structure of the final CRP report (ie at end of 1999)

It was recommended that the final CRP report should look as follows:

1. Standard cover page
2. Contents page
3. Introduction
4. Reports on areas 2.1, 2.2, 2.3, 2.4 and the new area 2.5
   (discussion of the results at the end of each section)
5. Summary
6. Conclusions and recommendations

6 Appendices

6.1 Information sheet for the meeting

6.2 List of participants

6.3 Meeting agenda

6.4 Project titles

INFORMATION SHEET

on

Co-ordinated Research Programme

entitled

'Bulk Hydrogen Analysis, using Neutrons'

(1) SCIENTIFIC AND TECHNICAL BACKGROUND

The measurement of hydrogen in materials is an endeavour which is common to several areas. In metallurgy, for example, because the presence of hydrogen in metals and alloys ('hydrogen embrittlement') causes structural weakness in aircraft components and in pipe systems of nuclear and petro-chemical plants, etc. Similarly, it is the detection of hydrogen which is required in systems which measure the moisture content of materials, for example in mineral ores, industrial powders and agricultural products (crops, grains, etc.). A further (indirect) application is the measurement of the fat content of meat.

In most of these situations, the hydrogen is required to be measured in a **bulk** medium, rather than merely at a surface. For this reason, it is **neutrons** which are used because of their high penetrating power in dense material (due to their zero charge). In addition, the mass attenuation coefficient for neutrons in hydrogen is significantly larger than for all other elements, meaning that neutrons have a higher probability of interacting with hydrogen than with other (competing) elements in the sample matrix.

Four areas where neutrons have been used for bulk hydrogen analysis are:

1.1 Fast Neutron/Gamma Transmission Technique (FNGT)

In the fast neutron and gamma-ray transmission technique (FNGT), neutrons and gamma-rays from a radioactive source, mostly californium-252, are passed through a sample. (In industrial situations, the sample is typically on a moving conveyor belt). The transmission of the fast neutrons depends predominantly on the hydrogen concentration and on the sample mass per unit area, whereas the gamma-ray transmission depends solely on the sample mass per unit area. Combining measurements of neutron and gamma-ray transmission therefore permits hydrogen (and, in most cases, moisture) in the sample to be determined, independently of sample mass per unit area.

This technique uses portable neutron sources, which can be located in industrial plants. It does not use nuclear reactors.

The FNGT technique has been developed and implemented in Japan, Australia and New Zealand for two specific on-line analysis applications, which involve conveyor belt and falling-ore-stream configurations. These applications are:

(a) moisture in coke [conveyor belt (Australia) and ore-stream (Japan)]; and

(b) fat in meat [conveyor belt (New Zealand)].

However, several other possible developments of the technique demand to be studied, and could be done in this CRP. These are described in section 2, 'Scientific Scope'.

(Note that this transmission technique is quite a different technique from the neutron backscatter technique, which is the technique underlying the operation of the widely-used neutron moisture (backscatter) devices for roads, fields, bore-holes, etc. The backscatter devices are not useable for conveyor belt and falling-ore-stream configurations, because the sample thickness and/or sample density are not necessarily constant in these configurations).

1.2 Digital Neutron Imaging

The nondestructive evaluation of hydrogen in metals and alloys is a major challenge, with significant impact for the prevention of catastrophic failure in critical engineering structures. Radiography using neutrons has previously exploited the large neutron-hydrogen cross section to visualize corrosion products and moisture in metals; however, the method is limited due to the effective averaging of the hydrogen density over the entire particle path length: thus, internal details may be hidden in thick components.

A technique called digital neutron imaging has been developed specifically for the detection of hydrogen. This technique uses charge coupled devices (CCDs), which may be thought of as 'neutron cameras' capable of detecting single neutron events and which can determine hydrogen spatial distribution with a position resolution of 0.1 mm.

In several aircraft accidents in the USA, failure of engine components, namely the titanium compressor blades have been implicated as contributing to the accidents. Previous destructive methods of quantifying hydrogen in the blades indicated that hydrogen concentrations of approximately 500 ppm were present and may have contributed to the unexpected failures. However, digital neutron techniques on the same blades, non-destructively, detected local hydrogen concentrations in the range of 1,000 to 7,000 ppm in spatially heterogeneous distributions. In addition, it was discovered that the hydrogen detected was not hydride as previously thought, but rather, interstitial or trapped hydrogen.

These results demonstrated a significant role in the detection of hydrogen in critical aircraft components and pointed toward applications in other areas where hydrogen embrittlement is known to be a major problem, e.g. in the pipe systems of petrochemical and nuclear plants. The further work which is required in this area and which could be done in this CRP, is described in section 2, 'Scientific Scope'.

1.3 Hydrogen Detection by Epithermal Neutrons

Hydrogen belongs together with boron, cadmium, samarium and gadolinium to the class of elements with very high mass attenuation coefficients for neutrons. Therefore, even small quantities of these materials are easy detectable by neutron radiography.

The neutron absorption coefficient for hydrogen is dominated by the scattering component. The scattering cross sections for neutrons in barn as a function of neutron energy are listed hereafter (for the following four typical neutron energy ranges):

(1) 0.001 to 0.01 eV (sub-thermal) 120 to 70
(2) 0.01 to 0.25 eV (thermal) 70 to 25
(3) 0.25 eV to 1 keV (epithermal) 25 to 20 and
(4) above 1 keV (fast) 20 to 1

Thus, with conventional neutron radiography techniques, the best results of hydrogen detection will be obtained with sub-thermal neutron beams. In the literature, the following sensitivities have been reported:

(1) $\approx$ 0.5 mg (hydrogen) cm^{-2} for sub-thermal neutron radiography and
(2) 0.5 to 1 mg (hydrogen) cm^{-2} for thermal neutron radiography

When resonance detectors are employed in neutron radiography, a substantial increase in neutron detection can be achieved. Indium is such a detector with resonances in the 1 eV to 1 keV range, which compares to the epithermal neutron energy range. Already in 1971 work on the HYSEN technique (i.e. HYdrogen Sensitive Epithermal Neutron Radiography) using an indium detector and epithermal neutrons was reported. The sensitivity of hydrogen detection by this method lies in the range of:

(3) 0.02 to 0.1 mg (hydrogen) cm^{-2}

For zirconium, a detection limit of 10 to 20 ppm hydrogen was obtained by the HYSEN method.

