ICANS-XI International Collaboration on Advanced Neutron Sources
KEK, Tsukuba, October 22-26, 1990

Why Total Performance

N. WATANABE
National Laboratory for High Energy Physics
1-1 Oho, Tsukuba-shi, Ibaraki 305 Japan

ABSTRACT
The importance of total performance and, consequently, total optimization, of the entire system for neutron scattering experiments is discussed in terms of two examples using existing instruments.

I. INTRODUCTION

Why is total performance important? The reason is very clear: the quality of neutron scattering data or scientic information obtained depends exactly on the total performance of the entire system, including the accelerator, neutron source, neutron transport line, instrument (itself), sample environment, data taking and analysis system. Thus, total optimization becomes indispensably important. Even though a great deal of effort to optimize each component has been made, total optimization has not yet been well established.

First, let us list up what components have to be considered. Table I summerizes main components with their importance on total performance.

The accelerator system is the most expensive and important component of a spallation neutron facility and, in some cases, is shared with other facilities, such as the Japanese Hadron Project. An accelerator system used for a pulsed neutron source can be characterized by the time-averaged proton-beam power, $\overline{P}$; pulse width, τ_P; and repetition frequency, f, although it is often graded only by $\overline{P}$. The figure of merit of an accelerator, FOM_{acc}, is really expressed at the epithermal neuton region, such as $FOM_{acc} = \overline{P}$, within certain limits of f and τ. In the cold neutron region, however, the proton-beam power per pulse becomes much more important (discussed later) and, $FOM_{acc} = \overline{P}/f$. Although τp is important, as far as a synchrotron or a compressor ring is concerned, it is usually sufficiently short even for epithermal neutrons. It becomes important only when the macroscopic pulses from a proton linac are directly utilized. The stability of the proton beam or the reliability of an accelerator system is, of course, another important factor regarding the performance: the long-term duty cycle is strongly dependent on both the beam-break time and the shortened target life (beam time loss for a target exchange).

The performance of a neutron source is mainly determined by the target, moderator as well as coupling between them. The choice of a target material is most important: non-fissile (non actinide heavy metal), non-enriched (usually depleted) or enriched uranium. Although the neutron yield from these three are roughly 1:2:5, the fast-neutron background caused by delayed neutrons becomes much more severe than this order. There is strong limitation in the choice of target and moderator materials which depends on $\overline{P}$. The target life also depends on $\overline{P}$.

Table I Main Components of neutron facility with their importance on total performance

Components	Choice/parameters	Importance on total performance
Accelerator	Time-averaged proton-beam current ($\bar{I}_p$) or power ($\bar{P}$)	Total neutron yield
	Repetition frequency (f)	Bandwidth of neutron wavelength
	$\bar{P}/f$	Especially important for cold neutron experiments
	Pulse width (τ_p)	Important only when long pulse from linac is directly used
	Stability and reliability	Target life, long-term duty cycle
Proton-beam injection schene	Horizontal/vertical	Determines target-moderator coupling (wing/flux-trap) Total number of neutron beams
Proton-beam delivery scheme	To single/multi TMRA'(s) (or target station(s))	Efficiency of proton-beam utilization and total facility gain
Target	Material (non-fissile, depleted U, enriched U)	Neutron yield, delayed neutron background
Target-moderator coupling	Wing or flux-trap	Slow neutron intensity, Number of neutron beams Fast neutron leakage
Moderator		
for cold neutrons	Material (liq. H_2, supercritical H_2, CH_4 at 20K or 100 K, etc) with/without premoderator, size (thickness), flat or groved	Fast-to-cold neutron conversion efficiency Pulse characteristics
for thermal neutrons	Material (H_2O, CH_4 at 100K, liq. H_2, etc), size and poisoning	Intensity and pulse width (resolution)
for epithermal neutrons	Material (mostly H_2O), size	Intensity and pulse width (resolution)
Moderator/reflector coupling	Coupled or decoupled	Slow neutron intensity, pulse width (resolution)
Reflector	Material (depends on moderator, coupling scheme and neutron energy used)	Slow neutron intensity, pulse width (resolution) Shielding
Target/moderator/reflector assembly (TMRA)	Number (single or multi,-dedicated to cold neutron source, thermal/epithermal neutron source, etc.)	Number of neutron beams totally avairable, More efficient proton beam utilization, Futher optimization for each TMRA.
Target station	Number (single or multi)	Number of neutron beams totally avairable, More efficient proton beam utilization, Futher optimization for each TMRA.
Beam collimator block		
inside void vessel (space)	With/without	Minimize background caused by high-energy neutrons and delayed neutrons when it exists
in bulk shield	Beam size, careful alignment	Best compromization between beam-intensity and background
Guide	Material (^{N}Ni, 58Ni, super mirror, etc.)	Transmittance and emittance, Beam size.
	Length	Useful bandwidth of neutrons, resolution, space for instruments
	Distance between source and inlet of the guide	Beam acceptance
	Air gap on both side of tail culler	Transmission loss
Background suppercession chopper	Stopping power	Background level
	Rise-up time, distance from the source	Maximum incident neutron energy
Monochromating chopper	Chopper pulse width, distance from the source	Energy resolution
Overlap suppersion chopper		Bandwidth
Spectrometer	Sample position	Incident neutron solid angle (intensity) and resolution
	Analyzer and/or detector	Resolution and detector/analyzer solid angle (detection efficiency)
Special sample environment	To be discussed elsewhere	
Layout in surrounding instruments	Avairable space	Minimum incident flight path length for high intensity requirement Maximum flight path length for scattered neutrons (resolution limit)
Experimental Hall	Size	Maximum total flight path length (resolution) Total number of instruments
Data taking system	To be discussed elsewhere	
Data analysis technique	To be discussed elsewhere	

