optimally for extraction using fast kicker magnets and a septum magnet. However, for the SNS the beam is to be removed vertically whereas for the HIS radial extraction is proposed. The dispersive properties of the beam handling after extraction impose some additional complications for the SNS cheme. The kick angle for the SNS extraction scheme is about half that necessary for the HIS extraction although the apertures necessary for high intensity beams force the kicker designs to present some degree of difficulty in engineering and operation.

Critical review and discussion of the proposed methods has already contributed to the spirit of collaboration. The suggestion was made that the HIS scheme should examine the dispersive properties of the bumped orbit and consider also the possibility of vertical extraction. Concern was also expressed as to the consequences of back voltages on the thyratrons for the power supply circuits proposed for the SNS kickers.

SNS plans to build a prototype supply for the kicker magnets to test their circuit design. Results of investigations along these lines as well as experience at Argonne with the Booster II kicker magnet operation will provide information as input to both efforts.

B. Targets, Moderators, Calculations, Codes, Instruments

Participants

J. Ball	Argonne National Laboratory
A. Carne	Rutherford Laboratory
J. M. Carpenter	Argonne National Laboratory
R. K. Crawford	Argonne National Laboratory
B. Johnson	ARACOR
R. Kleb	Argonne National Laboratory
B. A. Loomis	Argonne National Laboratory

R. Prael	Argonne National Laboratory
G. J. Russell	Los Alamos Scientific Laboratory
T. G. Worlton	Argonne National Laboratory

B.1 Target System, Neutron Production, and Related Calculations

The agenda for these workshop discussions consisted of:

Target materials
Energy deposition
Target geometry
Irradiation damage
Gas production
Fabrication
Neutron production
Activation of target and coolant
Handling of radioactive target
Coolants
Lifetime of target
Prototype testing
Comparision of Rutherford, LASL, and ANL designs
Benchmark calculations and experimental testing

The above items were discussed in varying degrees of detail by presentation of the different designs envisioned by Rutherford, LASL, and ANL. The design parameters are summarized in Table 1.

	Rutherford	ANL IPNS-II (Neutron scattering)	ANL IPNS-II (Radiation effects)	LASL
Target Material	Springfields U	U- 7-10 w/o Mo	Ta or W	Ta
Target Cladding	Zircaloy-2 (0.25 mm)	Zircaloy-2 (0.25 mm)	none	none
Max. Target temperature, °C	600	600	1000	300
Target Coolant	Water	NaK	NaK	Water
Target Geometry	Stacked discs	Stacked discs	rod	rod
Target Element dimension	9-10 cm square .6-1.2 cm thick	10 cm dia, 1.0 cm, thick } disk	10 cm	2.5 cm dia.
Length of Target (cm)	26	23	22	15
Coolant Channel (mm)	2	1	--	--
Proton beam diameter (cm)	6	7	7	1
Proton intensity (p/pulse)	3×10^{13}	5×10^{13}	5×10^{13}	5×10^{11}
Pulse frequency (H_z)	53	60	60	120
Target heating	420 kw	490 kw	200 kw	230 kw
Beam intensity distribution assumed for calculations	parabolic	gaussian	gaussian	gaussian

The Rutherford experience on roll-bonding of zircaloy-2 to uranium shows good results for 0.6 cm thick uranium but much poorer results on increasing uranium thickness to 1.2 cm thickness. Diffusion bonding will be attempted for the future fabrications.

The Alsmiller (ORNL) calculations show the following dependence of neutron production/incident proton on target diameter for 800 MeV protons with gaussian distribution (FWHM = 3 cm). The target length is 34 cm. The data were obtained on a homogenized target of disks each with a thickness of U = 1 cm, NaK = 0.1 cm. Na = 0.0127 cm, and stainless steel = 0.0254 cm.

Target diameter	Neutrons/protons
6 cm	20.1
8 cm	21.9
10 cm	24.6
12 cm	25.5

∿ 10% of neutrons backstream and ∿ 0.3% of neutrons exit the 34 cm plane.

The lifetime of the target may be determined in part by the magnitude of cyclic stresses developed due to proton beam energy deposition.

The ARACOR results (Table 2 and 3) on the generation of tensile and compressive stresses suggest that a pulsed energy deposition (10^8 cycles) of 1.9 KW/cm^3 in a U disk at 600°C is likely to exceed the endurance strength. A U-10% Mo disk has a marginal chance of survival. Ta or W disks have an adequate margin of safety against the cyclic stresses whereas the rods (∿ 20 cm length) are likely to fail.

