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SUMMARY OF MEETINGS ON

a) Energy Deposition in Moderators
b) Shielding
c) Activation
d) Safety

a) Energy Deposition in Moderators

Early papers in the meeting gave the performance of the KENS cold moderator, the ZING-P' cold moderators and estimates of powers in the SIN and SNQ cold moderators. These examples of the pulsed and continuous sources posed for us two problems:-

i) How the pulsed moderator energy depositions compared, especially when extrapolated to the SNS.

ii) How well the energy deposition in the C.W. liquid H_2 or D_2 moderators could be estimated, where at kW levels a factor 2 represents very large quantities of money.

A number of participants met to collect the information on existing and proposed moderators. This is shown in Table 1 and contains, we believe, all the relevant information for making reasonable comparisons. The left hand columns show the input conditions; the right hand ones show the moderator characteristics and information on material, decoupler and reflector. Table 2 compares measured powers extrapolated roughly to SNS moderators and also the SNS estimates. The SNS estimates agree well with the extrapolated ANL values but not with the KENS value.

It is hoped further measurements will be done on the KENS moderator to help resolve the differences. We look forward to early measurements on the IPNS-1 cold moderator when that facility starts up in April 1981.

Of the continuous source cold moderators, the SIN 30ℓ D_2 moderator has power depositions of 600 W due to capture γ's and 1.2 kW due to neutron slowing down. Such estimates are very difficult to make and it is clear that with such large powers errors can be very costly. It is hoped that TRIUMF might be able to mount an isolated moderator in the TNF. SIN and TRIUMF will explore this possibility.

b) Shielding

i) General Problems

The session opened with a discussion on the problems of shielding against

fast and slow neutrons, both for radiation protection and reduction of spectrometer background. Whereas neutrons transmitted by the bulk shield were "easy" to calculate, shielding of external beam tubes is much less easy, but just as important. Bright surfaces, ie those seen by the moderator, must be minimised in area and preferably be absorbing; visible surfaces, ie those seen by the sample, should also be minimised and absorbing. Visible surfaces should never be bright ones!

There is a clear need to provide good thermal neutron shielding around choppers to reduce the area of visible surfaces. Gadolinium oxide paint is an excellent material for making surfaces black to thermal neutrons.

The location of the final collimator is important but not easy to decide. The beam stop must be effective in absorbing fast neutrons and in preventing moderated neutrons reaching the spectrometer. There were severe background problems at WNR, especially due to the beam stops.

Many ad-hoc solutions have been obtained to shielding problems, but few written up and reported. Solutions to some of the problems are probably more easily obtained from communication of hard-won experience than by large scale use of Monte-Carlo codes.

ii) Particular Topics

The meeting heard of measurements taken on the newest of the spallation source target stations - that of KENS. Measurements were made using 500 MeV protons on the neutron production target, using several activation detectors. From measurements of saturation activity in both forward and transverse directions the effective attenuation lengths of iron were obtained. In particular the value at 90^o was 116 g/cm^2. Similarly, by adding heavy concrete around the target within the iron surround attenuation values at 0^o (130 g/cm^2) and 90^o (96 g/cm^2) were obtained. Radiation measurements were made at the top of the KENS, and some of the longitudinal beam holes were open (we recall the KENS vertical shield is 4 m high containing 1.65 m of iron and 0.8 m of heavy concrete). The levels measured fell nicely between the value expected from the original design figures for attenuation length and that based on the newly evaluated figures. In the discussion on comparative shielding assemblies it was felt there is a need for care in defining the input beam intensity and how it was measured.

In a discussion on shielding materials themselves, cost proportional factors were presented for basic geometries, material and allowing for the dependence of attenuation length on neutron energy. It was found that in the basic geometries considered that over the fission-to-thermal energy range, iron oxide mortar (Fe 50 w/o) was the cheapest material. In a practical target station with several functions to perform a combination of materials was considered more effective. Iron shot is a cheap and convenient material to use in providing packing for holes and gaps. However great care must be taken to avoid severe problems later if dismantling becomes necessary, due to rust, activation and contamination.

The problems of the design of primary beam collimators were considered. The aim is to reduce the amount of scattering from the collimating system whilst keeping good beam definition. This is obtained by a series of defining apertures and absorbers, based on the use of ray diagrams. However the beams contain both high and low energy neutrons and the collimators must have materials and geometry to take both into account.

c) Activation and Component Materials Irradiation

Activation and component materials irradiation are major problem areas in the operation of neutron sources and solutions are required which:

i) Maximise safe operating conditions and component longevity.
ii) Minimise initial construction costs and operating costs.
iii) Simplify maintenance and handling requirements.

