REVIEW OF SPALLATION NEUTRON SOURCES

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Abstract

A review of current spallation neutron sources and their present status is given. Possible future developments of some of these sources are described.

Introduction

Recent years have seen a marked growth in the use of pulsed spallation neutron sources for condensed matter research using neutron scattering techniques. Detailed information on neutron sources can be found in the proceedings of the ICANS 1 - 9 conferences (International Collaboration on Neutron Sources). In addition a comparison of reactor sources and proton beam driven spallation sources is given in ref[1]. Present reactor sources are capable of producing a thermal neutron flux of 1E15 n/sq cm/s for external neutron beams and these beams have been used successfully for many years. Attempts to increase these fluxes led to proposals for accelerator based sources. A large spallation source, ING (Intense Neutron Generator) was first proposed in the early sixties at CHALK RIVER although it was never built. The design flux was 1E16 n/sq cm/s and the proposal required a 1 Gev 65 mA CW proton linac with a flowing liquid lead - bismuth target.

The first accelerator based neutron sources using proton beams were developed as additional facilities on existing accelerator complexes, firstly at ARGONNE with IPNS and then KENS at KEK in Japan and WNR at LOS ALAMOS. Spallation sources can be split into two types, namely, those which operate with continuous beams and those which operate with pulsed beams. The latter sources are now able to produce instantaneous neutron fluxes several orders of magnitude greater than reactors in some regions of the neutron energy spectrum, see Fig. 1. These intensities are achieved with manageable energy density in the targets but at the cost of lower mean neutron fluxes. On pulsed neutron sources the neutron energy is measured by time of flight techniques and hence the short duration of the neutron pulse is a positive advantage, and an ideal pulse length is achieved if the incident beam pulse is kept less than 500 nano-secs. The repetition rate of the neutron pulses must be low enough to allow the lowest energy neutrons to be detected before the arrival of the next pulse. This usually implies repetition rates of 10 - 100 Hz. Where high mean fluxes are required then a continuous beam accelerator must be used with the resultant high energy density in the spallation target. Such a source is now under construction at SIN.[4]

Various materials are used for spallation targets and data for different metals are shown in Fig 2, ref[3]. Increased proton energy gives increased neutron yield but this also increases the proton range, thus energies of about 1 Gev and a heavy metal target are required. The mechanisms of neutron production in spallation targets via cascade, evaporation and fission processes are described in ref[5] and, for example, each 800 Mev proton incident on a lead target is estimated to produce 16 neutrons. Neutron production

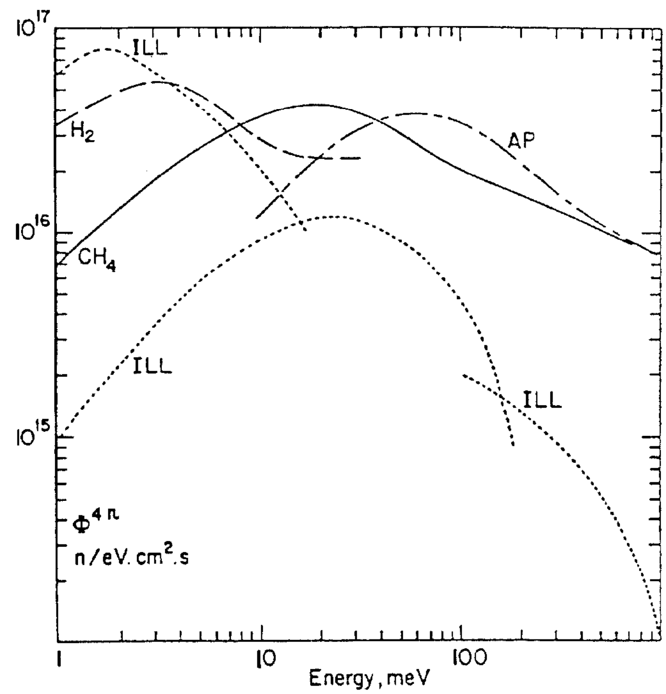

Fig 1. The predicted 4*PI equivalent flux for ISIS at 200 micro-amps compared with the flux of the three moderators at the ILL high flux reactor in Grenoble [2]. (AP ambient temp. water, CH_4 liquid methane, H_2 liquid hydrogen)