The NaK coolant (Table 4) will have an activity of ∿60 Curies on shutdown after a 90 day operation. Approximately 10 days of activity decay will be required to allow manageable safe handling. Direct activation of water give yields of ∿0.1

TABLE 2

PEAK TENSILE STRESS GENERATED IN PROTON-TARGET CONFIGURATIONS AT TWO SINGLE-PULSE POWER DEPOSITIONS

ABSORBER MATERIAL	CONFIGURATION	INITIAL COMPRESSIVE STRESS (KBAR)*	PEAK TENSILE STRESS (KBAR) ABSORBER AT 600°C	
			2.8 $\mathrm{kW/cm^3}$	1.9 $\mathrm{kW/cm^3}$
URANIUM	UNCLAD DISK	0.88	0.82	0.55 EST.
URANIUM	STAINLESS STEEL CLAD DISK	0.88	0.75	0.50 EST.
URANIUM	ZIRCALOY-2 CLAD DISK	0.88	0.76	0.52 EST.
URANIUM	UNCLAD CYLINDRICAL ROD	0.88	2.5	1.7 EST.
TUNGSTEN	UNCLAD CYLINDRICAL ROD	0.72	3.7	2.5 EST.
TUNGSTEN	UNCLAD DISK	0.72	0.7 EST.	0.47 EST.
TANTALUM	UNCLAD CYLINDRICAL ROD	0.69	3.3	2.2 EST.

*AT 2.8 $\mathrm{kW/cm^3}$

TABLE 3

MATERIALS PROPERTIES

ESTIMATED LOWER-LIMIT (STATIC) MATERIAL STRENGTHS OF URANIUM, TUNGSTEN, AND TANTALUM WITH AND WITHOUT IRRADIATION DAMAGE

	TENSILE STRENGTH (KBAR)			ENDURANCE STRENGTH (KBAR, 10^8 CYCLES)			
ABSORBER MATERIAL	24°C	600°C	600°C W/NEUTRON DAMAGE	24°C	600°C	400°C W/NEUTRON DAMAGE	600°C W/NEUTRON DAMAGE
PURE URANIUM	3.8-13	0.38-1.3	0.18-0.65	1.2-4.3	0.12-0.43	0.013-0.46	0.06-0.21
URANIUM (10% Mo)	3.8-13	1.0-3.5	0.5-1.7[1]	1.2-4.3	0.3-1.1	0.33-1.1	0.15-0.5
TUNGSTEN (SWAGED ROD)	3.4-14	1.4-6	1.1-4.7[2]	1.1-4.6	0.46-2.0	0.56-2.36	0.36-1.5
TANTALUM	2.5-5	1.9-3.7	1.9-3.7[2]	0.83-1.6	0.63-1.2	0.72-1.33	0.63-1.2

[1] EXPOSURE WAS 10^{19} TO 10^{20} NVT. IRRADIATION DATA WAS GIVEN AT ROOM TEMPERATURE

[2] EXPOSURE WAS 1×10^{19} NVT SLOW NEUTRONS AND 5×10^{19} NVT FAST NEUTRONS. IRRADIATION DATA WAS GIVEN AT ROOM TEMPERATURE.

TABLE 4

CLADDING EFFECT ON COOLANT CONTAMINATION

COOLANT CONTAMINATION (TOTAL CURIES)

TIME AFTER SHUT-DOWN FROM (DAYS)	SPALLATION[A] PRODUCTS	ACTIVATION[B] OF COOLANT	FISSION[C] FRAGMENTS	TOTAL WITH CLADDING	TOTAL WITHOUT CLADDI
0	350[D]	57	340	417	750
	(365)	(57)	(360)	(425)	(780)
1	60	15	135	75	210
	(95)	(15)	(160)	(120)	(280)
10	53	(10^{-3})	35	53	88
	(79)	(0)	(74)	(79)	(150)

[A] FROM ASSUMED DISTRIBUTION

[B] NA 24 AND K 42

[C] ESTIMATED LEAKAGE INTO COOLANT WITHOUT CLADDING

[D] XXX - FROM 90-DAY OPERATION
(XXX) - FROM 1-YEAR OPERATION

Curie of tritium and 1 Curie of ^{7}Be per day.

