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ICANS-IV Summary on target engineering

During the five years following the first experiments with a proton-beam driven spallation source performed at ANL in 1974 and 1975, a rapid and wide-ranged development has taken place. Today a point has been reached, where the first production targets have already been put out of operation after a substantial time of service, thus providing an opportunity not only for theoretical studies but also for practical checks. New assemblies are under construction for more powerful sources requiring more sophistication in design and operating conditions, and proposals have been forwarded to go to even higher beam powers, which makes special measures necessary such as moving the target to deal with the heat dissipation. Table 1 gives a summary of spallation source projects worldwide.

	Target	Proton beam power (maximum)	Proton energy	Mode of operation
Facilities shut down				
ZING-P'	U-238	3.6 kW	500 MeV	pulsed, 30 Hz
Facilities in operation				
KENS	W	0.7 kW	500 MeV	pulsed, 15 Hz
WNR	W	4.8 kW	800 MeV	pulsed, 120 Hz
TRIUMF	Pb	50 kW	500 MeV	continuous
Facilities under construction				
IPNS-1	U-238	12 kW	500 MeV	pulsed, 30 Hz
SNS	U-238	160 kW	800 MeV	pulsed, 60 Hz
Proposed Facilities				
IPNS-2	U-238	380 kW	800 MeV	pulsed, 60 Hz
LAMPF + PSR	?	800 kW	800 MeV	pulsed
Swiss project	Pb-Bi	500 kW	500 MeV	continuous
German project	Pb	5500 kW	1100 MeV	intensity modulated

Table 1 Target parameters of spallation sources worldwide

The overwhelming majority of the projects listed in Table 1 are pulsed neutron sources with their characteristics frequently dictated by existing accelerators or other constraints. Notable exceptions are the cyclotron-driven sources at TRIUMF and the one proposed at SIN. With a continuously operating accelerator those sources will, from the point of view of the user, resemble much more a reactor than the pulsed sources do. Consequently the design objectives are also different, aiming at a high time average neutron flux rather than a good time structure. The German proposal, characterized as 'intensity modulated' is intermediate between the two extremes in that its proton pulse duration of 0.5 ms at 100 Hz still allows to take advantage of such nice features as background suppression by detector gating and a good peak-to-average flux ratio, but does not allow to use the neutron pulse as primary resolution element in the experiments. The layout considerations are therefore again different in this case.

Thus, the ICANS-IV meeting was a timely point to get together and exchange information and promote new efforts.

Experience has been reported with targets of various designs. Surface cooled tungsten targets are or have been in use at WNR, ZING-P' and KENS, all of which are relatively low power facilities. It has been demonstrated especially at the KENS-facility that extremely good target-to-moderator coupling is possible if the target is not diluted by cooling channels and engineering constraints are relaxed due to the low power dissipation. These smaller spallation neutron sources therefore have a potential to be not only precursor to the more powerful ones but are likely to become valuable research tools in their own right.

An interesting target design has been in use at TRIUMF for some time now, where a lead target encased in a stainless steel container is allowed to melt and transport its heat to the water cooled container by natural convection during operation. Experience has shown that such a repetitively melting target can be operated reliably. It, too, has the advantage of not being diluted by cooling channels and because of the phase change involved it is very flexible with respect to changes in beam power. It has been noted that most of the mercury produced in the spallation process tends to evaporate and be pumped off the surface of the target.

For the more powerful pulsed sources now under construction at Argonne (IPNS-1) and Rutherford Lab. (SNS) heterogeneously cooled targets of depleted uranium are being developed. Here the target is composed of a series of discs individually clad in zircaloy with the coolant flowing between these discs. For the IPNS-1 target, the zircaloy-2 cladding cans are fabricated in two halfs and electron beam welded to hold the depleted uranium discs. High temperature isostatic pressure bonding is applied to diffusion weld the cladding to the disc for optimum thermal contact. A target of this type has been in use at ZING-P' before its final shutdown and has exceeded its predicted fatigue life time without any obvious signs of damage. The target has now been removed and is ready for detailed examination. Since fatigue is the

most likely damage to limit the life time of these targets it will be interesting to see the results of this examination. At SNS, where circular uranium discs will be embedded in rectangular circaloy frames, development work is still going on to avoid fracturing of the cladding along the edge of the target discs.

Operating facilities, especially ZING-P' have made possible a number of measurements relevant to future target design and engineering. Among them are measurements, as reported by J.M. Carpenter, of power density and power distribution, neutron beam currents, radiation fields in the beam holes and target radioactivity. Some of these results, such as the total thermal power dissipated in the target, which was found to be considerably higher than predicted by calculations, are of great importance for the design o future facilities. Systematic studies relating to the design of high power spallation neutron sources have also been carried out by a joint Swiss-German study group at various European proton accelerators. Most of these experiments so far (as partially reported by W. Fischer) were conceived to assess the neutronic performance of high power spallation sources, but future efforts will be directed more and more at producing relevant engineering data. Such data are indispensable with, if the limits of possible heat and radiation loads on materials are approached. At the SNS target concept this is more or less the case already. In this target with its discs of variing thickness and elaborate water flow guidance a fair amount of engineering effort manifests itself. Plates of six different thicknesses ranging from 0.65 cm to 2.45 cm and clad with 0.025 cm zircaloy will be used with 0.175 cm cooling gap between them. This means that in the front part of the target the volume fraction of uranium is 74% as imposed by heat removal requirements. This is at a total beam power of 170 kW.