A number of papers were presented at the meeting, also participants met to discuss some particular problems, as indicated below.

Irradiation of Coolants

Under irradiation radiolysis and activation of component cooling water occur, particularly in the target. Radiolysis requires special handling for recombination and venting, whilst activation (primarily from spallation of oxygen) requires positive containment for biological safety purposes. Corrosion can also present problems. Tests on the KENS target and magnet cooling water for a 2.4 μA-day irradiation were described, giving respectively 10^{-4} μCi/cm³ and 10^{-6} μCi/cm³ of ^{7}Be. Experience with ZING-P′ at the ANL showed the target cooling water blanket gas (He) to be rich in hydrogen and deficient in oxygen for no identifiable reason.

Irradiation of hydrocarbons in moderators (eg CH_4) can be expected to cause hydrogen displacement and associated polymerisation. Total radiolysis products in the KENS cold CH_4 moderator were found to be about 1% (including initial impurities).

Tritium and ^{7}Be as spallation products of carbon have also been seen. The moderator is frequently replaced. Some neutronic changes have been observed as the concentration of radiolysis products increases. The ANL reported that for a total 1.8×10^{18} n/cm² (ie about 1 year's irradiation) about 4 μCi/gm of ^{7}Be was found in CH_4. Provisions have been made at IPNS-I to allow a continuous purge of fresh methane for its two methane moderators.

Fission/Spallation Products in Targets

The SNS and IPNS-I will use segmented uranium targets, clad in Zircaloy-2 to prevent corrosion and to contain the fission/spallation products. Much effort has gone into the enumeration of these products, where, for example, some 1200 nuclides were surveyed to determine total activity and decay of the SNS target. The effects of high irradiation and nuclides on the cladding is not well known. A report was presented of a preliminary study made at KENS on the induced activities in a uranium target. A segmented target, overall length 9.5 cm, of "Yellow Cake" uranium was irradiated with a total of 6×10^{13} 500 MeV protons. Exposure rates, decay characteristics including radioacive nuclide analysis, spatial and temporal changes in the β-ray distribution of the target were studied. Preliminary measurements of α-decay were also made. Such quantitative measurements are of great importance for the proposed uranium targets, not least as independent tests on the HETC code packages.

With the proposed SNQ source considerable effort is being devoted to the study of proton and fast neutron radiation damage. Mercury, a spallation product of lead, will cause corrosion and high temperature embrittlement problems. Much effort is going into the selection of materials and there will be several complex technological problems with fabrication.

Target Window Materials

A number of different window materials are being considered for the spallation source targets, as can be seen in Table 3. The material selections have been made based on experiences in similar but not identical environments. Little is known about high radiation damage effects due to protons: much is yet to be learned and documented. The results of future tests and post-irradiation inspections are of great interest to all source designers.

Thermal Cycling Effects in Targets

Inherent instabilities associated with some accelerator operations impose severe operating conditions to target materials due to cycling of induced thermal stresses. This cycling is expected to be the governing factor in the life of most targets. The anticipated materials fatigue may be exaggerated by the effects of irradiation. Normally applied codes to depict the effects of thermal cycling will require refinement to allow for irradiation effects. A report is in preparation at the ANL to define the effects of thermal cycling in the IPNS-I targets. Dissemination of experience in these areas will be of considerable value.

d) Safety

For effective and efficient operation of a facility it must be easy to maintain. Similarly, easy dismantling, whether for change of scope or even final disposal, is a basic engineering requirement. Design must reflect these requirements at the outset of a project and experience is to be gained from related fields, eg reactor technology and remote handling.

A fundamental requirement is that the facility must be safe to operate. The facility must have a full hazard assessment, show safe operation and proper emergency procedures.

Though many of the papers and discussions contained safety needs implicitly, and all of the proposed designs reflected their in-built safety requirements, only one paper addressed the problems of safety as such. There remains the need to compare hazard assessments, safety and emergency procedures. Much benefit is to be obtained by the mutual discussion of problems. It remains our duty to show we can operate properly these exciting new facilities.

Conclusions on the Summaries

During many of the discussions, as typified above, many of the solutions were clear or available from hard won experience. The cost and time burdens can be reduced by mutual exchange of information at ICANS meetings but also through continued interchange of ideas through open communication. The ICANS IV was very successful meeting in the development of the art of neutron sources. Much work remains to be done and many problems still require detailed study: in fine shielding and backgrounds, activation and component material irradiation, target limitations and safety. Future ICANS meetings will derive great benefit from the close study of these topics.