The Rutherford calculations indicate a 13°C thermal cycle per pulse at the target for a 600°C maximum temperature.

The lifetime of the target will also be determined by the dimensional changes caused by the accumulation of helium, krypton and xenon gas in bubbles. The gas filled bubbles may cause a loss of adequate cooling and/or rupture of target cladding.

The Rutherford calculations indicate for Springfields U a volume change of 0.65%/0.1% burnup (ratio of atoms fissioned/total U atoms). This value does not include the He contribution from the evaporation reactions. The 0.65% $\Delta v/v$/0.1% burnup suggests $\sim$10-12% $\Delta v/v$ of U in 100 days of operation at 600°C (3×10^{13} protons/pulse). The ANL calculations suggest a swelling value at 600°C for Springfields U of 13% in 100 days for 5×10^{13} protons/pulse intensity. The corresponding swelling for U-10% Mo is 6.5% in 100 days. The ANL calculations consider the contribution of He, Kr, and Xe. The above calculations are based on Kr and Xe production data for thermal neutron fission. The Kr and Xe production is expected to be less for fast neutron fission.

The experimental determination of the effects of thermal cycling on the dimensional stability of the proposed target materials would be useful data to acquire. Cross-section data for production of He, Kr, and Xe are needed for a more accurate prediction of the volume changes that may be expected.

The expected lifetime of the various target materials according to ARACOR is shown in Table 5.

TABLE 5

TARGET DESIGN OPTIONS COMPARED

TARGET	MAX LEAKAGE^{D} PER PROTON	NEUTRONS PER PROTON	LIFETIME^{A}	F.O.M.^{B}	FACTOR FOR^{C} ANNUAL COST	COMMENTS
DISKS						
BASELINE (CLAD U-MO)	0.040	22.2	3 MO.	1		
UNCLAD U-MO	0.043	23.6	3 MO.	1.06		
CLAD U^{E}	0.044	24	2 MO.	0.72		
UNCLAD U	0.047	25.5	1 MO.	0.38		
CLAD TH-U	0.029	20.5	4 MO.	1.23		30 WT PERCENT U; 20% INCREASE IN LENGTH REQUIRED FOR NEUTRON OUTPUT
UNCLAD TH-U	0.031	22	4 MO.	1.32		
STACKED U RODS	0.048	26	?	--		REJECTED BECAUSE OF STRESS FAILURE
MELTABLE U	0.047	25.5	1 YEAR	4.6		EXTERNALLY COOLABLE BY HE OR NAK; LIFETIME LIMITED BY EXTERNAL CONTAINMENT
MELTABLE^{F} U-MN	0.044	24	1.2 YEAR	5.2		
PURE TUNGSTEN DISK	0.026	14	1 YEAR	2.5		RANGE OF PROTONS IN W COMPARABLE TO THAT IN U

A ESTIMATED MAXIMUM

B FIGURE OF MERIT = (NEUTRONS PER PROTON) X LIFETIME

C DATA PENDING

D NEUTRONS/CM^{2}-PROTON (AT AXIAL MAXIMUM)

E FROM ALSMILLER CALCULATIONS

F DENSITY ESTIMATED

B.2 Computer Codes and Calculations

The workshop discussion included a review of the Monte Carlo computational capabilities of the participating laboratories. At Rutherford Laboratory, a modified version of the 0RNL high energy nucleon transport code HETC is used for target calculations and is being interfaced with 05R to extend the target calculations below 20 MeV. The TIM0C code is used for reflector-moderator studies and may also be directly interfaced with HETC. At LASL, the HETC code or its predecessor, NMTC, are interfaced with the LASL code MCNG below 20 MeV; in the future, the improved code MCNP will be used. At ANL, a recent version of HETC is interfaced with the VIM code below 15 MeV; potentially, the M0RSE could also be used for the low energy calculations.

At the present time, it appears that none of the laboratories has a complete code system for directly calculating thermal neutron beam intensity from incident proton beam intensity. The Rutherford and LASL codes have time dependance but lack a true thermal scattering capability, while the ANL VIM code includes a full thermal treatment but lacks time dependence. The development of a thermal scattering capability for MCNP of LASL is comtemplated; at ANL, the production version of VIM will be modified to include the time dependence and variance reduction techniques used in early VIM calculations of leakage spectra from spallation neutron sources.