There are several choices available for each component. For example, regarding the target station, one must decide which is the better; horizontal or vertical proton injection; a wing or flux-trap geometry in the target-moderator coupling; coupled or decoupled moderators; how many target stations or target-moderator-reflector assmblies (TMRA's); what is the optimal proton-beam delivery scheme; what combination of moderators with different characteristics; and what neutron-beam allocation are the optimal for various kinds of experiments. All of those should be considered on the basis of total performance. However, it is not easy to totally optimize so many components. When we construct a new facility or improve an existing one, we first have to establish a philosophy, a fundamental concept and a strategy under give boundary conditions. A preliminary thought of this kind concering JHP is given in ref. 1.

In our experience, the size of the experimental hall is one of the most important components. A finite size hall limits various possibilities for higher performance. There are very many components to be optimized totally, as listed in table I. In the existing instruments, only some parts have been optimized. We discuss in the next section two existing instruments as examples of how to consider whether something has been totally optimized or not.

II. EXAMPLES ON TOTAL PERFPRMANCE

The first example is a case which is favourable for KENS: i.e., the case of LAM-80ET, which has been fairly well totally optimized for high-resolution spectroscopy in the low-energy transfer range. The various parameters of this instrument are listed in Table II and are compared with those of IRIS, a corresponding instrument at ISIS. This table is a modified version of that which appears in ref. 4. LAM-80ET has large analyzer mirrors comprising small mica crystals; recently, IRIS has also been equipped with a new analyzer system comprising the mica crystals.[5] Although the number of fast neutrons produced at the KENS target is only 1/34 of that at ISIS, the total gain or the performance (resolution and data rate) is almost the same as shown in the table and Fig. 1[6,7]. The higher efficiency of LAM-80ET is mainly due to a higher conversion efficiency (from fast-to-cold neutrons) of the KENS solid methane moderator and larger solid angle of the analyzer mirrors. The advantages of LAM-80ET over IRIS are a better signal-to-background ratio and a larger energy window due to a lower repetition rate of neutron pulses (relatively large $\bar{P}/f$) in KENS (20 Hz). *Note that the cold neutron intensity per pulse in KENS is almost the same as that in ISIS (see Table II).* The energy window in IRIS is about ±300 μeV with $E_f \sim 0.832$ eV (the 004 reflection of mica crystal), and a full repetition rate of 50 Hz;[5] the corresponding value for LAM-80ET is about +1000, -500 μeV. The energy window of 300 μeV is just sufficient for measuring the tunneling spectrum in the above example; when a larger energy window is essential, however, 50 Hz is two high, and thinned out repetition using a chopper becomes indispensable while, of course, sacrificing intensity. Futhermore, LAM-80ET can simultaneously be used to measure different spectra with different E_f's by different reflections of mica crystal (006, 008,....). This increases the range of the Q-ω space simultaneously accessible with LAM-80ET. As a consequence, the relative gain of LAM-80ET to IRIS is effectively larger than the value listed in the table. However, there still exists an important mismatch in LAM-80ET: the instrument has a neutron guide, the cross section of which is 5×3 cm^2 in the first 3.5 m and 5×2 cm^2 in the succeeding part, and has no super mirror converging guide as is used in IRIS. If we were to have a similar guide as that used in IRIS (5×5 cm^2 guide and super mirror converging guide), we could expect an additional gain of about 2.8.

