Key Innovations at J-PARC – Through a Prize Lecture by Professor Watanabe

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ABSTRACT
In the last part of his lecture as the first recipient of the AONSA Prize, Professor Watanabe described in 2011 the MLF spallation source facility at J-PARC as a suite of innovative technical choices. Indeed, the high power at low repetition rate, exclusively cold moderators, the unique para H2 large volume moderator, the optimal use of water premoderators opened up new ways in conceiving pulsed spallation sources. The present recollection of these novel neutronic features tries to recall the perception of these trendsetting achievements in his most memorable prize lecture.

Keywords: Pulsed spallation sources, para hydrogen moderators, premoderators

1. Introduction
I came to Japan the first time in 1982 for a few most memorable weeks, including a visit to Sendai. At Tohoku University I shared an office for 2-3 days with Pierre-Gilles de Gennes. He was known no fan of large scale research facilities; nevertheless he highly appreciated the importance of neutron scattering research. Neutron spectroscopy indeed played a fundamental role of providing proofs for some of his famous predictions, including de Gennes narrowing and reptation. He was already a living legend by that time, I happened to have heard of referees at physics journals refusing the publication of experimental results because they did not agree with what de Gennes’ theory said. I was reminded to this in a positive sense a few decades later when a group of ESS target engineers returned from a very helpful experience gathering visit to J-PARC. One of them recalled that when he asked colleagues at J-PARC why they made this or that choice, sometimes the answer was “Because Watanabe said so.”

Indeed, Japanese pulsed neutron source research and the construction of the MLF spallation source facility at J-PARC was and is a very important source of inspiration and experience in the neutron research community, including for conceiving and building the European Spallation Source ESS. Professor Watanabe’s prize lecture [1] at his receiving of the inaugural Asia-Oceania Neutron Scattering Association (AONSA) prize in 2011 is an inspiring account of outstanding spirit of progress by innovation. I will go through here, following his AONSA prize lecture the main innovative neutronic features of the spallation source at J-PARC. Figures and citations (in Italic) are from this lecture of Prof. Watanabe.

2. J-PARC suite of neutronic innovations.
J-PARC “is high power (1 MW) at a low repetition rate (25 Hz)”. This combination leads to high power per pulse, where on the way to the nominal 40 kJ per pulse the 24 kJ already achieved by J-PARC is by now the highest worldwide. The advantage is not only more neutrons per pulse (i.e. also higher source peak intensity) but easier use of a broader fraction of the pulsed spectrum over the longer time interval between pulses. ESS followed the lead of J-PARC in the direction “high power at low repetition rate” (5 MW & 14 Hz, respectively).

The Figure-of-Merit “(FOM) of the source is expressed as the sum of each beam’s FOM (FOMi): FOMsource = Σ i FOMi, where N is the number of beams. To increase FOMsource, N must be maximized...”. J-PARC has broken new grounds by reducing the minimal angular separation between beam lines to 6.7° for a total of 23 independent beam lines. ESS followed suite with 6° average separation between beams for a total number of 42 possible beamlines.

A key innovation of the layout of the J-PARC spallation source compared to all other short pulse spallation sources is that it was “…decided that all moderators should be H2 moderator: no H2O judging from the neutronic performance...” and “…use 100 % para H2 for all moderators because of better neutronic...
performance than other para H₂ ratios”. The performance of the three types of para H₂ moderators used at J-PARC is illustrated in Fig. 1.

This figure reveals another innovative approach at J-PARC: communication of the observed absolute moderator intensities. The actual numerical values of neutron intensities emitted by the moderators at spallation sources are commonly treated as well-kept secrets. Usually only data on spectra in arbitrary units and “corresponding to expectations” are available. By the way, it is not quite simple to measure reliable absolute moderator emission intensities. The ILL Yellow Book contains extensive data on many beam-lines as determined by some 40 years ago. It is a most respectable tradition to not to change an iota on these data originally measured by Paul Ageron, the legendary designer and builder of the ILL beam extraction system. The open secret known to most insiders is that today the flux of the cold neutron beams is about 2 times higher and that of the thermal beams about 2 times lower than in the Yellow Book.