It was the consensus of the workshop that the calculation of high energy fission product yields is essential for questions of hazards analysis and irradiated target disposal. The ability to provide such calculations has been implemented in the HETC codes at Rutherford Laboratory. A similar capability may be forthcoming is an improved version of HETC from ORNL; however, over the short term, we will probably have to look to Rutherford for codes and/or calculations in this area.

The MUSTA experiments undertaken by Rutherford Laboratory provide an opportunity for benchmark calculations on thermal and epithermal neutron spectral shape, with a possible extension to absolute intensity calculations. Undertaken primarily at 720 MeV, with some experiments at 800 MeV and 900 MeV, the MUSTA experiments provide data for H_2O moderator, H_2O, D_2O, and N_2 coolants, and graphite and Be reflectors. The final report, with analysis and benchmark specifications, is expected soon.

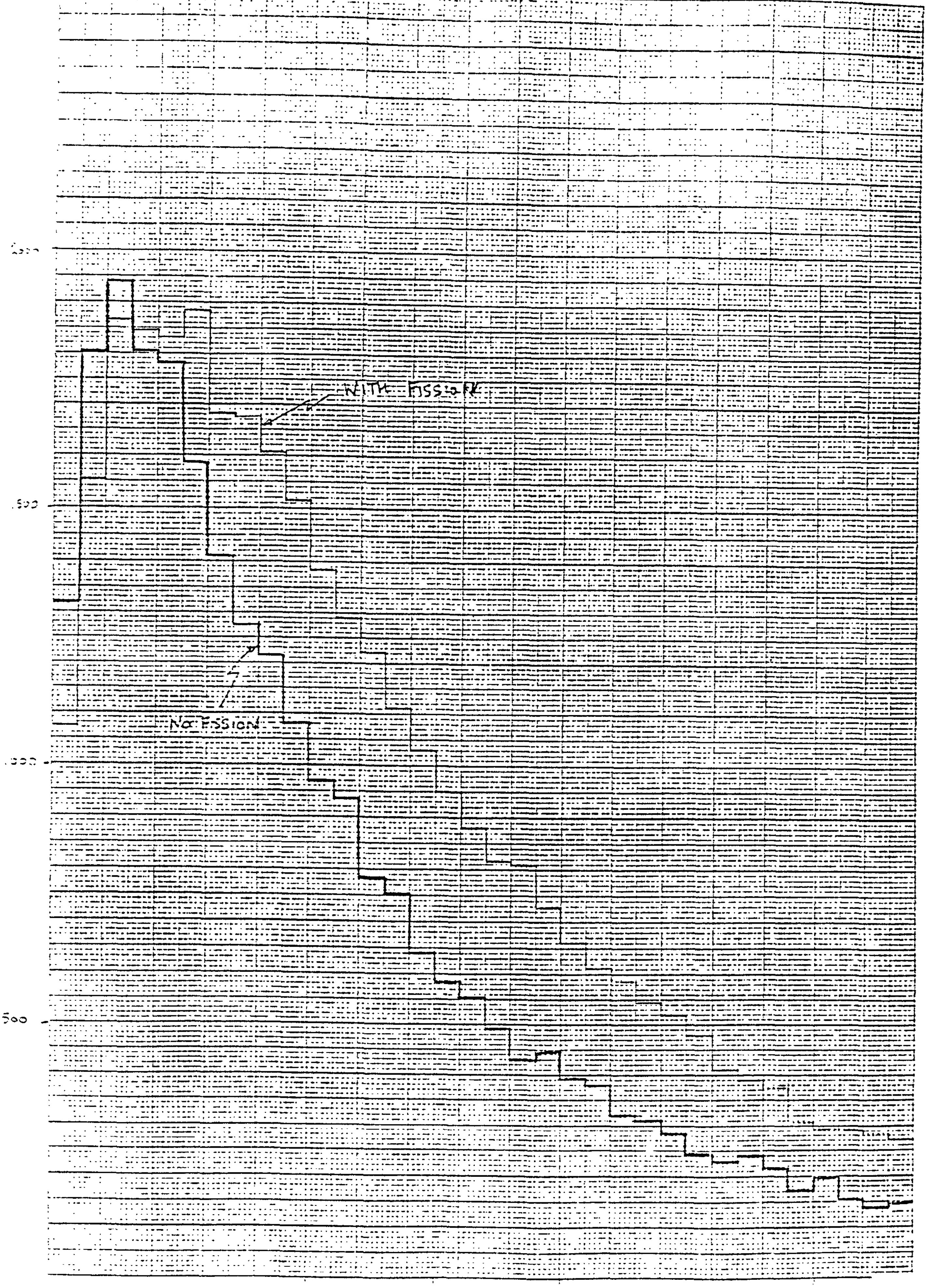
A benchmark for neutron production and energy deposition calculations will be provided by upcoming LASL experiments on a cylindrical Pb target. Further experiments on a 37 rod U cluster may be equally useful, but the desirability of a clean calculational benchmark for neutron production from fissionable material is so great that it is recommended that a cylindrical U target be included in the experiments if at all possible.