The next example is a case which is not favourable for KENS; i.e. the chopper spectrometer, INC, in KENS. Figure 2 shows time-of-flight (TOF) and energy spectra from a YbN sample at room temperature measured on INC, compared with the

Table II Comparison of the various parameters between LAM-80ET and IRIS

Componets	IRIS	Relative gain of LAM-80ET to IRIS	LAM-80ET
Proton beam Energy (MeV)	750		500
Time-averaged current (μA)	100		5
Protons per pulse	1.3×10^{13}		1.56×10^{12}
Repetition rate (Hz)	50		20
Fast neutron yield	1.72×10^{16}	1/34.4	5×10^{14}
Fast neutrons per pulse	3.4×10^{14}	1/13.6	2.5×10^{13}
Moderator	Liquid H_2 at 25K (decoupled)		Solid methane at 20K (decoupled)
Conversion efficiency from fast to cold neutrons (rerative values)	1	8	8
Cold neutrons per pulse (relative values)	**1**	**1/1.7**	**1/1.7**
Bandwidth Δλ (A)	2	(4)	8
Energy window (μeV) (with the 004 reflection of mica)	±300	(3.3)	+1000 -500
Guide tube gsin (relative value)	1	1/2.8	1/2.8
Analyzer mirror (mica)			
Reflectivity (relative value)	1	1	1
Solid angle (relative value)	1	9	9
Total gain		**0.75**	
Overall energy resolution (μeV) (with the 004 mica reflection)	**4.2**		**5.6**