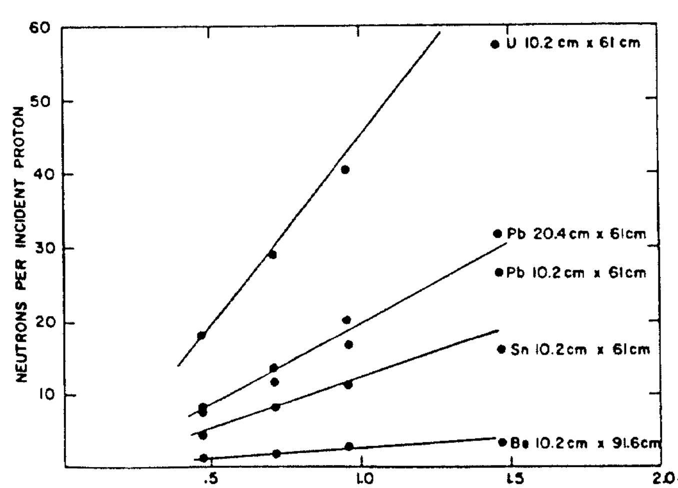

Fig 2 Measured neutron yield vs proton energy for various target materials [3].

can be enhanced by the use of fissionable material as on ISIS and KENS, or further enhanced by enrichment of the target with fissile material as on IPNS. Both steps lead to some additional complication in the target design but give worthwhile increases in the available neutron flux, a factor of 2 in the ISIS and KENS cases and an additional factor of 3 in the IPNS case.

Moderators situated close to the target reduce the energy of the neutrons to the thermal range giving a spectrum of energy specific to the temperature and material of the moderator. Frequently used types are liquid hydrogen, liquid methane and water.

Existing Sources

The existing proton driven sources and those under construction are listed in Table 1 along with the main design parameters. The numbers in brackets indicate the current normal operating values.

Lost Beam Protection Systems

With a beam power of many kW now available on these machines uncontrolled beam loss at any stage can lead to thermal damage to the vacuum vessels and to high levels of radiation, which in turn give high levels of induced activity. The methods of lost beam collection which were developed on intense beam cyclotrons have been adapted for use on some of the synchrotrons and the storage ring. Devices comprised of beam scrapers, collectors and collimators are used to define the points of beam loss. Most of the accelerators incorporate a beam loss monitor system and this, combined with intensity measurements throughout each cycle of the machine, is used to detect unacceptable beam loss. Turning the accelerator off or, dropping the repetition rate, immediately that lost beam is detected protects the accelerator components but the spallation target suffers a severe heat quench. Many severe thermal cycles can lead to failure of some types of targets which operate at high temperatures. Thus lost beam protection systems now being developed must protect the accelerator components and deal with the problems specific to each machine.

Some data on the efficiencies of stages of the acceleration processes for pulsed sources are listed in table 2.

	IPNS Argonne USA	KENS KEK Japan	ISIS RAL UK	LANSCE Los Alamos USA
Injection		97	97	92
Trapping		94	90	99.5
Acceleration or Storage	93	94	99	99.3
Extraction		88	>99	99.7
Transport		96	>99	
Overall	90	72	86	90.6

Table 2. Percentage beam intensities after the completion of various processes on pulsed spallation sources.

Improvements and Possible Further Developments

IPNS

Improvements to the ion source and the beam phase loop, better correction magnets and the movement of the extraction time to 1.8 msec before field maximum have produced significant increases in the accelerator performance. These coupled with additional control loops on the linac field gradient, the ion source intensity, and the injection field level have increased the beam current from 8 to 15 micro-Amps and raised the operating energy to between 450 and 500 MeV.

The 16 months to July 1986 produced 67,000 micro-Amp hours.

Interest is now centred on the installation of the first ever enriched Uranium Booster Target. This will give an expected factor of 3 improvement in the neutron intensity.

KENS

Over the past few years the accelerator and target system have been improved with the aim of increasing the neutron beam intensity by a factor of 10. The improvements have consisted of:-

1. An increase in the injector energy from 20 to 40 Mev.
2. Alteration of the injection scheme to H- charge exchange.
3. Replacement of the Tungsten Target with a depleted Uranium Target.

These alterations have increased the neutron beam intensity by a factor of about 6 and the remaining factor of 1.5 is expected from improvements to the synchrotron RF.

The facility was operated for 3600 hours in the fiscal year 1986 with 1300 hours of this being used for neutron production, giving 3900 micro-Amp hours.

Future plans at KEK may include a 1 Gev H-minus linac and a 2 Gev rapid cycling synchrotron with a time averaged current of 200 micro-Amps. Alternative schemes propose the use of a 1 Gev storage ring with the linac to give a spallation source with a time averaged current of 100 micro-Amps.