Included as an attachment are sample results obtained by Rutherford Laboratory for evaporation neutron spectum (Fig 1) and residual masses after evaporation (Fig 2) using their modified HETC code to account for high energy fission. Results shown are for 800 MeV protons incident on a 1000 m^3 cube of ^{238}U, with a normalization of events per 1000 proton-induced cascades.

B.3 Neutron Scattering Instrumentation

The status of the ANL program of design and development of neutron scattering instruments for IPNS was briefly discussed. Prototype work is being carried out at the pulsed source prototype ZING-P' which started producing neutrons in November, 1977. Four instruments are nearly complete for operation at ZING-P' now. These are a High Intensity Powder Diffractometer which is also intended for studies of liquids and glasses, a High Resolution Powder Diffractometer (0.3% resolution), a Crystal Analyzer Spectrometer for inelastic spectroscopy at energy transfers up to 300 meV but with no momentum transfer resolution, and a Chopper Spectrometer for energy transfers up to about 500 meV. Two more ZING-P' instruments are in the construction

Evaporated neutron spectrum for U^{235} induced by 800 MeV [illegible] on 1000 m³ Cube



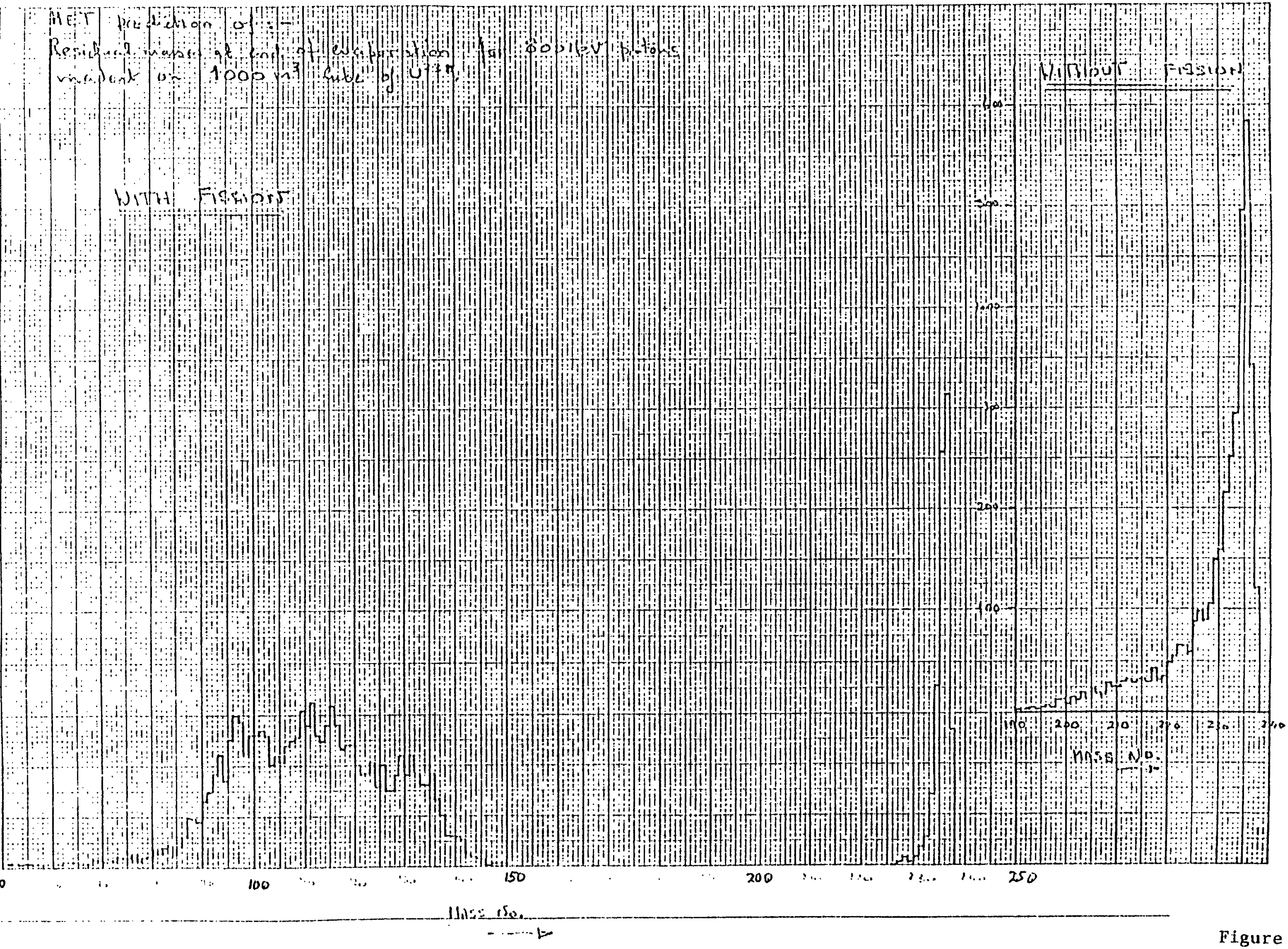

HET prediction of :-
Residual mass at end of evaporation for 800MeV protons
incident on 1000 m³ cube of U[illegible]
WITH FISSION
WITHOUT FISSION
500
400
300
200
100
190
200
210
220
230
240
MASS No.
0
100
150
200
250
Mass No.

Figure 2