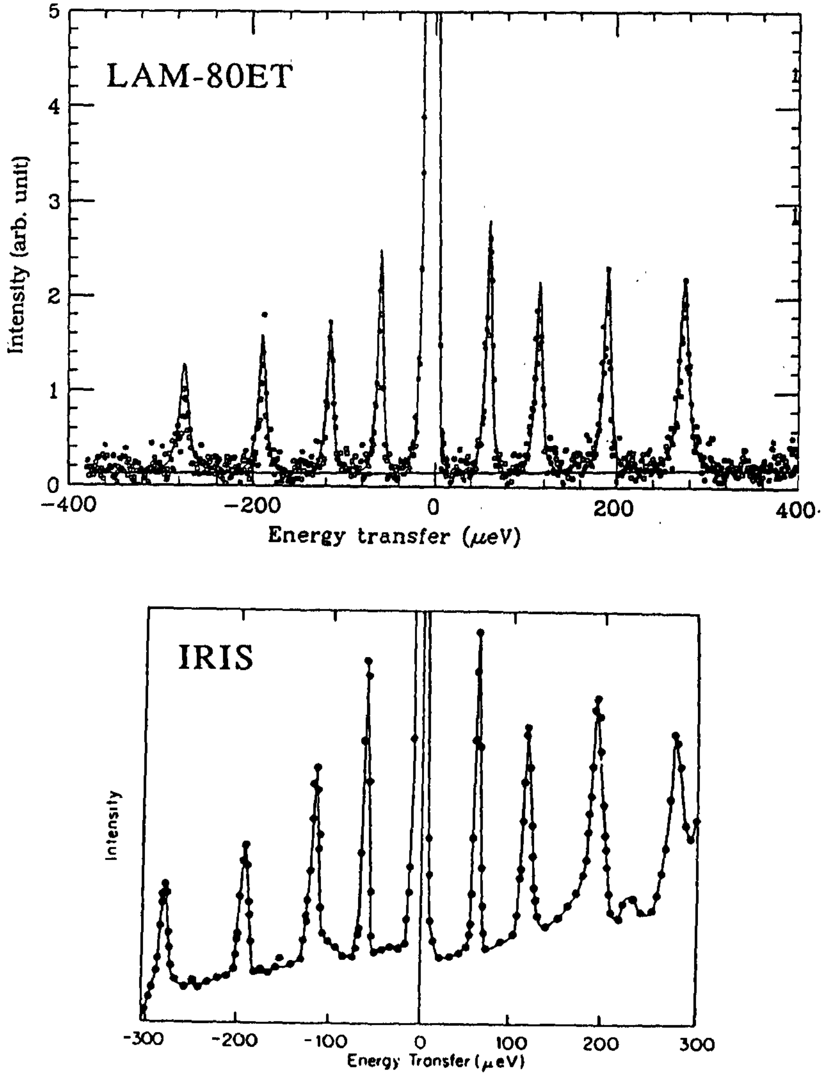


Fig. 1 Tunneling spectra of N-oxy γ-picoline measured on LAM-80ET (upper) and IRIS (lower) with E_f=0.832 μeV using the 004 reflection of mica crystals in analyzer system.

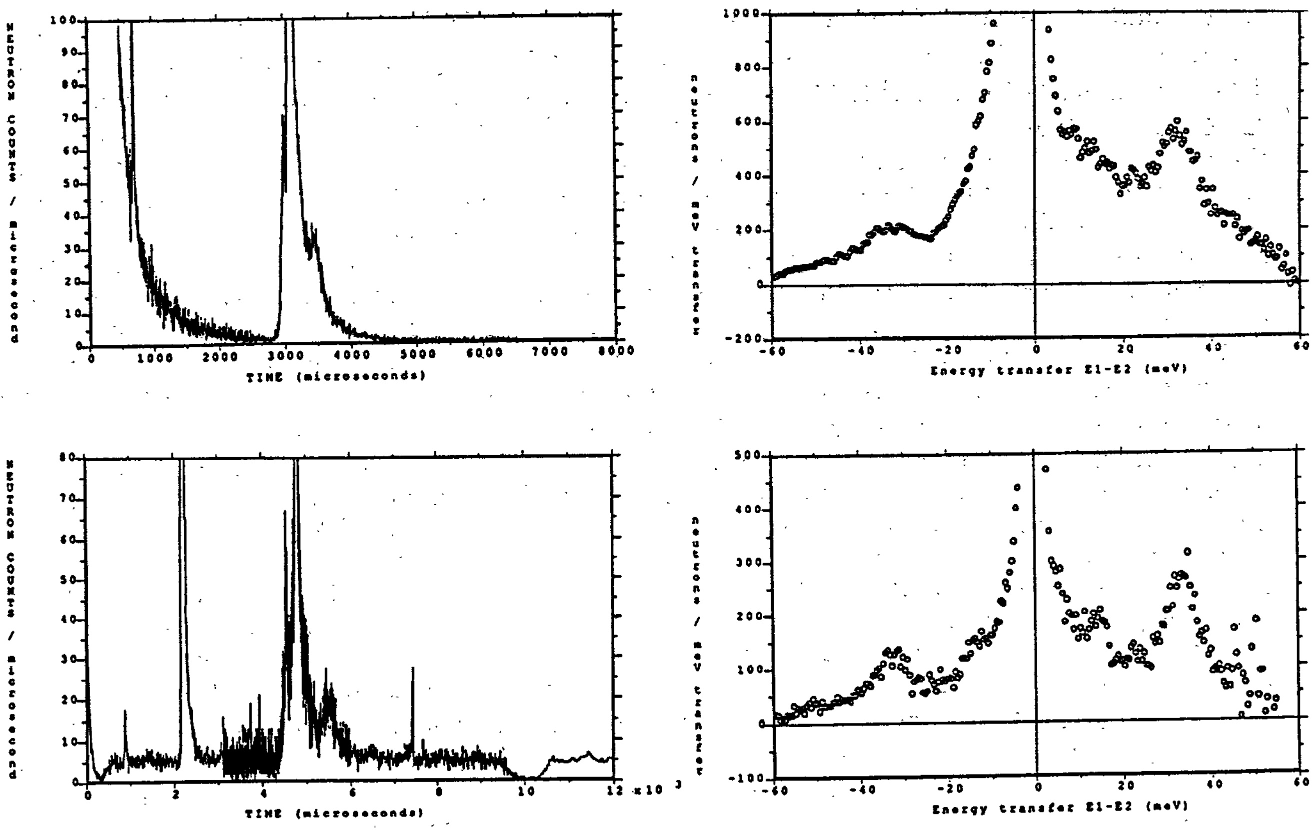
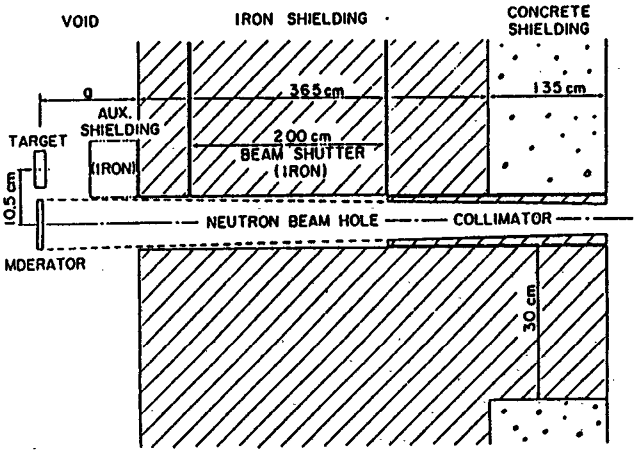