Unfortunately, the original HYSEN system has not been operational for a long time - but, in the meantime, no other neutron radiography facility has taken up this technique.

Because much progress has been made in neutron radiography systems, neutron filtering techniques and image analysis, and also because there is a need for a modern hydrogen sensitive detection method, it is recommended to set-up and study the HYSEN method with presently available equipment and techniques.

1.4 Microscopic Behaviour of Hydrogen in Bulk Materials.

At the microscopic level, as hydrogen concentration in materials builds up, the following effects can take place:

(i) Hydrogen can go to interstitial locations in the lattice and at fairly high concentrations (few percent) the lattice can swell. This results in local stresses and strains.

(ii) Hydrogen can migrate from its location due to various temperature dependent phenomena.

(iii) Hydrogen can form stoichiometric and nonstoichiometric compounds with the parent metal or alloy locally. Due to this phenomenon, heterogenous phases evolve which can lead to local blisters, etc.

Medium flux research reactors can be used quite easily for a variety of studies and applications here. The advantages of using neutrons to examine these microscopic effects for hydrogen are:

- the total scattering of hydrogen for neutrons is the largest amongst all elements.
- the coherent scattering amplitudes of hydrogen and deuterium for neutrons are comparable to the coherent scattering amplitudes of the majority of elements.
- the energy loss of neutrons in scattering from hydrogen is a maximum per collision.
- Neutrons can penetrate bulk materials to depths of several tens of centimetres.

Section 2.4 shows the work proposed in this area for the CRP.

(2) SCIENTIFIC SCOPE AND PROPOSED PROGRAMME GOALS

The setting up of a CRP on the topic 'Bulk Hydrogen Analysis, using Neutrons' was unanimously recommended by the five experts at a consultants' meeting called to consider this question (Agency HQ, Vienna, 6-8 December 1995). Within each of the four areas described in section 1, it was recommended that work should be done to further develop the techniques and to extend them to new applications. The scope and goals of this work would be as follows:

2.1 Fast Neutron/Gamma Transmission Technique (FNGT)

The aim would be to investigate and develop new applications of the FNGT technique, in particular by and for developing countries. Examples of potential new applications are:

- Measurement of hydrogen (and moisture) in minerals such as iron ore, cement, etc.
- Measurement of moisture in coke in steel plants: applications where existing commercial gauges are not suitable because of plant configuration, etc.
- Hydrogen in plastics
- Coal quality (in combination with other techniques such as microwave transmission)
- Moisture in agricultural products (e.g. crops, grains, cotton, etc.)
- Fat quantity and fat distribution in meat [e.g. determination of fat clusters ('marbling')]

The FNGT technique would be developed both by experiment and by modelling. One would need to develop suitable geometries: including source, shielding and collimation geometries. Detector selection; shielding material; electronics for particular requirements of accuracy, counting time and stability; calibration and standardization procedures; etc. would all need to be looked at. The direction would be governed by the needs of industry, where possible.

2.2 Digital Neutron Imaging

The areas to be looked at here would be:

2.2.1 Development and evaluation of demonstration kits for CCD based neutron imaging

The development of low cost cooled CCD systems for use by amateur astronomers has demonstrated that cooled CCD imaging can be obtained using inexpensive components. Development of a low cost neutron imaging demonstration system would permit quantitative radiography and tomography at small reactors. The development could consist of either investigating modifications to existing low cost CCD systems or perhaps developing a new low cost system specifically for neutron radiography.

2.2.2 Digital neutron radiography

Use of digital electronic imaging for neutron radiography would permit the development of new techniques for detection of hydrogen in bulk materials using neutron radiography and tomography. New detectors and the availability of small PCs can make this practical even for small laboratories, provided.that an appropriate combination of hardware and software can be developed.

2.3 Hydrogen Detection by Epithermal Neutrons

2.3.1 Development of epithermal neutron beams from accelerators using reaction thresholds

There exists a need for beams of epithermal neutrons for high sensitivity neutron radiography and detection of hydrogen using detectors with resonant behaviour in the few eV range, as shown above. These beams could be obtained from small accelerators using reactions just at threshold for a reaction, thereby producing neutrons in the keV range and below. This might be done using electrostatic accelerators in the range of 3 MeV and below or other accelerators could be investigated. Development of techniques for detection of neutrons in this range would be necessary.

2.3.2 Use of epithermal filtered neutron beams

The use of epithermal filtered neutron beams from reactors for hydrogen detection has the advantage that higher neutron fluence rates are available and that the development could start with the implementation and study of the HYSEN system. The use of epithermal filtered neutron beams from non-reactor-based systems would have the advantage of more energy tailoring, however, at the price of a lower neutron fluence rate.

Such epithermal filtered neutron beams could be employed for the following tasks:

- Study, optimization and characterization of the integral HYSEN method,
- Study of the indium detector sensitivity,
- Study of other resonant detectors including electronic detectors,
- Development of hydrogen sensitivity indicators, eventually combined with image quality indicators

2.3.3 Hydrogen sensitive epithermal neutron radiography

Some of the test reactor-based neutron radiography facilities are operating with various filtered neutron beams. These facilities might also be suited for epithermal neutron radiography when additional filtering is applied. In some test reactors, epithermal filtered neutron beams which are presently under preparation for BNCT (Boron Neutron Capture Therapy) could be upgraded for epithermal neutron radiography. These facilities provide large area beams.

It is recommended to start the epithermal neutron radiography work on hydrogen detection by the HYSEN method and to extend the study with work on electronic detectors and the development of hydrogen sensitivity and image quality indicators as mentioned above under point 2.3.2.

2.4 Microscopic Behaviour of Hydrogen in Bulk Materials

2.4.1 Hydrogen Blisters. Hydrogen blisters of sizes 0.5 mm or larger can be detected by conventional radiography. This lower limit can be pushed down to smaller size blisters and lower hydrogen concentrations by the use of electronic cameras.

2.4.2 Stresses and Strains. High resolution powder diffraction can be used to measure strains directly and thereby residual stresses. Also stresses and strains under high pressure and high temperature conditions can be measured using high pressure cells.