stage. These are an Ultra-Cold Neutron Generator using a doppler shifting technique (ready in 1978), and a Single Crystal Diffractometer which will use a position sensitive multidetector 20x20 cm^2 (40x40 resolution elements) which will be built at Oak Ridge by ANL personnel (instrument should be ready in 1979). A diffractometer with polarization analysis of the diffracted neutrons is being designed and construction will begin in 1978 (ready in 1979). Some tests of "white beam" polarizing techniques will be carried out in 1978 as well. Other instruments contemplated (but not necessarily planned) for operation at ZING-P' include a High Pressure Powder Diffractometer and an adaptation of the Chopper Spectrometer (TNTOFS) currently in operation at CP-5 reactor. Development work on a resonance detector and on guide tubes is also planned.

In addition to this prototype development work, a number of conceptual designs for actual IPNS instruments have been considered and their performance has been evaluated. Instruments considered in such detail are listed in the Table 6. One general conclusion reached from these analyses is that chopper spectrometers are more versatile than are crystal ayalyzer spectrometers and are thus to be preferred for most inelastic scattering applications at IPNS. Highest priority for IPNS instrument construction will probably be given to a General Purpose Powder Diffractometer, a High Pressure Powder Diffractometer, and to chopper spectrometers similar to the designs CS1, CS2, and CS3. In addition some ZING-P' prototype instruments may be installed as part of the initial IPNS instrument complement. These include the High Intensity Powder Diffractometer (similar to design HID1), Single Crystal Diffractometer, and the Ultra Cold Neutron Generator.

TABLE 6

Summary of Instruments Considered in Detail, Including Prototype Development Status Where Applicable