Fig. 2 TOF (left) and energy (right) spectra from YbN sample measured on INC (upper) and MARI (lower). Many peaks in the TOF spectrum measured on MARI are the sprious except for those appear between 4~6 msec.



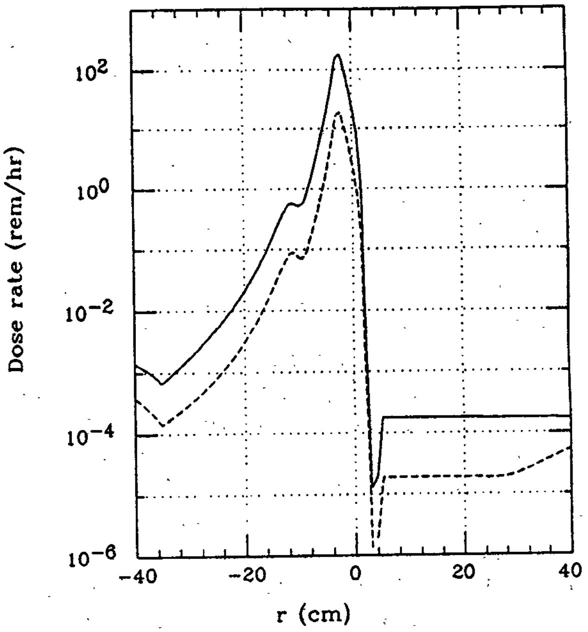


Fig. 3 Model target station used for the calculation of dose equivalent rate.

Fig. 4 Calculated dose equivalent rate at the exit of neutron beam hole: solid/dashed curves refer to without/with auxiliary iron block of 50 cm thick.

corresponding spectra from the same sample on MARI, a high-resolution chopper spectrometer in ISIS, by the same experimenter.[8)] INC can provide almost the same data rate, with about a 10-times better signal-to-background ratio, but with much poor energy-resolution in a lower energy transfer range (20 ~ 30 meV), as in this case. We think that the better signal-to-background ratio in INC is due to better beam collimation in the bulk shield with a minimum void space between the souce and inner iron-collimator-block, as well as a lower repetition. The leakage of fast neutrons from a neutron-beam-hole is especially enhanced in the case that a large void space exists between the target and bulk shield. We performed a calculation on the dose equivalent rate, mainly concerning high-energy and fast neutrons, at the outer surface of the bulk shield around the neutron beam hole. High-energy neutrons produce fast neutrons and, eventually, epithermal neutrons when they are stopped. Therefore, the dose equivalent rate is a good measure of fast-neutron contamination in a slow neutron-beam. A model target station is shown in Fig. 3.[9)] Figure 4 shows the calculated results. The dose equivalent rate is very high in the case of a void space with a=1 m. If we put an auxiliary iron block of only 50 cm thick inside the void vessel (as shown in Fig. 3), it is possible to decrease the dose equivalent rate by one order of magnitude, as shown by the dashed curve in Fig. 4. We actually experienced a higher background in various spectrometers when the previous tungsten target was replaced by the present depleted-uranium type. We overcame this by inserting a narrower beam collimator, stacked iron and B_4C picture frames (as used in ISIS) into the beam hole. The size of the aperture at the inner end of the collimator (about 1.7 m from the moderator) is 8 × 8 cm, which is smaller than the previous size (10×10 cm^2). Although the new collimator slightly limits the moderator viewed surface, the reduction in beam intensity is less than 10 %. We succeeded in reducing the background by one order of magnitude by this method. Note that even though the distance between the target and first iron shielding block in the present KENS facility is only 0.35 m (just reflector thickness), loose collimation resulted in a serious background problem. This means that the existence of a large void space between target and the inner surface of iron shielding makes the background problem more difficult.