2.4.3 Phase and Loading. Powder diffraction can also be used to measure the phase of hydrogen compounds that can result from hydrogen ingress e.g. for the zirconium cladding of reactor fuel rods, whether ZrH_2 in Zr is in γ-phase or in δ-phase. The characteristics of in-situ hydrogen loading can also be studied.

2.4.4 Inelastic and quasi-elastic neutron scattering. This technique can determine:

- whether hydrogen in certain systems is free or bound.
- the density of phonon states of hydrogeneous materials. This can be used to calculate a variety of macroscopic thermodynamic properties like specific heat, thermal expansion, bulk modulus and the equation of state.
- the process of diffusion of hydrogen can be monitored by measuring the line broadening of a monoenergetic neutron beam.

Department of Research & Isotopes RI)
Division of Physical & Chemical Sciences (RIPC)

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NOTIFICATION OF AN AGENCY-SPONSORED MEETING

Title of meeting: First Research Co-ordination Meeting of the CRP on Bulk Hydrogen Analysis, using Neutrons (F1.RC-665)

Dates of meeting: 15-18 July 1997

Scientific Secretary: R. Walsh (A2373, x21753)

Place of meeting: IAEA HQ, Room C0249
Telephone extension 26395 (internally)
2060 - 26395 (externally)

Secretary: L. Uyaan (A2374, x21754)

PARTICIPANTS	ADDRESS ABROAD	ADDRESS IN VIENNA	PERIOD
Dr. Marton BALASKO	Atomic Energy Research Institute Konkoly Thege Str. 29-33 H-1525 Budapest HUNGARY *fax: +36-1-3959162* *e-mail:*		15-18 July
Dr. Colin Murray BARTLE	Institute of Geological and Nuclear Sciences Nuclear Science Centre P.O. Box 31312 Lower Hutt NEW ZEALAND *fax: +64-4-5704657* *e-mail:*	Hotel Nordbahn phone: +43-1-21130 fax: +43-1-2113072	15-18 July
Dr. Francis BROOKS	Dept. of Physics University of Capetown Private Bag Rondebosch, Cape 7700 SOUTH AFRICA *fax: +27-21-6503342* *e-mail: fdb@uctvms.uct.ac.za*	Hotel Nordbahn phone: +43-1-21130 fax: +43-1-2113072	15-18 July

Appendix 6.2

PARTICIPANTS	ADDRESS ABROAD	ADDRESS IN VIENNA	PERIOD
Dr. Tawee CHIM-OYE	Dept. of Physics Thammasat University Rangsit Center, Khlongluang Pathumthani 12121 THAILAND *fax: +66-2-5160976* *e-mail:*	**Hotel Nordbahn** **phone: +43-1-21130** **fax: +43-1-2113072**	15-18 July
Dr. Gyula Julius CSIKAI	Dept. of Neutron Physics Institute of Experimental Physics Kossuth University Bem ter 18/a H-4026 Debrecen HUNGARY *fax: +36-52-315087* *e-mail: csikai@falcon.atomki.hu*		15-18 July
Ms. Teresa CYWICKA-JAKIEL	Institute of Nuclear Physics ul. Radzikowskiego PL-31 342 Krakow POLAND *fax: +48-12-375441* *e-mail: dyrektor@bron.ifj.edu.pl*		15-18 July
Dr. Mustafa Nizamettin ERDURAN	Turkish Atomic Energy Authority Cekmece Nuclear Research & Training Center P.K. Havaalani 34831 Istanbul TURKEY *fax: +90-212-5482230* *e-mail: erduran@cnacm.nukleeer.gov.tr*		15-18 July

PARTICIPANTS	ADDRESS ABROAD	ADDRESS IN VIENNA	PERIOD
Dr. Esam HUSSEIN	University of New Brunswick P.O. Box 4400 Fredericton, NB E3B 5A3 CANADA *fax: +1-506-4535025* *e-mail: hussein@unb.ca*	Hotel Nordbahn phone: +43-1-21130 fax: +43-1-2113072	15-18 July
Mr. Isamu ISHIKAWA	Japan Atomic Energy Research Institute 2-4 Shirane, Shirakata, Tokai-mura Naka-gun, Ibaraki-ken 319-11 JAPAN *fax: +81-29-2648483* *e-mail: isamu@popsvr.tokai.jaeri.go.jp*		15-18 July
Dr. Sunday Adesunloye JONAH	Centre for Energy Research & Training Ahmadu Bello University PMB 1014 Zaria NIGERIA *fax: +234-69-32780, 32412, 33135* *e-mail:*		15-18 July
Dr. Richard LANZA	Dept. of Nuclear Engineering, Rm NW 13-219 Massachusetts Institute of Technology Cambridge, Massachusetts 02139-4307 USA *fax: +1-617-2532343* *e-mail: lanza@mit.edu*	Hotel Nordbahn phone: +43-1-21130 fax: +43-1-2113072	15-18 July

PARTICIPANTS	ADDRESS ABROAD	ADDRESS IN VIENNA	PERIOD
Dr. Vitalii MIKEROV	P.N. Lebedev Physics Institute of the Academy of Sciences of Russia Leninsky prospect 53 117924 Moscow RUSSIA *fax: +7-095-9382251* *e-mail:*	Hotel Norbahn phone: +43-1-21130 fax: +43-1-2113072	15-18 July
Mr. Michael MILLEN	Division of Minerals CSIRO Private Mailbag 5 Menai NSW 2234 AUSTRALIA *fax: +61-2-97106789* *e-mail: brian.sowerby@minerals.csiro.au* *or mjm@mpe67.dmpe.csiro.au*	Hotel Reichshof phone: +43-1-2143178 fax: +43-1-214317866	15-18 July
Mr. Ivan PADRON DIAZ	Dept. of Radiation Biology Neutron Physics Laboratory CEADEN Calle 30 #502 e/5ta y 7ma, AP 6122 Miramar Playa, Havana CUBA *fax: +53-7-241188 (or 8777703 - thru' Cuban Mission Vienna)* *e-mail: ipadron@ceaden.edu.cu*		15-18 July
Dr. Akhtar Hussain SHAIKH	Bhabha Atomic Research Centre Solid State Physics Division Trombay, Mumbai 400 085 INDIA *fax: +91-22-5560750, 5560534* *e-mail:*		15-18 July

