Neutron-Beam Facilities for Nuclear Astrophysics Applications

Masayuki Igashira

Research Laboratory for Nuclear Reactors, Tokyo Institute of Technology Email: iga@nr.titech.ac.jp

Introduction (1/2)

- Accurate neutron capture cross section data in the keV region are necessary for the study on nucleosynthesis in the universe.
 - **# Primordial Nucleosynthesis**
 - **# Nucleosynthesis in Stars**
 - **# Nucleosynthesis in Supernovae**
- Intense and Pulsed neutron sources are necessary for the precise measurement of neutron cross sections.

Introduction (2/2)

 Intense and Pulsed neutron sources:
 # Electron Linear Accelerators: Photo-Neutron Sources ORELA, GENINA, etc. (40 - 200 MeV) 0.01 - 0.001 neutron/electron
 # Proton Linear Accelerators (+ Synchrotron): Spallation Neutron Sources
 LANCE, n_TOF, J-PARC/MLF, SNS, etc. (0.8 - 20 GeV) 20 - 300 neutrons/proton

- Some Spallation Neutron Facilities (SNFs) are available for Astrophysicists.

Overview of SNFs available to nuclear astrophysicists Characteristics of J-PARC/MLF, LANSCE, n_TOF Comparison among those facilities Recent research activities at those facilities

Spallation Neutron Facilities (SNFs)

MLF at J-PARC: 3 GeV protons + Hg target (>200 KW)
 J-PARC: Japan Proton Accelerator Research Complex
 MLF: Material and Life Sciences Experimental Facilities

- LANSCE: 0.8 GeV protons + W target (80 KW) LANSCE: Los Alamos Neutron Science Center WNR (Weapon Neutron Research Facility) Lujan Center
- n_TOF at CERN: 20 GeV + Pb target (9 KW)

SNS at ORNL: 1 GeV proton + W target (800 kW)

Comparison of Neutron Fluxes



Comparison of Neutron Intensities/Pulse



J-PARC MLF

J-PARC : Japan Proton Accelerator Research Complex



MLF: Materials and Life Science Experimental Facility



ANNRI at J-PARC/MLF

ANNRI was installed in the beam line 04 of MLF of J-PARC in a Nuclear Data Project.

ANNRI: Accurate Neutron-Nucleus Reaction Measurement Instrument

ANNRI at J-PARC/MLF



Proton Beam

ANNRI (March 5, 2008)

.....



ANNRI



4π Ge Spectrometer at 21.5 m





4π Ge Spectrometer at 21.5 m



*T. Kin et al., the 2009 NSS-MIC Conf. Rec., N24-2 (2009)

Nal(TI) Spectrometer at 27 m



Nal(TI) Spectrometer at 27 m



LANSCE(Los Alamos Neutron Science Center), cite in "http://michael.e.gruchalla.org/WebpageImages/Lansce1.jpg"

Weapons Neutron Research Facility Isotope Production Facility

> Proton Radiography Facility

Lujan Neutron Scattering Center Ultra-Cold Neutron Facility

LANSCE



- Facility is driven by the 800-MeV proton accelerator using a proton storage ring to accumulate beam, I_p ≈ 100 μA, 20 Hz, _t = 200 ns
- Moderated W target gives "white" neutron spectrum, ~14 neutrons/proton
- DANCE is on a 20 m flight path / ~1 cm φ beam after collimation Φ ≈ 8.7 x 10⁴ n/(cm²-sec) / E_n (eV) Integral flux ≈ 2 x 10⁵ n/(cm²-sec) per energy decade



DANCE

Detector for Advanced Capture Experiments

Specifications		
Moderator	Water (2nd Tier)	
Flight Path	20 m to sample	
Beam Size at Sample Location	1 cm diameter	
Sample Size	> 100 micrograms	
Gamma Detection	160 BaF ₂ scintillators	
Flux Monitoring	⁶ Li, BF ₃ , ²³⁵ U fission	
Typical Experiment Duration	10 days	

http://lansce.lanl.gov/lujan/instruments/DANCE/pdfs/DANCE.pdf



http://geanie.lanl.gov/

GEANIE

Germanium Array for Neutron-Induced Excitations



http://www.lanl.gov/news/currents/2008/july/geanie.shtml/



Journal of the Korean Physical Society, Vol. 59, No. 2, August 2011, pp. 1558-1562

FIGARO

Fast Neutron Induced Neutron and Gamma Ray Observer

LSDS

Lead Slowing Down Spectrometer



n_TOF



"http://pceet075.cern.ch/ "CERN n_TOF Facility: Performance Report"

n_TOF TAC for (n,g) measurements



Parallel Plate Avalanche Counters PPACs



EAE-2 of n_TOF



"EAR-2 :UPDATE FEASIBILITY STUDY", E.Chiaveri, n_TOF Collaboration Board CERN, October 6 ,2011

Cross Section Measurements at SNFs

- ANNRI

Capture Cross Sections of Long Lived Fission Products (LLFP) and Minor Actinides (MAs) # Nuclear Fuels (Th, U, Pu) and unsealed RI are not usable in MLF.