Footnote: During the final session it was announced that the ANL has produced its safety assessment document (October 80). This is available to participants.

SITE	I_p	E_p	n_f	ENERGY DEPOSITION	MODERATOR	MOD. r	COMMENTS MATERIAL DEC^N CONT^N REFL^R
KENS	2μA	500	0.8×10^{14} (W)	≯ 10 W TOTAL EXCL. CRYOSTAT	w 12 h 15 d 5 T 20°K	17m W→CH_4	CH_4 Cd Al Be
ANL	22	500	2×10^{15} n_f/SEC.	MEAS. 11·6 mW/cm³, CAL. 17·4 mW/cm³ } LH_2 MEAS. 29·7 mW/cm³ } CH_2, CAL. 36·8 mW/cm³ } (→ CH_4) MEASURED AT ~ 11·5 cm FROM SOURCE	A 824 cm³, B 727 cm³ } LH_2 C 524 cm³, D 524 cm³ } LCH_4 AT ~ 12 cm FROM SOURCE	≈ 12 cm FROM U_r ℄ TO MOD. ℄	A NONE B Gd C Cd D Gd
SIN	1mA	590	6×10^{16}	600 W CAPTURED γ's 1·2 KW NEUTRONS ?	SPHERE 30 LITRES 20°K	40 cms	Al, Zr D_2
SNQ	5mA	1100 MeV		H_2 2·3 kW D_2 1·5 KW	d = 13 cms 15 cms DISTANCE FROM TARGET		
RL	2.5×10^{13} 50Hz 200 μA	800	3×10^{16}	283 + CRYOSTAT LOSSES	w = 11·5 cm h = 11·5 cm d = 5·0 cm T = 20–77°K	3·2 9·7	CH_4 D B_4C C Al+ R Be+D_2O

TABLE 1. MODERATOR ENERGY DEPOSITION

KENS. EXTRAPOLATION TO SNS	SNS ESTIMATED VALUE
(10w) ⟶ 3-4 kw	283w (CH_4)
ANL EXTRAPOLATION TO SNS	
(11·6 mW/cm³) ⟶ 200 w FOR 2×10^{15} n_f/s	240w (LH_2)
FOR (30 mW/cm³) ⟶ 330 w	~ 283w (CH_4)

TABLE 2. MODERATOR ENERGY DEPOSITIONS : EXTRAPOLATIONS TO SNS

PLACE, DATE	MATERIAL	DIMENSION	TEMP. °C	ENERGY MeV	INTENSITY mAh	SPOT cm^2	RESULT
SIN 7-80	GRAPHITE	3 MM ø 20 MM	1000-1200	600	20	0.2	OK ON INSPECTION
SIN 8-80	PYRO-GRAPHITE	6 MM ø 20 MM	1500-2000	600	80	0.2	UNKNOWN
LAMPF 11-80	SUPER-PYRO	6 MM	~1500	800	~200?	1	TEST IN PROGRESS
LAMPF 81	AL, Fe REFR. MATL. METALLIC GLASS		200 1500 800	800 800 800		1? 1? 1?	PLANNED
TRIUMF	AL 6000 AL 6000 AL 6000	3 MM 3 MM 3 MM	100 100 100	450 450 450	50 100 350	30 30 30	OK ON INSPECTION WINDOW WORKS PLANNED

TABLE 3 WINDOWS, RADIATION DAMAGE TESTS

N. Watanabe

A Comment on Energy Deposition in the KENS Cold Moderator

We would like to revise the estimate that was reported at ICANS-IV of the energy deposition in the KENS solid methane moderator, as we have found our earlier measurements to be somewhat misleading. On checking these measurements we found that the position of the electrical heater used to simulate the nuclear heating was quite different from that anticipated and we have therefore since performed a new measurement without using this heater.

In this new measurement, the temperature of the moderator was monitored as a function of time after a sudden halt of the proton beam. The temperature was measured by a hydrogen vapour-pressure thermometer installed inside the moderator chamber. The thermal energy deposited by radiation was calculated from the measured rate of temperature decrease using known values for the heat capacity of the solid methane and the moderator vessel. The new value was found to be 1.2 Watt for a proton beam current of 1.3 μA. The moderator volume was 900 cm^3 (12 cm^W x 5 cm^T x 15 cm^H), and the distance between the target center and bottom of the moderator was 4.55 cm, Cd decoupled. The tungsten target was irradiated by 500 MeV protons. The average value of the nuclear heating is therefore 1 m Watt/cm^3,μA. The present result is thus in reasonable agreement with that of ANL if the differences in the target and moderator materials and the different coupling efficiencies of target-moderator systems are taken into account.