PARTICIPANTS	ADDRESS ABROAD	ADDRESS IN VIENNA	PERIOD
Dr. M.S. ALLIE **(OBSERVER)**	Dept. of Physics University of Capetown Private Bag Rondebosch, Cape 7700 SOUTH AFRICA *fax: +27-21-6503342* *e-mail: allie@physci.uct.ac.za*	Hotel Nordbahn phone: +43-1-21130 fax: +43-1-2113072	15-18 July
Mr. A. BUFFLER **(OBSERVER)**	Dept. of Physics University of Capetown Private Bag Rondebosch, Cape 7700 SOUTH AFRICA *fax: +27-21-6503342* *e-mail:*	Hotel Nordbahn phone: +43-1-21130 fax: +43-1-2113072	15-18 July
R. IYER	DIR-RIPC	Room A2302, x21700	15-18 July
T. DOLAN	Head, Physics Section, RIPC	Room A2375, x21756	15-18 July
H. VERA RUIZ	Head, Industrial Applications & Chemistry Section, RIPC	Room A2369, x21748	15-18 July
R. WALSH	Physics Section, RIPC	Room A2373, x 21753	15-18 July

FIRST RESEARCH CO-ORDINATION MEETING FOR CRP 'BULK HYDROGEN ANALYSIS, USING NEUTRONS'

IAEA, Vienna, Room C0249 (ext 26395), 15-18 July 1997

PRELIMINARY AGENDA

	Tuesday 15 July	Wednesday 16 July	Thursday 17 July	Friday 18 July
09.00 - 10.30	09.00 Registration 09.30 Opening of the meeting R. Iyer, DIR-RIPC R. Walsh, RIPC (Scientific Secretary) Election of Chairman & Rapporteur Adoption of agenda RCM requirements, R. Walsh.	Session IV (Research Contracts) V. Mikerov (Russia) I. Padron Diaz (Cuba) A. Shaikh (India)	Session VIII . Consideration of other areas . Specific collaboration between groups	Session XII . Preparation of Meeting Report and Recommendations . Review of Meeting Report
10.30 - 11.00	COFFEE BREAK	COFFEE BREAK	COFFEE BREAK	COFFEE BREAK
11.00 - 12.30	Session I (Research Agreements) C.M. Bartle (New Zealand) E. Hussein (Canada) I. Ishikawa (Japan) R. Lanza (USA)	Session V Discussion/modification of proposals - Area 2.1	Session IX . Specific collaboration between groups . Preparation of Meeting Report and Recommendations	Session XIII Review of Meeting Report
12.30 - 14.00	LUNCH	LUNCH	LUNCH	LUNCH
14.00 - 15.30	Session II (Research Agreements) M. Millen (Australia) Session II (Research Contracts) M. Balasko (Hungary) F. Brooks (South Africa) T. Chim-Oye (Thailand)	Session VI Discussion/modification of proposals - Areas 2.1, 2.2	Session X Preparation of Meeting Report and Recommendations	Session XIV . Presentation of Meeting Report and Discussion . Closing of the Meeting
15.30 - 16.00	COFFEE BREAK	COFFEE BREAK	COFFEE BREAK	COFFEE BREAK
16.00 - 17.30	Session III (Research Contracts) J. Csikai (Hungary) T. Cywicka-Jakiel (Poland) M. Erduran (Turkey) S. Jonah (Nigeria)	Session VII Discussion/modification of proposals - Areas 2.3, 2.4	Session XI Preparation of Meeting Report and Recommendations	
17.30 - 19.00	Cocktail Reception, Reception Room A, VIC Restaurant			

First RCM on 'Bulk Hydrogen Analysis, using Neutrons'
Vienna, 15-18 July 1997.

Research Agreements

		CRP area (refer Information Sheet)
C.M. Bartle IGNS, New Zealand	Industrial product evaluation using neutron and gamma ray transmission	2.1
E. Hussein UNB, Canada	Neutron scattering/transmission methods for bulk hydrogen detection	2.1
I. Ishikawa JAERI, Japan	Bulk hydrogen analysis using neutrons in Japan	2.1, 2.3, 2.4
R. Lanza MIT, USA	Development of inexpensive digital neutron imagers	2.2
M. Millen/B. Sowerby CSIRO, Australia	On-line analysis of hydrogen and moisture in the mineral and energy industries	2.1

Research Contracts

M. Balasko AEKI, Hungary	Neutron radiography imaging of hydrogen containing materials	2.3
F. Brooks UCT, South Africa	Bulk hydrogen analysis by neutron scattering	2.1, 2.3
T. Chim-Oye Thammasat Univ, Thailand	A comparison of neutron reflection and transmission methods used in bulk hydrogen analysis	2.1
J. Csikai Kossuth Univ, Hungary	Measurements of macroscopic and microscopic behaviors of hydrogen in bulk materials	2.1, 2.4
T. Cywicka-Jakiel INP, Poland	Computational and experimental research on humidity measurements of coke and/or cement	2.1
M. Erduran CNRTC, Turkey	Hydrogen determination in bulk material using fast neutron generator	2.1
S. Jonah CERT, Nigeria	Development of a neutron facility for bulk hydrogen/ moisture analysis	2.1
V. Mikerov PNLPI, Russian Fed.	The development of fast neutron (14MeV) radiography and laminography methods on the basis of a portable equipment	2.2
I. Padron Diaz CEADEN, Cuba	Bulk hydrogen analysis in metals and welding joints by fast neutron/gamma transmission technique	2.1
A. Shaikh BARC, India	Bulk hydrogen analysis using neutrons in India	2.2, 2.3, 2.4

Appendix 6.5

Project Summaries

Project Summary

C Murray Bartle, Scientist, Nuclear Sciences Group, Institute of Geological and Nuclear Sciences, PO Box 31312, Lower Hutt, New Zealand.

Ph 64 4 5704655, Fax 64 4 5704657, e-mail m.bartle@gns.cri.nz

Project Title: Industrial product evaluation using neutron and gamma ray transmission

Scientific Scope of the Project:

a) The Institute shall undertake a research project as named which forms part of the IAEA's Co-ordinated Research project in 'Bulk hydrogen analysis, using neutrons' (herein after referred to the "CRP").

