PROGRESS REPORT ON THE CONSTRUCTION OF THE SPALLATION NEUTRON SOURCE AT THE RUTHERFORD AND APPLETON LABORATORIES

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1. Introduction.

The delivered version of this talk will report progress largely by showing slides of work completed or work in progress. The written version cannot be the same. It will serve no useful purpose if it provides a logical progression through each item of the machine stating our precise position on the first of October 1980. The procedure I have followed below is to give a general introduction to remind the reader of the specification and main parameters of the machine and to state our current financial approval. I then cover our planned timescale and our philosophy for priorities in that time scale. The remaining sections of the paper provide a statement of what we have achieved, where we are making good progress and perhaps more importantly where we expect problems. No attempt has been made to be complete - items that involve a lot of work are often omitted because their careful coverage will be of no help to others and they would have only lengthened the report.

2. Specification of the SNS.

Table 1 gives the specification of the SNS and some of its basic parameters. The machine will be an 800 MeV, 50Hz proton synchrotron delivering 2.5×10^{13} protons per pulse - an average current of 200 μA. Extraction will be single turn by kicking the beam out in the vertical direction. Each cycle of the machine will provide two pulses of protons of base width 100ns separated by 220 ns - an effective pulse width for neutron experiments of 0.4 μs. The beam will be transported onto a depleted uranium target of 9 cm diameter and 25 cm long and each proton will produce about 25 neutrons - this will provide $\simeq 6 \times 10^{14}$ neutrons per pulse at 50 Hz repetition rate or $\simeq 3\ 10^{16}$ neutrons per second. The neutrons are produced at energies ~ 1 MeV and will be slowed to "thermal" energies in moderators placed immediately above and below the target. 18 beam ports will be provided through the biological shield. The facility can support about 25 neutron beam instruments but financial provision has been made for only about 15.

Figures 1 shows an artist's impression of the facility.

3. Finance and Manpower.

The Laboratory received approval for the construction of the SNS in June 1977. The authorised capital cost for the machine and target station is £11.374M at 1 April 79 prices - this does not include staff costs or the research and development but it does include first line spares. Table 2 gives information on the breakdown.

We have authorisation for £1.804M at 1 April 79 prices to build the first seven of the neutron instruments. The financial plans include a total of £5.7M for the construction of 15 instruments, for computing requirements, sample environments etc. Further authorisation will be sought when detailed designs are ready.

The total financial provision for the SNS provides about £7.2M (at today's prices) per year over the next five years. It is this provision rather than technical matters that determine the construction timescale.

Although the SNS was approved in June 1977 appreciable manpower did not become available until June 1978 with the closure of the 7 GeV proton accelerator (NIMROD) used for High Energy Physics. The current manpower used on the SNS is about 200 and this will decrease over the next few years as construction is completed - the operation crew for the machine and target station will be 105.

Much of the equipment from NIMROD is used for the SNS and a rough estimate of the current value of that equipment is £24M allowing for amortization. Its replacement cost in current prices would be about £43M.

4. Timescale.

A series of milestones has been set for the construction and commissioning of the SNS. These milestones and the dates planned for their achievement are listed below:

1. Early 1982 - Injector complete. 70 MeV H$^-$ beam.
2. Early 1983 - Magnet ring and vacuum complete. Injection line and injection system complete. Some machine diagnostics installed. Injection tests.
3. Mid 1983 - 2 RF stations installed (out of 6). Main magnet power supply working. Acceleration studies at low intensity.
4. Late 1983 - 4 RF stations. Extracted system installed. Extraction studies at low intensity.
5. Early 1984 - With 4 RF stations. Extracted proton beam installed Target Station installed. 600 MeV protons (low intensity) producing neutrons in the target.
6. Late 1984 - 6 RF stations installed. 800 MeV protons (low intensity).
7. ∿ 1986 - Full intensity operation with 800 MeV protons

The philosophy adopted is to give the greatest priority to the early completion of the machine to a stage to study injection, acceleration and extraction at very low intensity (milestones 1 - 3). Second priority is given to providing protons onto a target and provision of some neutrons. Milestone 4 provides 600 MeV protons (determined by the fact that only 4 RF cavities are ready) at an intensity that will be no more than 10% of full design.