Instrument	Examples of Scientific Area	Comments
High Intensity Diffractometer (Design HID1	Surface structures, absorbed and intercalated species. Transuranic compounds. High spatial resolution studies of glasses and molecular liquids.	$\Delta Q/Q \sim 0.01 - 0.03$ $0.2 < Q < 50$ Å^{-1} An instrument very similar to HID1 is ready to operate at ZING-P′.
High Resolution Diffractometer (Design HRD1)	Medium-size crystal structure analysis with powders. Line broadening by anisotropic particle sizes, strains.	$\Delta Q/Q \sim 0.001$ $1.3 < Q < 12.6$ Å^{-1} A similar instrument with Q/Q 0.003 is ready to operate at ZING-P′.
Single Crystal Diffractometer (Design SCD1)	Protein structures (position of H, H/D substitution, resonant nuclei). Weak satellite reflections in 1-D conductors at low temp.	Unit cells up to $\sim$ 100 Å. A smaller scale prototype with a two-dimensional position-sensitive multidetector is scheduled for operation at ZING-P′ beginning in 1979.
Small Angle Diffractometer (Design SAD1)	Studies of macromolecules in solution. Structures of polymers. Studies of precipitation, void formation and other metallurgical problems.	$0.0001 < Q < 0.2$ Å^{-1}, $\Delta Q = 0.0001 - 0.001$ Å Development will be based on development work for the Single Crystal Diffractometer
Medium Energy Chopper Spectrometer (Design CS1)	Higher harmonic modes in hydrides. Paramagnetic scattering from mixed-valence systems. Stoner excitations in ferromagnets. Spectroscopy of optically forbidden electronic transitions. Measurements of ground state momentum distributions.	$150 \text{ meV} < E < 1000 \text{ meV}$ $\Delta E/E \sim 0.01 - 0.10$ A prototype version is ready for operation at ZING-P′.

TABLE 6, Cont'd

Instrument	Examples of Scientific Area	Comments
Low Energy Chopper Spectrometer (Design CS2)	$S(Q,\omega)$ in amorphous solids, hydrides, dense gases, liquids. Dispersion of high-lying lattice modes. Metallurgical studies of elastic diffuse scattering. (clustering, short range order, interstitials, precipitates.)	$E < 150$ meV $\Delta E \sim 1$ meV Involves fairly minor modifications of an instrument now in use at the CP-5 reactor at ANL
Ultra High Resolution Chopper Spectrometer (Design CS3)	Diffusion in superionic conductors and other materials. Low-energy motions in plastic and liquid crystals, polymers, biomolecules. Tunnelling.	$E < 20$ meV $\Delta E = 10^{-6} - 10^{-4}$ eV
Constant-$\vec{Q}$ Spectrometer (Design CAS1)	Excitations in single crystals. Some items listed for CS1 and CS2.	$E < 500$ meV $\Delta E/E \sim 0.03 - 0.10$ Constant vector Q scans. Could be adapted for polarization analysis.
General Purpose Crystal Analyzer Spectrometer (Design CAS2)	Most items listed for CS1 and CS2.	$E < 500$ meV $\Delta E \sim 0.2 - 50$ meV Could be adapted for polarization analysis.
Energy Focussed Crystal Analyzer Spectrometer (Design CAS3)	Molecular vibrations in solids.	$E < 300$ meV $\Delta E \sim 2 - 10$ meV This instrument is ready to operate at ZING-P'.
Polarized Neutron Instrumentation	Dynamics of spin glasses, amorphous magnets. Separation of $S(Q,\omega)/S_{inc}(Q,\omega)$ in liquids, etc.	A prototype diffractometer with polarization analysis of the scattered neutrons with a crystal monochromator polarizer is being designed for operation at ZING-P'.
Ultra Cold Neutron Generator	Basic measurements of the electric dipole moment, charge, and lifetime of the neutron. Studies of surface effects in "bottle".	10^6 n/l/pulse A prototype is being built for operation at ZING-P'.

INFORMATION EXCHANGE

To help facilitate information exchange among the participating laboratories it was requested that technical communications be routed through specific contact points in each laboratory, or at least that these contacts receive a copy of all technical communications. The contact persons for the different areas are listed below.

Please route pulsed neutron source information exchange to or through these persons.

	IPNS (ANL)	SNS (RL)	WNR (LASL)
Accelerator	J. D. Simpson (360)	Brian Boardman	R. Cooper (AT3)
Target	T. G. Worlton (330)	Brian Boardman	G. Russell (P9)
Instrumentation	R. K. Crawford (223)	Brian Boardman	T. Kitchens (P8)
Mailing Adress:	Argonne National Lab. Argonne, Illinois 60439, USA	Rutherford Lab. Chilton, Didcot, OXON OX11 OQX ENGLAND	Los Alamos Scientific Lab. Los Alamos, New Mexico 87544 USA

FUTURE MEETINGS

It was unanimously agreed that similar additional meetings with these or other topics emphasized would be most valuable. Tentative locations, times, and agenda for the next two meetings were proposed, with the stipulation that final details regarding the first of these two should be worked out as soon as possilbe. These tentative meeting plans are included below. Any suggestions or questions regarding these meetings should be directed to the proposed host institutions.