The Chief Scientific Investigator shall be Dr. C Murray Bartle

b) The programme of work shall be:

To extend the fast neutron-gamma technique to new areas for industrial applications

The programme of work may be further detailed by communications and meetings.

Workplan for the First Year:

a) Establish contact with representatives of world-wide groups (IAEA member nations) wanting improved industrial product composition monitoring.

b) Develop interest and establish the benefits of the fast neutron/gamma method.

b) Gain a commitment for resource input and establish a practical schedule.

Project Summary

Esam Hussein, PhD. P.Eng., Professor
Department of Mechanical Engineering
University of New Brunswick,
P.O. Box 4400, Fredericton, N.B.
Canada E3B 5A3
Tel: (506) 447-3105, Fax: (506) 453-5025, E-mail: Hussein@unb.ca

Project Title
Bulk Detection of Hydrogen with Fast Neutron Scattering

Scientific Scope of the Project

The project aims at utilizing the slowing-down of fast neutrons for bulk detection of hydrogen. This is done by measuring the amount of low-energy neutrons scattered off an object exposed to fast neutrons. Since metals do not significantly slow-down neutrons, the technique is best suited for the detection of hydrogen in the presence of metal. The incident neutron energy has however to be optimized so that the present amount of hydrogen produces a detectable amount of slow neutrons. The technique was successfully used for measuring the liquid content in boiling-water two-phase flow in metallic pipes of various sizes, as well as for flow within channels containing metallic rod-bundles. The high background produced by fast neutrons resulted however in a low contrast-ratio.

Workplan for the First Year

The first year of the project will concentrate on devising methods for detecting slow-neutrons in the presence of a large field of higher-energy neutrons. Since most thermal-neutron detectors are also sensitive to fast neutrons (via the $1/v$ cross-section), a method has to be found to discriminate online against fast neutrons. Success in solving this problem will enable the detection of small quantities of hydrogen embedded in a metallic matrix, using readily available unmoderated fats-neutron sources, such as ^{252}Cf.

Project Summary

Isamu ISHIKAWA

Application and Development Division
Department of Radioisotopes
Japan Atomic Energy Research Institute

Oarai,Ibaraki-ken 311-13,JAPAN

1. Project Title : Hydrogen Analysis using a Small Neutron Source.

2. Scientific Scope of the Project :

   The accuracy of the small sample assay system at the LANL has been shown to affected by the presence of small amount of hydrogen.

   Thereafter we have confirmed more sensitive system with our point of view than before.

   We hope it is possible to come up to our expectations in various fields of civil engineering,steel industry, etc..

3. Workplan for the First Year :

   The investigation for the circumstances of applicable fields.

Richard C. Lanza
Massachusetts Institute of Technology
Cambridge, MA 02139 USA
Tel: +1 617 253 2399 FAX: +1 617 253 2343 e-mail: LANZA@MIT.EDU

Project Title: Development of Inexpensive Digital Neutron Imagers

Scientific Scope of the Project:

There is an increasing interest in the use of digital imaging techniques for neutron imaging. The basic technology which is currently employed uses electronic optical imagers, generally charged coupled devices (CCD) to capture images from neutron sensitive scintillation screens. Although originally developed for military satellite use, CCDs are now widely used for consumer products such as video cameras and have become considerably less expensive. Despite this, the CCD technology has limitations when used for neutron imaging. One typical arrangement used for this application is the imaging of a neutron sensitive scintillation screen using a lens-coupled CCD.

A straightforward calculation shows that the light collected or, more correctly, the number of photoelectrons generated in the detector, by such a system is:

$$n_e = \frac{\eta_s \eta_{\det} \eta_{lens}}{(2F(1+m))^2}$$

where η_s is the number of light photons generated in the scintillator by a neutron interaction, $\eta_{\det}$ the quantum efficiency of the detector, η_{lens} the transmission efficiency of the lens, and F the lens f number, and m the ratio of image size to detector size (the "minification" of the system). In practice, the best choice for detectors is to use the lowest value of m, that is the *largest* size detector, increasing the cost of the device. Recently, a new class of imaging devices has be developed using complementary metal oxide semiconductor (CMOS) fabrication rather than the more specialized CCD technology. The advantage of this technology is the use of the standard fabrication process common to integrated circuit chips such as microprocessors and memories which are produced in very large quantities. As a result, the cost of imagers is expected to decline in the future and indeed the first series of chips are already on the market in price sensitive consumer products. Recently, there have been announcements of consumer oriented cameras with CMOS imagers and digital signal processing chips built into the camera. Further, due to the lower cost of manufacturing, large CMOS chips are less expensive than smaller CCD chips. This implies that we can use less minification and hence increase the signal output of the imager.

Workplan for the First Year

We propose to investigate the performance of such CMOS devices when used in neutron imaging systems with the goal of designing a system which will make digital neutron imaging practical even for small laboratories. Throughout the design process, we will keep as a design goal the use of inexpensive, standard components to the greatest extent possible. We hope to collaborate with several industrial entities to use their technology.

The development of such systems would permit the use of neutron imaging even in very small laboratories. In particular, this would utilize small reactors which are currently underutilized, and would permit researchers in these countries to develop applications for neutron imaging as well as using modern image processing techniques which are not possible using conventional scintillation screen-film combinations. Further, once data are available in digital format, collaborations may be possible between MIT and these small laboratories using computer networks such as the Internet and World Wide Web.

PROJECT SUMMARY

NAME : Mr. Michael Millen,
CSIRO Division of Minerals
PMB 5, Menai
NSW 2234, Australia.
Tel : +61 2 97106733
Fax +61 2 97106789
email : michael.millen@minerals.csiro.au;

PROJECT TITLE : *On-line analysis of hydrogen and moisture in the minerals and* energy industries.

SCIENTIFIC SCOPE OF PROJECT : The objective of the project is the development and industrial application of nuclear and microwave techniques for the on-line determination of hydrogen, moisture and other parameters.

WORKPLAN FOR FIRST YEAR* :

Moisture :

- Develop new laboratory low frequency microwave transmission gauge. The gauge will improve the dynamic range of the present commercial analyser and allow operation on high thickness, high moisture samples
- Assess accuracy of prototype microwave gauge on a range of samples including black and brown coal and iron ore.
- Investigate other applications of the fast neutron and gamma ray transmission (FNGT) gauge. Present commercial gauge is only used for coke feed to a blast furnace in a on belt geometry.