Full energy will be reached by late 1984 but full intensity is expected to take some time to achieve because the procedure will be to limit the beam injected so that beam losses are low enough to allow hands-on maintenance. Beam intensity will only be raised as we learn to control beam loss and we estimate that full intensity may not be reached until 1986.

The provision of instruments will have to have the lowest priority and with the present financial plans they are expected to come into operation as indicated below.

	1984	1985	1986	1987
Number installed in that year	4*	4	5	2
Total number installed	4*	8	13	15

* 2 of these will be used on the Harwell Linac from 1981-1984.

If more funds become available the provision will be advanced. It is possible that international collaboration on the SNS could provide a means for improving the instrument provision.

5. Progress Made.

I list below brief notes on progress made in major areas of the project - no attempt is made to be complete nor does the number of words reflect in any way the effort taken.

5.1 Civil Engineering

The Nimrod magnet and experimental halls have been cleared of Nimrod equipment and the necessary modification are well under way. All work should be complete by about April 1981.

5.2 Injector and Injection

Injection is to be made using H$^-$ ions at 70 MeV. 20 mA of H$^-$ will be injected for 470 μs (315 turns). Conversion of the 70 MeV linac from 1 Hz to 50 Hz and from H$^+$ to H$^-$ is well in hand and we expect to achieve full specification by early 1982. Most of the work to be done is "conventional engineering" and is not breaking new ground. The new areas are the ion source and the stripping foil.

We have constructed a prototype Phillips ion gauge (PIG) ion source of the Russian/Los Alamos/Argonne type, modified to provide water cooling to allow a higher duty cycle. We require 20-40 mA for 500 μs at 50 Hz We have run the source at full duty cycle with 50A arc current for considerable periods and have extracted 40 mA for limited periods but we have not yet analysed the output beam. We have yet to establish running conditions, measure lifetime, caesium consumption, gas consumption etc.

Our requirement for stripping the H^- is for a foil of 50 μg/cm^2 (about ¼ micron) of 10 cm x 5 cm with one 10 cm edge unsupported. We have placed a development contract with the Fulmer Research Institute and so far they have made an aluminium oxide foil of quarter size and correct thickness and a boron nitrode foil of full size and 4 μ thickness. They are also trying carbon foils. The work will continue.

5.3 Magnets for Synchrotron Ring

Each superperiod of the main ring requires a bending magnet which also focusses horizontally, a singlet quadrupole which focusses vertically, a pair of doublet quadrupoles and a pair of trim quadrupoles. There are 10 superperiods. All of the elements are on order and the present position with each is:

bending magnets (GEC/UK) - prototype due at end of this year,
singlet quadrupole (TESLA/UK) - prototype due early next year,
doublet quadrupoles (LINTOTT/UK) - all the 20 required plus 2 spares are delivered.
trim quadrupoles (DANFYSIK/Denmark) - all the 20 required are delivered. 2 spares plus 2 more to be used as skew quadrupoles are due very soon.

Designs are ready for octupoles ($\lesssim$ 12 required) and for correction dipoles (12 required) but orders have not yet been placed. Space has been reserved in the lattice for sextupoles but we do not expect to need them.

5.4 Magnet Power Supplies

The main ring components (other than trim and correction magnets) are powered in series at 50 Hz from a choke and resonating capacitor system that is already available. Make-up for losses will be from a 1 MVA alternator that we are about to purchase. This will initially be run at mains frequency but can be changed to fixed frequency if necessary at a later stage.

The trim quadrupole power supplies are on order from DANFYSIK, Denmark and the prototype is due soon.

5.5 Main Ring Vacuum

The vacuum vessels in the magnets are to be made from ceramic. Sections of ceramic of the relevant cross section are provided (WADES/UK) with the ends glazed with glass and with dowels to locate adjacent sections. The sections are stacked vertically in a furnace to make a complete chamber and the temperature is raised to 1100°C to form a glass joint between the sections. This work is done in the Laboratory. Three prototype chambers have been made: 60cm chamber for the singlet quadrupole, 3 m chamber for a pair of doublet quadrupoles plus a pair of trim quadrupoles, and a 5 m chamber with a 36° bend for the bending magnet. All are successful and have been pumped to below 10^{-8} Torr (a pressure of 5×10^{-7} Torr is required). Production has now started.