For future spallation sources operating in the multimegawatt beam power range it will not be possible to retain the concept of a target which is stationary in the proton beam. Power densities of the order of 5 - 10 kW/cm^3 time average will make it mandatory to move the target through the proton beam and allow it to cool down elsewhere. Another major concern in high power targets is radiation damage caused by the intense proton beam as well as by the high flux of fast neutrons. A very elegant way to handle some of these difficulties is the liquid metal target concept as proposed as early as in the late 1960's for the Canadian ING concept. The eutectic of lead and bismuth, both of which are good spallation targets materials, has a melting point of only 123°C and can therefore quite conveniently serve as a liquid target. Work on such a concept has been resumed recently in the context of the Swiss and German high power target proposals, as reported by C. Tschalär and J.E. Vetter (see paper by Hoffman et al.). Forced convection loops are considered with the proton beam hiting the target flowing parallel to the proton beam. For a horizontal proton beam - as in the Swiss proposal - this requires a beam entrance window. This is considered the most critical part because it is subject to radiation damage from both proton and fast neutron irradiation and to a mechanical load as well as thermal stresses. Although a suitable choice of the window's shape may relieve some of these problems, it is not yet

clear whether such a window can withstand the thermal stresses set up in it and in particular the thermal shocks occurring in the case of sudden short term beam breakdowns. A concept in which such a window is avoided by taking advantage of centrifugal forces has been outlined, but no detailed layout has been attempted so far. Another possibility to avoid a beam window is the vertically streaming target as described in the paper by Hoffmann et al.. Some development work on this concept is continuing at the Kernforschungszentrum Karlsruhe. However, it is well understood that a beam line to bring a 5 mA 1.1 GeV proton beam in from above is a complex and expensive thing to build. Another concern is the fact that in such a target the walls of the flow tube would be subject to high radiation doses at temperatures which are quite unfavourable with respect to swelling and helium embrittlement for many materials. The choice of materials is further limited by corrosion problems, mechanical strength and neutronic considerations. Graphite has been envisaged for the Swiss concept because of its good neutronic properties, high temperature resistance and good compatibility with Pb-Bi. Although some successful development in joining graphite to copper has been reported recently in Los Alamos, fabrication of a complete target containment out of graphite seems to require some more development work. Concern has also been expressed about radiation damage which, in particular in the case of pyrolytic graphite leads to anisotropic swelling and contraction.

Since liquid metal target systems are more or less confined to the Pb-Bi eutectic as target material, a different concept has been selected for the German project which will in principle also allow to use uranium as target material. Here the disc-shaped and internally cooled target is rotated around a vertical axis with the proton beam entering through the outer circumference of the disc. Apart from enabling the heat removal over a time period 200 times longer than the time interval between two proton pulses, this concept will reduce the radiation load on the target and its structural components by the same ratio. Several ways of arranging the target material in the disc have been considered. In the concept finally selected the target consists of a large number of individually canned vertical pins directly cooled by the water flowing between them. For a lead target with Al canning the higher thermal expansion and higher temperature rise in the lead will ensure good thermal contact between the lead and the canning. Fabrication of these pins is easily accomplished by electron beam welding. Under the envisaged operating conditions, thermal cycling will be 50 K at the hot spot in the lead and 12 K in the aluminium once every two seconds. Should depleted uranium be used in a later stage, the possibility of establishing thermal contact to the cans by means of a molten metal will be investigated. Although the weight of such a target amounts to 5000 kg, its mechanics is very conservative. Nevertheless some development has to go into the rotating coolant sealing and radiation resistant bearings. It is quite clear that with beam powers in the multi-megawatt range, spallation neutron sources will become a good deal more sophisticated machines than those presently in operation. However, performance data derived from mockup experiments are very promising and seem to justify the efforts going into this development.

Apart from concepts reported as frozen in or proposed, interesting new ideas were forwarded which animated the discussion and showed that, in a field which is developping as rapidly as the design of spallation targets a lot of immagination is active. This is a very positive situation because the discussion of such apparently out-of-the-way concepts may often produce spinoffs which are very useful in solving existing problems.

Finally, it should not remain unmentioned that with all the optimism about the neutron flux that can be obtained from suitably designed moderators, there is also some concern regarding the contamination of the neutron beams with high energy neutrons and the possibility of working on the experiments while the source is operating. Some measurements along this line have been reported from the ZING-P' facility and WNR and more data will soon become available from the new KENS facility. However, looking at the beam power levels given in Table 1, it is obvious that this problem is much more serious in projects proposed for the future. Along with extensive studies related to moderator-target-reflector performance an effort has therefore been made by the German study group to obtain information on this questions from mockup experiments. Evaluation of these data is still under ways but it is clear that it is very difficult to obtain significant results from relatively poorly shielded low power arrangements which can be used to predict the situation in a high power system. Here, more experience from sources to become operational in the near future will certainly fill a gap in our knowledge and possibly give important information for a suitable choice of design and operating parameters.