Hydrogen

- Manufacture improved laboratory facilities for neutron/gamma analysis of bulk coal and mineral samples for elemental determination including hydrogen.
- Test samples on new neutron laboratory facility using backscatter and transmission geometries, employing Am-Be, Cf-252 radioisotopes and neutron generator.
- Compare the use of a neutron generator and radioisotope sources for elemental determinations.
- Develop and implement advanced spectral analysis techniques ie response function methods, principal components analysis, neural network techniques, spectral fitting.

* - Parts of workplan are subject to industry funding.

Project Summary

Name: Dr BALASKÓ, Márton
Accreditation: Neutron radiography project leader
Contact: Address: KFKI Atomic Energy Research Institute
1221 Budapest Konkoly Thege str. 29-33
HUNGARY
Phone: (36-1) 3959220 Ext. 1434
Fax: (36-1) 3959162
E-mail: svab@power.szfki.kfki.hu

Project Title: Bulk hydrogen analysis, using neutrons

Scientific Scope of the Project: Neutron radiography imaging of hydrogen containing materials

Workplan for the First Year:

1. Study of the behaviour of hydrogen containing materials in compressor-type refrigerators.
2. Study of the motion of hydrogen containing materials in absorption-type refrigerators.
3. Construction of special Pd-valve for hydrogen occlusion in order to measure the partial pressure of hydrogen in aggressive two phase systems.
4. Application of HYSEN method with the use of indium foil.

Project Summary

Professor F D Brooks
Dept of Physics, University of Cape Town, Private Bag, Rondebosch 7701,
South Africa
Telephone: +21 650 3325 *Fax*: +21 650 3342 *email*: FDB@UCTVMS.UCT.AC.ZA

Project Title: Bulk hydrogen analysis by neutron scattering

Scientific Scope of the Project

When monoenergetic neutrons are scattered (*without* multiple scattering) from a sample of material the energy spectrum of neutrons scattered at a given angle θ contains information which can, in principle, be used to determine the elemental composition of the sample. For scattering on hydrogen, (^1H) the scattered neutron is restricted to forward angles, $\theta < 90^0$, and the ratio of scattered to incident energies is given by $E/E_0 = \cos^2\theta$. For other nuclides the maximum energy change in scattering (minimum E/E_0) occurs for $\theta = 180^0$ and the value of E/E_0 at this angle increases smoothly with mass number A, from 0.11 for $A = 2$ to very close to unity for $A > 200$. Thus simultaneous measurements of E/E_0 at a forward angle, eg $\theta = 30^0$, and a backward angle, eg $\theta = 150^0$, will provide information from which the relative proportions of hydrogen and heavier elements in the sample may be estimated. If the energy resolution of the measurement made at the backward angle is good enough, then it should also be possible to resolve contributions from different light elements, eg for $A < 16$, and thus to determine the atomic proportions of these elements in the sample also. The aims of this project are:

(a) to examine the feasibility of determining hydrogen in bulk (0.1-1000 kg) samples, from measurements of the ratio of forward-to-backward scattering of MeV neutrons, as outlined above (*FNSA method*); and

(b) to investigate the possibility of applying the same principle of kinematic energy changes as a hydrogen signature for measurements in small samples (< 1 g) using lower energy (0.5 eV - 300 keV) neutrons (*SNSA method*).

Workplan for the first year

The following work is planned on the FNSA method:

(a) scattering measurements and analyses, using monoenergetic 5-15 MeV neutrons and single samples (0.3-1 kg) of different elements and compounds, with particular interest on compounds containing hydrogen;

(b) scattering measurements and analyses, as in (a), but for multiple samples and for samples concealed in containers packed with other materials;

(c) Monte-Carlo simulations, using the code MCBEND, of the measurements (a) and (b); and

(d) measurements, analyses and simulations, as in (a) - (c), but for ^{241}AmBe or ^{252}Cf neutron sources instead of monoenergetic neutron beams.

The following work is planned on the SNSA method:

(e) time-of-flight studies of neutron scattering from small samples (few % H in 1g) using 30-300 keV pulsed monoenergetic neutrons and ^{6}Li-loaded glass scintillation detectors;

(f) a feasibility study of a reactor-driven, or accelerator-driven, monoenergetic eV neutron source based on resonance scattering; and

(g) a feasibility study of a "tuned" neutron detector (based on a neutron capture resonance) to be operated in association with the source (f), so as to select neutrons scattered from hydrogen by means of their characteristic (kinematic) energy loss in scattering.

Dr. T. Chimoye, M. FeungFoong, P. Rungrairatanaroj

Department of Physics, Faculty of Science and Technology,

Thammasat University, Pathumthani, Thailand.

Project Title :

A Comparison of neutron reflection and transmission methods used in bulk hydrogen Analysis

Scientific Scope of the project :

Bulk hydrogen (moisture) is planned to determine for various geological and industrial samples collected in Thailand. The neutron reflection method will be improved by using activation foil detectors and cadmium difference method. The optimal combination of materials will be studied by transmission method to suppress the detection limit for hydrogen. The transmitted neutrons will be detected by an energy independent neutron detector.

Workplan for the first year :

Studies on the sensitivity of foil activation technique used for the bulk hydrogen analysis by neutron reflection method. Matrix effect on the detection limit of hydrogen and moisture contents. Selection of typical standard samples for calibration. A Comparison of the sensitivity of the neutron reflection and transmission methods.

PROJECT SUMMARY

Contract number: 9645/RO

Prof. Dr. Julius Csikai
Institute of Experimental Physics, Kossuth University
H-4001 Debrecen, Pf. 105, Tel : 36 52 415 222, Fax: 36 52 315 087,
E-mail: CSIKAI@FALCON.ATOMKI.HU

Project Title:

„Measurements on macroscopic and microscopic behaviours of hydrogen in bulk materials"

Scientific Scope of the Project:

Measurements of hydrogen content and C/H atomic ratio in minerals, agricultural products and coal samples by thermal neutron reflection method. Results will be compared with those obtained by the recoil proton, neutron transmission, capture gamma-ray and leakage spectrum techniques.