5.6 RF Shields for Main Ring

All of the ceramic vacuum chambers will require RF shields to isolate the beam from the high RF impedance of the laminated magnets. A system has been designed that uses 2 mm diameter stainless steel wires supported by ceramic spacers. The stainless wires follow the envelope of the beam to minimise the RF impedance. These wires are shorted directly to each other at one end and are connected to the next screen via small 0.1μF capacitors at the other end. There will be about 4000 capacitors in the SNS vacuum system. Their radiation resistance is being tested at SIN. A prototype RF shield has been constructed for the bending magnet and is mechanically acceptable but its RF impedance has yet to be measured.

5.7 Main Ring RF

The SNS will have six RF cavities which will be placed in straight sections 2,3,4,7,8,9. A frequency swing from 1.3 - 3.1 MHz is required and this will be achieved by a single turn bias current to 2800A through the ferrite rings of the RF cavities. Power levels of $\simeq$ 1MW are required and all the cavities have to be accurately controlled in frequency, voltage and phase. Beam compensation will also be needed at full intensity.

A prototype cavity, drive system and bias system is being assembled in the Laboratory and should be ready for test early next year. Reasonable progress has been made on the design and prototype work for the low power RF system that will have to provide the phase and voltage controls.

5.8 Diagnostics

The SNS main ring is to have diagnostics equipment to determine the beam position to an accuracy of a fraction of a millimetre, beam intensity to an accuracy of one thousandth of full intensity and to determine the beam profile. Prototypes have been built and successfully tested for the first two of these and development work is in hand for the profile monitor.

5.9 Extraction

Extraction from the SNS will be achieved by bumping the beam vertically upwards in straight section No 1 and then by using 3 ferrite kicker magnets kicking the beam vertically into a DC septum magnet. The field in these magnets must reach full value in 220 ns and stay flat to 1% for 500 ns.

A prototype kicker magnet and drive system using thyratons is being developed and tested. At the moment the rise time is about 300 ns and further development is proceeding. The system has been tested for 4 x 10^7 pulses and testing is continuing.

5.10 Beam Loss Protection

We believe that the factor that will determine the operational intensity of the SNS will be the control of the beam loss. We intend to limit the beam that is injected so that we can use hands on maintenance for the accelerator. This will mean that the intensity of the SNS will only be raised as we learn to control the beam loss and as we successfully develop beam loss catchers.

We anticipate that at full intensity we will trap about 50% of the injected beam and that the rest will be lost from 70-100 MeV. This leaves 17 kW of beam power to be dumped somewhere. We have studied ways of collecting this lost beam and intend to use thin foils to scatter protons in the wings of the beam followed by beam catchers placed downstream. Both the scattering foils and the beam catchers will be installed on remotely controlled drive systems that can be accurately moved towards the beam. Prototype beam catchers have been made using carbon blocks that are brazed to water cooled copper plates. These catchers are designed to be removed and inserted by remote handling equipment. Space has been reserved to place four such systems in the accelerator for vertical and horizontal losses. A computer simulation of the complete system indicates that about 90% of the injection losses should be collected in this way. We hope to develop the system so that at least 95% can be collected in preferred places and we believe that this will be acceptable. At the start up of the accelerator we will install only the horizontal low energy catchers.

There will also be unavoidable beam loss at extraction. It is impossible to calculate this as it depends upon the detailed shape of the beam way out in the wings. We have based our plans on the assumption that the loss will be 1%. We have studied a scattering foil and collector system for this and intend in the first instance to install a system in the vertical plane in the long straight following the kicker magnets. We have also reserved space for a horizontal system. We have based our radiation calculations on the assumption that we will collect 90% of these extraction losses. We hope to keep losses during acceleration to considerably less than 1%.