ISIS

Since the first production of neutrons in 1984 the beam energy has been increased from 550 to 750 Mev and the beam current has been raised to 80 micro-Amps with short runs at 100 micro-amps. Present plans are to improve or replace the older and less reliable equipment on the injector and 750 Mev beam transport line in order to increase the reliability, while continuing to provide beams of about 80 to 100 micro-Amps. Improved beam diagnostics and further machine study will be used to determine the means of increasing the beam intesity to the design level of 200 micro-Amps. The present intensity is limited by losses during trapping in the synchrotron [6].

Operation for the year ending in March 1987 gave 20,000 micro-Amp hours at 550 Mev. The last 12 months has produced 160,000 micro-Amp hours at 750 Mev.

Future plans include an improved ion source, further study of automated beam control, and development of the synchrotron RF system which may include an additional small buncher cavity.

Longer term plans will consider the addition of a second target station to ISIS. This could take one

	IPNS Argonne USA	KENS KEK Japan	ISIS RAL UK	LANSCE Los Alamos USA	SINQ PSI Switzerland	TNF TRIUMF Canada
Accelerator	50 Mev Linac & Synchrotron	40 Mev Linac & Synchrotron	70 Mev Linac & Synchrotron	800 Mev Linac & Storage Ring	Cyclotron & Cyclotron	Cyclotron
Proton Energy Mev	500 (450)	500 (500)	800 (750)	800 (800)	590	(H-) 500 (500)
Target Material	U 238	U 238	U 238	Tungsten	Lead-Bismuth	Lead
Mean Current micro-Amps	20 (15)	10 (3)	200 (80)	100 (30)	1000	300 (140)
Peak Intensity per pulse	4.0E12 (3.3E12)	3.5E12 (1.1E12)	2.5E13 (1.0E13)	5.0E13 (1.5E13)	---	---
Pulse Repetition Rate Hz	30	20	50	12 (15)	Continuous	Continuous
Pulse Length ns	100	50	450	270	----	----
Status	Operational	Operational	Operational	Operational	Target Under Construction	Operational
Number of instruments	12	14	10	6	----	1
Beam Power kWatts	10 (6.8)	5.0 (1.5)	160 (60)	80 (24)	590	150 (70)
Mean Circulating Current at Full Energy Amps	3.4 (2.8)	3.4 (1.1)	6.2 (2.4)	22.4 (6.7)		
Circumference metres	42	37.7	163.4	90.2		
Periodicity	6	8	10	10		
Q - Values H V	2.2 2.3	2.2 2.3	4.3 3.8	3.2 2.2		
Injection Energy Mev	50	40	70	800	72	
Injection Method	H- to p Foil	H- to p Foil	H- to p Foil	H- to Ho Grad Magnet Ho to p Foil	Direct p	Direct H-
Foil Thickness ugm/sq cm	80	22	50	200		
Material	C	C	Al Oxide	C		
Size cms	5.0x5.0		12.2x4.0			
Lifetime uA hrs		Infinite	10,000	>10,000		

Table 1. Some parameters of existing spallation sources and those under construction. The numbers in brackets indicate the current normal operating values.

pulse in five from the accelerator and in its simplest form would be a non fissile target. This would be of most benefit to those instruments which at present suffer from frame over-lap problems. An alternative scheme foresees the use of a second target enriched with fissile material but this would require a nuclear licence for the RAL site. A third possibility is to build an 800 Mev linac and to convert the synchrotron to a storge ring. This could produce a time averaged beam current of 1.6 mA with 50 Hz operation and the beam would be shared between a new Target Station (1.3 mA) and a modified version of the present Target Station which would receive 300 micro-Amps at 10 Hz. This will provide a major improvement for ISIS in the future.

LANSCE

Since its first operation in 1985 the beam current deliverd to the target has been raised to 30 micro-Amps using a repetition rate of 15 Hz and operation of the machine produced 14,894 micro-Amp hours in 1987. Study of the machine during the intervening period has indicated that improved performance could be achieved by alteration of the injection scheme to direct H-. The present operating intensity limit is set by the small but significant losses which occur during injection, storage and extraction. Further improvements could include a modified extraction system, additional beam collimation and lost beam monitoring, and an improved H- ion source to take the intensity up to 100 micro-Amps.

Longer term plans for an Advanced Hadron Facility at Los Alamos include a spallation source driven by a 1.6 Gev, 24 Hz, 1.6E14 protons per pulse accelerator or a 0.8 Gev, 24 Hz, 3.2E14 protons per pulse accelerator which could provide a time averaged current of 600 micro-Amps or 1200 micro-Amps respectively.

SINQ

Design and construction of a molten lead-bismuth target are continuing and initial beam intensity will be 1 milli-Amp. A plan of the target is shown in Fig 4 with the incident beam coming vertically upwards.