Studies on the microscopic behaviour of of hydrogen in bulk materials:

- Accumulation of deuterium as a hydrogen in bulk materials, alloys, plastic, metallic glasses and semiconductors;
- Concentration profiles in different materials;
-Change in physical properties of materials vs. hydrogen concentration.

Workplan for the First Year:

Studies on the advantages and limitations of neutron/gamma reflection method for bulk hydrogen analysis of various materials.

Development of a method for the determination of C/H atomic ratio in hydrocarbons.

Measurements of hydrogen contents of semi-thin samples by the detection of recoil protons in coincidence with ^{3}He particle produced in $^{2}H(d,n)$ reaction.

Evaluations of the effects of accumulated deuterons on some physical parameters of solids.

[redacted]

Cywicka-Jakiel Teresa - Institute of Nuclear Physics, Kraków ul. Radzikowskiego 152, POLAND
tel. (012) 37 02 22 (i.c. extension .344), fax: (00 48 12) 37 54 41
email: Cywicka@bron.ifj.edu.pl

[redacted]

IAEA Research Contract No: 302-F1-POL-9613
B5-POL-25547

[redacted]

Project will be concentrated on using FNGT technique for high precision coke moisture measurements in the Polish steelworks and can be extended to the cement moisture measurement as cement industry will be ready to co-operation.

[redacted]

Detailed work plan for the first year (1997/1998) includes:

(1) The computer studies of geometry configuration for FNGT in falling material geometry for coke and/or cement industries. The calculations will use DOORS 3.1 (instead of TORT which is no longer issued as a separate package) or MCNP4.

(2) Studies of geometry configurations suitable for industrial applications through visits and contacts with industrial organisations.

(3) Acquisition of a part of detecting, electronic and computer modules necessary for carrying out the experimental investigations.

Ad(1) The computer studies of geometry configuration for FNGT.

Optimisation of FNGT measurement conditions need some geometrical configuration to be adjusted for better accuracy of moisture content determination which includes source, shielding and collimator configurations. This optimisation will be done using computers programs: DOORS 3.1 (CCC-650) from RSICC (Radiation Safety Information Computational Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee) and MCNP4 (CCC-200A/B) from RSIC Los Alamos National Laboratory, Los Alamos, New Mexico.

[redacted]

The principle application of discrete ordinates code system DOORS 3.1 is to the deep-penetration transport of neutrons and photons.

DOORS reads ANISN-format cross-section libraries, which are not included in the package.

The DLC-75/BUGLE-80 library - the 47 neutron, 20 γ-ray group, P3, cross section library has been using by our group for ANISN calculation and it can be used for TORT calculation as it contains data concerning the most important elements of coke and coal.

For more detailed calculations for complex geometries concerning arrangement of source shielding container with collimator system inside, and sample of changing moisture content Monte Carlo program - MCNP4 will be used.

Ad(2) Studies of geometry configurations suitable for industrial applications through visits and contacts with industrial organisations.

For preliminary DOORS and MCNP calculations studies of geometry configurations suitable for industrial applications are needed. This will be done through visits and contacts with representatives of steelworks particularly those applying „MWK-3B" gauges.

Ad(3) Acquisition of a part of detecting, electronic and computer modules necessary for carrying out the experimental investigations.

We received quotation for scintillation assembly with encapsulated liquid scintillator BC-501A (Φ 50 x 50 mm) from BICRON.

„Pulse shape Analyser/Timming SCA - type 552" has been ordered and will be bought in EG&G ORTEC as project funding starts.

PROJECT SUMMARY

Mustafa Nizamettin Erduran, PhD
Turkish Atomic Energy Authority,
Çekmece Nuclear Research and Training Centre,
Department of Physics
P.K: 1 Havaalanı 34831,
Istanbul - Turkey
e-mail:erduran@cnaem.nukleer.gov.tr

Project Title:

Hydrogen Determination in Bulk Material using Fast Neutron Generator

Scientific Scope of the Project:

Interrogation techniques based on fast neutron transmission measurements are very effective tools for elemental characterization of bulk media consisting of light elements such as H,C,N and O. Further enhancements can also be achieved combining the signatures of thermal neutron captured gamma rays or gamma rays produced through neutron inelastic scattering. The latter technique can be exploited to locate the detected material by measuring neutron flight time from its creation to the point of interaction with the substance of interest.

The aim of this project is by making use of existing equipment and knowledge to investigate and develop Fast Neutron/Gamma Transmission (FNGT) technique in the laboratory environment for plausible applications required by the industry. Research will be devoted to comparative studies by using the low energy ion accelerator and Pu/Be neutron sources. The optimization of source, shielding and detector geometry will have to be carried out and design and construction of the experimental set up including an associated particle chamber will then be realized. In the later stages stability and reliability of the system will have to be studied and parameters standardized. Beside the use of TOF technique, electron and proton recoil spectra unfolding methods are intended to be introduced in order to obtain gamma and neutron energy spectra using liquid scintillation detectors.

Workplan for the First Year:

- Testing the energy and timing resolution of the existing detectors,
- Design and construction of neutron producing target chamber for associated particle TOF measurements,
- Testing the spectrum unfolding codes with experimental data,
- Repeating the energy and timing resolution tests with a BaF_2 detector which will be required from the IAEA,
- Comparative studies of associated particle TOF and recoil spectrum unfolding techniques for FNGT measurements,
- Suitable equipment selection for industrial applications.

Project Summary

Research Contractor: Nuclear Science and Technology Section, Centre for Energy Research and Training, Ahmadu Bello University, Zaria, Nigeria.

Research Contract No. 9612

Chief Scientific Investigator: Dr. Sunday A. JONAH

Project Title: Development of a neutron facility for bulk hydrogen/moisture analysis.

Scientific Scope of the Project:

i) To develop and construct a simple and economic experimental facility using an isotopic neutron source for the determination of hydrogen/moisture content in industrial and agricultural products.

ii) To train young scientist and develop the capabilities of Nigerian industries in the field of nuclear techniques using the facility.

iii) To investigate the fabrication of an automatic facility for industrial purposes.