We have reserved space in the synchrotron hall so that we can install a shield tunnel around the main ring. This will reduce the irradiation of the synchrotron hall so that the induced activity is at an acceptable level and will shield personnel from radiation from activity induced in the accelerator. We do not intend to install this shield wall in the first instance.

We intend to keep the floor inside the synchrotron ring smooth and clear of obstructions so that we can use remote handling equipment if necessary at a later stage. We will provide no such equipment in the first instance. Magnets,vacuum equipment etc have been designed to make remote handling possible.

5.11 Extracted Proton Beam Line

A design has been made for the beam transport system from the extraction DC septum magnet to the target station. It will use 60 magnets and all but one of these are already available. The shielding for the beam line will use existing steel and concrete and is already being installed.

5.12 Target Station

The target station is designed to provide 18 beam tubes each of which will have an independently operated beam shutter of 2 metres length. Each beam can be equipped with a collimator to look at any one of the four moderators - two above and two below the target. Present thoughts are for one 20K , one 77K and two room temperature moderators. The reflector will be of beryllium and heavy water.

The target will consist of U ^{238}plates clad in Zircaloy-2 and cooled by heavy water. The U^{238} plates will vary from 6.5 mm thick to 12.5 mm thick. The cooling gaps will be 1.75 mm wide.

The downstream section of the biological shield can be moved backwards to carry the target, relector and moderators into a remote handling cell. A full scale mock-up of this cell has been assembled and will be used to test and verify all target equipment prior to installation.

The civil engineering of the target station has already started and 2½ metres of steel has been placed beneath ground level to stop ground shine and to ensure that water in the water table is not made radioactive. A neutrino cave 5 x 5 x 3 m^3 has been constructed beneath and to one side of the target at a distance of 7m from the target. The target base plate is to be installed in the next few months.

Full details of the target staion design will be given in later sessions.

5.13 Computer Control

The SNS control system will use four GEC 4070 computers, one as a central computer that will be connected to the control console, the other three will be satellites for the injector/injection, for the main ring and for the EPB/target station. All four computers have been delivered and considerable progress has been made on software and hardware for interfacing and connecting to the SNS equipment. Considerable use will be made of microcomputers for control of specific items of equipment and for data logging, but these will all be interfaced to the 4070 systems.

5.14 Experimental Instruments

Financial approval has been given for the seven instruments listed below:

		authorisation in £K (1/4/79 prices
Low Q spectrometer (small angle scattering)	(LOWQ)	330
High energy transfer spectrometer	(HET)	291
High resolution quasi elastic spectrometer	(IRIS)	354
High resolution powder diffractometer	(HRPD)	284
High intensity powder diffractometer	(HIPD)	164
Liquids and amorphous diffractometer	(LAD)	105
High throughput inelastic spectrometer	(HTIS)	112
		1640
contingency		164
		1804

Two of these (LAD) and (HTIS) will be constructed early in 1981 and will be initially installed on the Harwell electron Linac.

Full details of these seven instruments and of others planned will be given in later sessions.

6. Non Neutron Beam Uses

The extracted proton beam for the SNS has been designed so that an intermediate focus can be formed 20 - 30m upstream of the main uranium target. A thin target can be placed at this intermediate focus and can be used as a source of pions and muons. A design has been made for a pion beam, taken vertically above the target, that could be suitable for bio-medical work. A 5cmthick carbon target will give a beam of about $4 \times 10^8 \pi^-$ per second delivered to the final focus. This will produce about 10 rads/min over an irradiation volume of about 500cc.

A second possible beam from the intermediate target is a low momentum muon beam ($\sim$26 MeV/c)for SR work. A conceptual design has been made that could provide at least 10^4 μ^+ per pulse in a 5 nsec time slot.

Other possible non-neutron beam uses of the SNS that are being considered are isotope production, neutrino physics, rare muon decays, radiation damage studies, and neutron radiography. None of these is approved but options have been kept open and possibilities are being studied.

7. Conclusion

The SNS project is now well launched and visible progress is being made in most areas. We expect to start operation in 1984 but do not expect to reach full intensity until 1986. Our progress towards full intensity we believe will be determined by how quickly we can learn to control beam losses.