- LANSCE

Capture, Fission and Inelastic Cross Sections, DDX

- n_TOF

Capture and Fission Cross Sections

Measurement by using ANNRI

Capture Cross Section Measurements LLFP: Zr-93, Tc-99, Pd-107, I-129 MA: Np-237, Am-241, Am-243, <u>Cm-244</u>, <u>Cm-246</u>

For Cm-244 and Cm-246, the present measurements were the first ones with an accelerator neutron source.

(Previous measurements were performed with neutrons from nuclear devices.)

²⁴⁴Cm and ²⁴⁶Cm Samples

Cm-244 ($T_{1/2}$ =18.1y) Net weight: 0.6 mg Activity: 1.8 GBq Cm-246 ($T_{1/2}$ =4753y) Net weight: 2.1 mg Activity: 12.1 MBq (²⁴⁴Cm: 1.7GBq) Chemical form: CmO₂

Container: Al capsule

The isotopic composition of the ²⁴⁴ Cm and ²⁴⁶ Cm samples		
	²⁴⁴ Cm sample (%)	²⁴⁶ Cm sample (%)
²⁴⁴ Cm	89.57±1.68	27.52±0.45
²⁴⁵ Cm	2.66±0.34	1.06±0.28
²⁴⁶ Cm	7.08±0.33	59.40±1.29
²⁴⁷ Cm	Not Detect	2.86±0.36
²⁴⁸ Cm	Not Detect	9.10±0.24

Preliminary Result of ²⁴⁴Cm (0.6 mg, 2 GBq) (Ge Spectrometer)

The resonance results below 20 eV are the first experimental ones in the world.



M. S. Moore et.al., Phys. Rev. C, 3, 1656 (1971).

Preliminary Result of ²⁴⁶Cm (2.1 mg, 2 GBq) (Ge Spectrometer)



M. S. Moore et.al. , Phys. Rev. C, 3, 1656 (1971).

Perspective of Measurements at J-PARC/MLF

Until 2010.3 ANNRI was Dedicated to an Entrusted Project.

From 2010.4

MEXT approved studies on

- (1) Nuclear Energy Systems
- (2) Nucleosynthesis in the Universe
- (3) Nuclide-Quantification
- → Practically, ANNRI is available to worldwide users.

We expect ANNRI will be used for a variety of research fields from January, 2012.

Please visit the following: http://j-parc.jp/MatLife/en/applying/koubo.html

Announcement of the J-PARC MLF User Program for 2012A Call for Proposals

J-PARC and the MLF suffered significant damage in the earthquake that struck eastern Japan in March 2011. Recovery work is proceeding toward the goal of resuming experimental operations in January 2012. Accordingly, J-PARC MLF and CROSS-Tokai jointly announce that the call for proposals to use the neutron and muon instruments at J-PARC in the 2012A operations period opens on the 17th of November 2011. Users wishing to conduct experiments at the MLF during 2012A are encouraged to submit proposals via the web-based J-PARC Proposal System.

1. Using the MLF

Click here for general information about:

- Available access modes
- Types and categories of proposals
- Proposal submission and assessment procedures

2. Duration of the 2012A Operations Period

Accepted proposals will be scheduled within the period April to November 2012.

3. Deadline for proposal submission

Proposals must be submitted by

17:00 (JST) on Wednesday the 7th of December 2011.

Thank you for your attention!

Nuclide-Quantification

 All Elements Simultaneous, Non-Destructive, High-Sensitivity, ppt*, ppq** order sensitivity
 High-Accuracy, % order accuracy
 nuclide-quantification

- 3 Dimensional Analysis with a Micro-Size Neutron Beam

*ppt: 10⁻¹², part per trillion **ppq: 10⁻¹⁵, part per quadrillion

Schematic of LANSCE7's Beam Delivery

cite in LANSCE Activity Report 2010, http://lansce.lanl.gov/news/activityreport/LA NSCE%20Activity%20Report%202010.pdf



Spallation Neutron Source in J-PARC MLF

Optimization and Shielding design around Hg target





Spallation Neutron Source in J-PARC MLF

Spallation Neutron Source

Energy Range Incident Proton: 3 GeV Neutron Optics: ~ meV Energy deceleration: 10⁻⁹

- Dimension of System
 Scale of System: ~ 50 m
 Resolution: ~ 1 mm
- Calculations
 Beam Transfer, Beam Loss,
 Radiation Shielding,
 Heat of Target and Moderator,
 DPA,
 Activation of air and water,

••••••



Neutron spectrum at 27 m measured with a ⁶Li-glass detector and a C₆D₆ detector

The neutron spectrum is well represented with a 1/v spectrum. The spectrum is also checked with the standard Au capture cross section measured with C₆D₆ detector.



Neutron Spectrum at 22 m measured with a Coaxial Ge + Boron

Examples of γ spectrum and TOF spectrum (without filter)



LANSCE



http://accelconf.web.cern.ch/accelconf/p07/PAPERS/TUPAS062.PDF