Workplan for First Year:

i) The design of the facility based on literature survey and personal contacts with other institutes - concluded

ii) Fabrication of the facility which include:
- fabrication of a cylindrical-shaped aluminium container 50cm in diameter and length 50cm to house the paraffin wax extended moderator - 2 weeks.
- fabrication of a cylindrical-shaped aluminium container, 10cm diameter and length 10cm - 2 weekds.
- determination of optimal source - sample - detector geometry and other standardization procedures - 2 months.

iii) Sample collections from already identified fields. - 2 months.

iv) Facility testing using the samples collected and analysis - 2 months

v) Preparation of reports - 1 month.

Contract # 9614/R0

PROJECT SUMMARY

Chief Scientific Investigator: V. Mikerov,

Accreditation: Leading Research Worker, P.N. Lebedev Physics Institute of Academy of Sciences of Russia (117 924, Moscow, Leninsky Prospect 53, Russia). Fax: (007)(095) 938-22-51, phone: (007)(095) 132-66-56, E-mail: vmiker@sci.lpi.msk.su

Project Title:

The development of fast neutron (14MeV) radiography and laminography methods on the basis of a portable equipment

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Scientific Scope of the Project:

The aim of the Project is the development of fast neutron (14MeV) radiography and laminography methods on the basis of a portable neutron generator, a CCD-neutron detector and a computerised system for data acquisition, images processing and visualising.

The achievement of this aim will be provided by the development of:

- **a more available portable neutron generator with a high neutron output ($\geq 10^{10}$-10^{11} n/s) and a point like target;**
- **an effective detector based on a cooled CCD-matrix for visualising fast neutron fields with a view field of $\geq$100x100 mm^2 and a spatial resolution of 0.2 mm - 0.4 mm;**
- **a computerised registration system functioning in a real time mode (inspection time $\approx$10 min);**
- **an adequate mathematical apparatus and software.**

Work Plan for the First Year

A1. Study of major limitations on parameters of advanced fast neutron imaging techniques.
A2. Development of a general technical specification for a portable fast neutron facility.
A3. Development of a specification for the registering system.
A4. Development of a specification for the fast neutron generator.
A5. Development of the facility block-diagrams.
A6. Development of electronic circuit diagrams.
A7. Development and study of an effective ion source for the neutron tube..
A8. Development of a cooling system for the neutron tube target.
A9. Development and study of luminescent screens for fast neutrons imaging.
A10. Development and study of a fast optics for transferring of an image to the CCD-matrix.
A11. Development of a mathematical apparatus for data processing
A12. Development of a software.
A13. Upgrading of the experimental neutron facilities at LPI (Lebedev Physics Institute) and VNIIA (All Russia Research Institute of Automatics) for providing works on the project.

PROJECT SUMMARY.

PRINCIPAL RESEARCHER: Ivan Padron Diaz
CEADEN, La Havana, Cuba.
Street 30 No.502. Miramar.
FAX: 22 15 18 or 33 11 88.
Telef.: 22 15 18.
E-mail: ipadron@ceaden.edu.cu

PROJECT TITLE: "Bulk moisture determination in building materials by fast neutron/gamma technique".

SCIENTIFIC SCOPE OF THE PROJECT:

In order to reduce the energetic consumption and ecological contamination, it is very important to develop the fast neutron-gamma transmission technique for the moisture determination in building material industry. Basically, we are thinking on the following applications:

1. Moisture determination in cement paste conveyor belt for the humid way processes. (The optimal moisture is important to reduce the energetic consumption and to increases the product quality).
2. Moisture determination in ceramic pastes.
3. Moisture determination in concrete components in falling-ore-stream configuration in concrete production for blocks, flats, girders, columns, pipes, etc.
4. Moisture determination in asbestos cement production.

WORK PLAN FOR THE FIRST YEAR:

1. Setting up and testing the experimental array (detectors, associated electronics, holders, data acquisition system) with isotropic neutron sources.
2. Acquisition of the D or T target for the neutron generator.
3. Establishment and determination of the neutron generator parameters related to the neutron production (flux, energy spread, angular distribution).
4. Modelling the fast neutron and gamma interactions by Monte Carlo simulation method with the material samples to be measured.
5. Measuring by fast neutron technique the moisture content in building material samples.

PROJECT SUMMARY

Dr. Akhtar Hussain Shaikh, Scientific Officer (SE),
In charge, Neutron Detection Systems Section, Solid State Physics Division,
Bhabha Atomic Research Centre, Trombay Mumbai 400 085, India and
Chief Scientific Investigator for the present CRP.
FAX: +9122 - 5560750 e-mail: sspd@magnum.barc.in

Project Title : Bulk Hydrogen Analysis, using Neutrons

Scientific Scope of the Project:

The project deals with the detection of hydrogen in bulk materials using neutrons. The ubiquitous presence of hydrogen, its very low mass and relatively good neutron cross-section of hydrogen and deuterium can be exploited to study variety of details of hydrogen in metals alloys. Detection of hydrogen using neutrons has always been part of the research programme of the centres where neutron beam/sources are available. The objective of the CRP is to establish the application of neutrons in hydrogen bulk analysis in such Centres and encourage collaboration and scientific exchange between them. Thus the CRP has provided opportunity to establish neutron techniques for the applications of technological interest ranging from problems like hydrogen embrittlement to applications in metal-hydrogen systems. Neutron radiographic techniques are especially of great importance in non-destructive evaluation and testing. The real time radiography has great promise in many dynamic processes and tomographic applications.

As a part of this CRP following studies have been undertaken at BARC.

1. Setting of HYSEN radiography technique with existing NR facility at Apsara reactor and study of bulk hydrogen in metals hydrides.
2. Setting of an epithermal neutron beam using iron filter.
3. Digital radiography: Updating of existing NR facility with digital electronic imaging. Study of hydriding in zircaloy pressure tubes and corrosion in aluminium using neutron radiography and tomography.
4. Microscopic behaviour of hydrogen:
   i) Neutron powder diffraction study of pure and hydrided samples of zircaloy and identification of hydride phase. Measurement of residual stresses due to ingress of hydrogen in the lattice at fairly high concentrations.
   ii) Inelastic and quasi elastic neutron scattering study of some hydrogen containing intermetallic compounds will be studied.

<u>Work plan for the First year:</u>

(A) Procurement of instrument components for updating NR facility at Apsara reactor
(B) Establishment of HYSEN technique with existing NR facility at Apsara and examination of hydrogen loaded materials.
(C) Setting up of epithermal neutron facility.