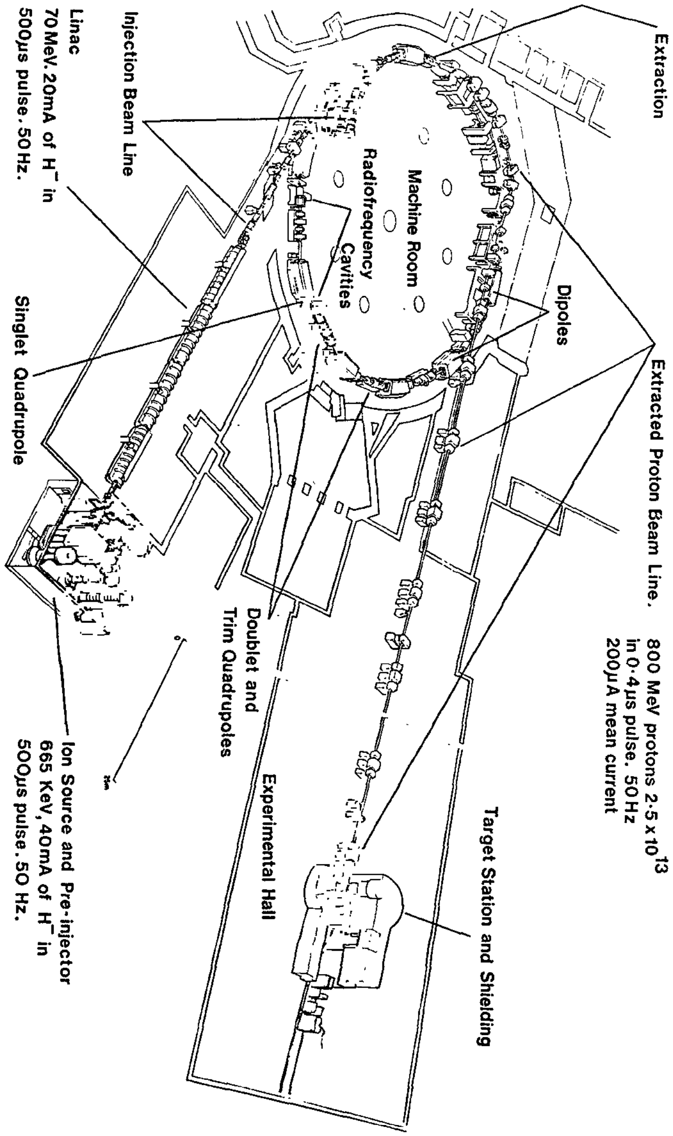
TABLE 1 MAIN PARAMETERS OF THE SNS

Proton design energy	800 MeV
Proton design intensity	2.5 10^{13} ppp
Nominal repetition frequency	50 Hz
Injection scheme	H^- charge exchange
Injection interval	476 μs
Injection energy	70.4 MeV
Injection intensity	20 mA
Injected beam emittance (area ÷ π)	20 μ rad m
Mean radius of synchrotron	26.0 m
Number of superperiods	10
Length of superperiod	16.336 m
Dipole field at 70.4 MeV	0.1764T
Dipole field at 800 MeV	0.697T
Betatron tune (Q_h,Q_v)	4.31, 3.83
Beam emmittance at 70.4 MeV (area ÷ π)	Horizontal 600 μ rad m Vertical 460 μ rad m
Number of RF cavities	6
Magnet currents (DC, AC)	661.5 A, ± 395A
Target material	depleted Uranium
Nominal fast neutron production rate	3 10^{16} neutrons/sec
Nominal neutron current from surface of moderator	10^{13} neutrons eV^{-1} ster s^{-1}

TABLE 2 BREAKDOWN OF THE CAPITAL COST OF THE SNS (1 APRIL 1979 PRICES)

	£K
Injector and injection	900
Synchrotron magnets	1748
Synchrotron power supplies	684
Vacuum system	897
RF and diagnostics	1976
Extraction and extracted proton beam line	771
Controls	435
Services	679
Target, moderators and reflectors	627
Target station shielding	1244
Remote handling for target assembly	238
Machine and target station spares	750
Reserve	425
	11374

FIGURE 1



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