TNF

Further development of the present source is unlikely and future development at the laboratory envisages the provision of a 30 Gev, 100 micro-Amp accelerator for a Kaon factory.

EURAC

A proposal has been made to produce a spallation neutron source based on a 600 Mev, 6 mA beam of protons and using a liquid lead target. This could be used to simulate the first wall conditions of a fusion power reactor [7].

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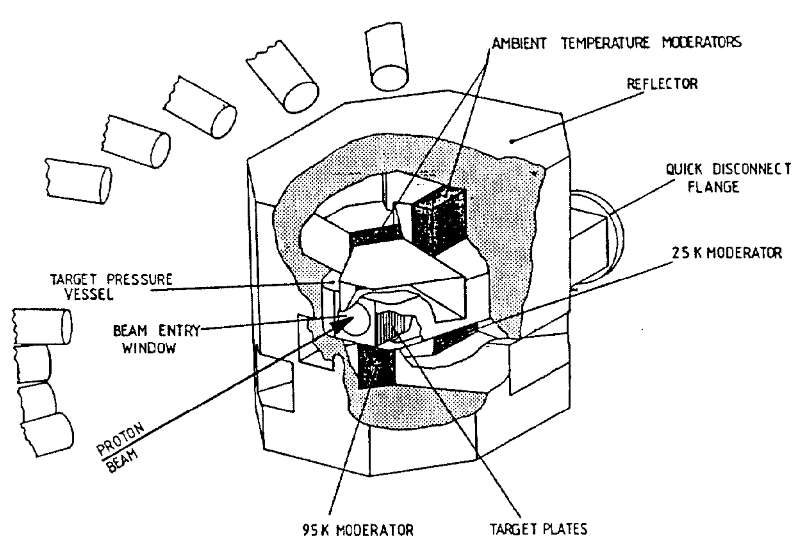

Fig. 3 ISIS Target and Moderators.

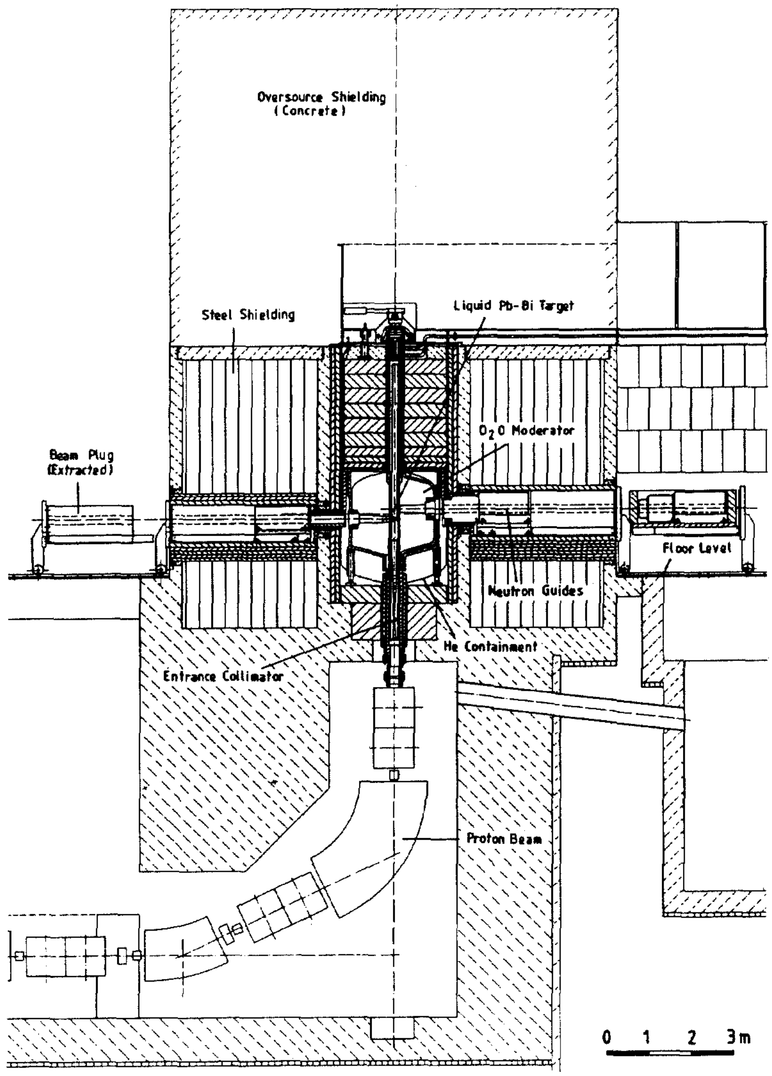

Fig. 4 Vertical cross section of SINQ target.