INC has no burst (t_0) chopper. The large background at a smaller TOF is due to the lack of such a chopper; INC data shows the importance of a burst chopper.

The energy-resolution of INC is about 1.5-times as large as that of MARI, if INC views the same moderator as MARI, since INC has shorter flight-path lengths (about 1/1.5)for incident and scattered neutrons. To our regret, INC views a room-temperature moderator without poisoning, causing the greatest mismatch for INC, especially when the incident neutron energy is below 100 meV. The observed resolution (full width at half maximum) is much greater than the above value due to the longer pulse width of thermal neutrons from the room-temperture moderator. The longer exponential die-away tail of a thermal neutron pulse is the worst, making it difficult to characterize the inelastic scattering peak in this example. In the energy-transfer range (as in this example) the energy resolution of LAM-D in KENS is much better than INC. The resolution is the most important in a chopper spectrometer. If we could install INC at a beam hole viewing the solid methane moderator, it could provide much better data in this energy range. At the epithermal neutron region, however, INC is , of couse, reasonablly good: although it has almost the same data rate as dose MARI, it has 1.5-times the relaxed resolution. The spacial limitation is another important disadvantage for INC. The flight-path length for scattered neutrons at higher angles is only 1.3 m, since we were not allowed to dig a large hole in the floor to install a larger detector chamber, and there was no enough space for a horizontal detector arrangement due to the existing instruments on both sides.

III. CONCLUSION

As a conclusion we emphasize that there are very many mismatchs when we consider the total performance; in other words, there is still much room for improvements.

IV. ACKNOWLEDGEMENT

The auther is thankful to Dr. M. Kohgi for providing YbN data measured both on INC and MARI and to Dr. M. Misawa for further calculations of the dose equivalent rate around the neutron beam hole.

REFERENCE

1 Y. Kiyanagi and N. Watanabe; Proc. ICANS-XI (Tsukuba, Oct. 22-26, 1990) P-408
2 Y. Kiyanagi, N. Watanabe, M. Furusaka, H. Iwasa and I. Fujikawa : ibid, P-388
3 N. Watanabe : ibid, P-471
4 K. Shibata and T. Kamiyama : A summary of Performance on IRIS and LAM-80ET, TUNNEL 902, Proc. Japan-U.K. Collaboration on Neutron Scattering Research, KEK Report 90-17 (Dec. 1990) P-39
5 C. J. Carlile : The design of the IRIS inelastic neutron spectrometer and improvements to its Analyzer, ibid. P-1
6 C. J. Carlile : Tunneling measurements of Methane, Methle Pyridine and its derivatives, and Ammonia in Caesium in tercalated Graphite on IRIS, ibid. P-59
7 S. Ikeda et al., : Neutron scattering form N-oxy γ-picoline, ibid. P-42
8 M. Kohgi, private communication
9 N. Watanabe, M. Misawa and S. Ikeda : Technical problems in KENS-II design, Proc. Meeting on BSF Future Prospect-II (Mar. 11-12, 1983), KEK Int. 83-7 (1983) P-199 (in Japanese)

Q(R.Pynn): What is the $\Delta d/d$ for mica? What is this matched to- the full width of the pulse from the moderator or the leading edge of pulse? At what energy have the matching been done? Have you thought about other analyzer crystals for LAM-80, such as silicon?

A(N.Watanabe): We have no data on $\Delta d/d$ of mica crystal. I think $\Delta E_f/E_f$ in LAM-80ET using 002 reflection of mica is mainly determined by a finite angular uncertainty between sample and analyzer crystal (1cm x 1cm) rather than $\Delta d/d$ of mica itself.

C(W.G.Williams): Optimization is a useful concept but in practical situations we are always concerned with compromise. IRIS at ISIS is a good example. It does not need a 50 Hz source.