Suppressing the thermal moderators in favor of a purely cryogenic set of moderators, in contrast to the unanimous practice at all other spallation sources, was a courageous and very judicious decision at J-PARC, which significantly enhanced its competitive edge. The intensity of thermal moderators is only superior to their cold counterparts in the neutron energy range of about 20 – 500 meV, but this advantage is essentially compensated by the considerably shorter cold moderator pulse length in this part of the neutron spectrum. (At long pulse sources such as ESS the neutron pulse lengths is equal to the long proton pulse duration and independent of the type of the moderator. Thus there is a real advantage of having a combination of cold and thermal moderators there, in contrast to short pulse sources, such as J-PARC.)

The reduction of the number of different moderators at J-PARC made possible to much better optimize them than at other short pulse sources. “We considered one cylindrical coupled moderator (15 cm in diameter) and compared to two coupled moderators case, showing that the single cylindrical gives higher total intensity.” This led to the birth of the unique coupled para-H₂ large volume moderator of J-PARC which provides at least about 2 times higher efficiency delivering cold neutron intensity than its predecessors at other spallation sources. This great achievement at J-PARC was the starting point of ESS cold moderator development.
Another trademark development, which stood very close to the heart of Professor Watanabe, was the use of water premoderator around the cryogenic H$_2$ moderators (and is part of the success of the above mentioned para-H$_2$ large volume moderator). His original worry actually was to shield the cryogenic moderator against the heat deposition by the radiation from the target, in order to reduce the high cooling needs.

Together with Professor Kiyanagi he “found that a water premoderator is very useful to increase the cold neutron intensity of H moderator. ... Measurement showed that solid methane moderator cannot surpass H$_2$ moderators both with optimized premoderator.” This very important design feature of cold moderators was also fully adopted at ESS.

Fig. 3. The impact of water premoderator (pm) on the flux of coupled H$_2$ moderator, compared with the decoupled case and bare moderator without reflector (graphite in this case).

3. Concluding

In a review article appeared in 2003 and entitled “Neutronics of pulsed spallation neutron sources” [2] Professor Watanabe gave an excellent summary of the state-of-the-art that was the basis of the conception of the J-PARC design. From that review of what was known at that stage it is still impossible to figure out the final outcome. The well performing facility he could report about in his 2011 Prize Lecture was the result of an exceptionally rare concentration of creativity and most judicious innovations in a short period of time at the same place, a most astonishing and appreciable contrast to the inertia and cautious conservatism of our bureaucratic time.

It is little surprise that the achievements in source development we have just recalled opened up the way to other milestone developments. Just one example is the first successful implementation of the holy grail of pulse shaping at a pulsed neutron source. Taking advantage of the large peak and integrated intensity of the J-PARC large volume coupled cold moderator (cf. Fig. 1, top), the multiplexing neutron chopper system of the DNA backscattering spectrometer delivers a pulsed spectrum to the sample with much shorter pulse length than a poisoned moderator could ever achieve [3], allowing this instrument to provide the highest resolution in its class at a pulsed spallation source.

References
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Brief personal history

Ferenc Mezei started to work in the field of neutron scattering in 1969, invented Neutron Spin Echo spectroscopy in 1972, supermirrors in 1976 and the long pulse spallation source concept in 1993. He and collaborators introduced and developed several other neutron instrumentation methods now in general use worldwide. He has received the Hewlett-Packard Europhysics Prize in 1986, the inaugural Haeig Prize of the European Neutron Scattering Association in 1999, the Sechenyi science prize of the Republic of Hungary in 2013. He is member of the Hungarian Academy of Sciences and of Academia Europaea.

Mezei studied physics at the Eötvös University in Budapest, worked as neutron instrument scientist at Institut Laue Langevin in France 1972 – 84 and was director of the Berlin Neutron Scattering Center (BENSC) at Hahn-Meitner-Institute from its foundation in 1992 to 2007, with an interruption from 1997 to 2001, when he was distinguished scholar at Los Alamos National Laboratory in the US. He was professor of Physics at Technical University Berlin from 1984 to 2007 and joined the FSS construction project in Lund, Sweden in 2010, where he is now technical coordinator.