APPLICATIONS OF X-BAND 30 MeV LINAC NEUTRON SOURCE TO NUCLEAR MATERIAL ANALYSIS FOR FUKUSHIMA NUCLEAR PLANT ACCIDENT

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Abstract

We plan to use our X-band (11.424GHz) electron linac as a neutron source for the nuclear analysis for the Fukushima nuclear plant accident. Originally we developed the linac for Compton scattering X-ray source. Quantitative material analysis and forensics for nuclear security will start several years later after the safe settlement of the accident is established. For the purpose, we should now accumulate more precise nuclear data of U, Pu, TRU and MA especially in epithermal (0.1-10 eV) neutrons. Therefore, we have decided to suspend the Compton scattering X-ray experiment and move the linac to the core of the experimental nuclear reactor "Yayoi" which is now under the decommission procedure. Due to the compactness of the X-band linac, the RF gun and accelerating tube and other components can be installed in a small space in the core. First we plan to perform the TOF (Time Of Flight) transmission measurement of the total cross sections of the nuclei for 0.1-10 eV neutrons. Therefore, if we adopt a TOF line of less than 10 m, the macro-pulse length of generated neutrons should be shorter than 100 ns. Electron energy, macro-pulse length, power and neutron yield are ~30 MeV, 100 ns – 1 micros, <0.5 kW and $<10^{12}$ n/s, respectively. Optimization of the design of a neutron target (Ta, W, U), TOF line and neutron detector (Ce:LiCAF) of high sensitivity and fast response is underway. Installation, commissioning and measurement starts in 2014. Detailed design and way how to contribute to the analysis of the Fukushima nuclear plant accident will be presented.

INTRODUCTION

We plan to use our X-band electron linac (11.424GHz, 30 MeV) as a neutron source [1, 2] for the nuclear analysis for the Fukushima nuclear plant accident. Originally we developed the linac for Compton scattering X-ray source. Quantitative material analysis and forensics will start several years later after the safe settlement of the accident is established. For the purpose, we should now accumulate more precise nuclear data of U, Pu, TRU and MA especially in epithermal (0.1-10eV) neutrons. Therefore, we have decided to suspend the Compton scattering X-ray experiment and allocate the linac to the core of the experimental nuclear reactor "Yayoi" (see Fig.1) which is now under the decommission procedure. Yayoi is the experimental fast neutron reactor (<1 MeV neutron, 2 kW, 10^{11} neutrons/ cm^2/s), which is now under decommission. Due to the compactness of the X-band linac, it can be installed into the fuel core space. Therefore, we can reuse the whole structure of the reactor and neutron beam-lines. It is becoming more important to maintain the activity as a neutron source facility recently.

Figure 1: Fast Neutron Experimental Reactor "Yayoi" of University of Tokyo.

30 MeV X-BAND (11.424GHz) ELECTRON LINAC

It is basically designed and operated as a Compton scattering monochromatic X-ray source. The X-band linac (see Fig. 2) consists of the 3 MeV thermionic RF gun, solenoid magnet for focusing, α magnet as an energy filter, 700 mm accelerating tube and other components. 50 MW 1 μs X-band klystron and 500 kV modulator are used. $\sim 10^4$ micro-bunches of 20 pC and 1 ps(rms) forms 200 mA for 1 μs and 10 μA in average at 50 Hz. The macro-pulse length can be tuned down to 100 ns. The 3 MeV thermionic RF gun, solenoid magnet and α magnet are adopted for low emittance beam with the radius of 0.1 mm (rms) at the collision point with our YAG laser. However, not low emittance but high average current is crucial as a neutron source. Therefore, the low energy part is replaced with 20 keV thermionic gun and ~5 MeV traveling wave buncher to get ~1 kW beam output.

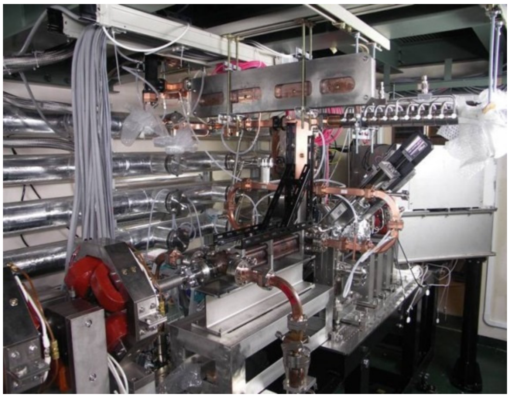


Figure 2: 30 MeV X-band (11.424GHz) Electron Linac.

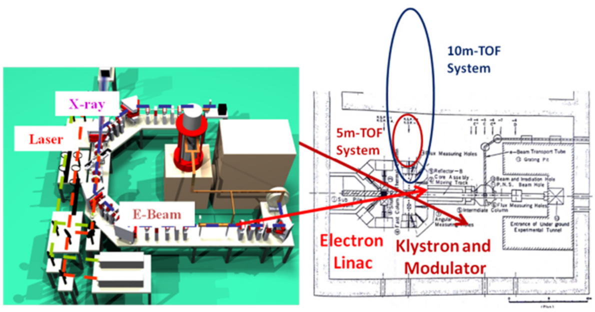


Figure 3: Allocation of the Linac to Yayoi area.

Schematic drawing of shipping and allocation of the linac to the Yayoi area is shown in Fig.3. The linac itself is set in the core space of the reactor and the klystron and modulator are put aside the shielding structure.

DESIGN OF TOF LINE AND DETECTOR FOR FUKUSHIMA NUCLEAR ACCIDENT ANALYSIS

We should prepare more precise nuclear data of U, Pu and related nuclei for the quantitative material analysis and forensics of melted fuel and structural materials. Neutron active method is most promising for the purpose. First we plan to perform the TOF transmission measurement of the total cross sections of the nuclei for 0.1-10eV neutrons (see Fig.4). Uncertainty of the data of Pu in this region contains ~5% [3] while less than 1% for thermal neutrons.

Optimization of the design of a neutron target (Ta, W, depleted U) and moderator, TOF line and neutron detector (Ce:LiCAF) of high sensitivity and fast response is underway. One example of the time-energy relation of neutron obtained by J-PARC is shown in Fig.5. 0.1 – 10eV energy range corresponds to ms time delay at TOF. In order to get this range and resolution at a TOF line of less than 10 m, the pulse length of electron and neutron should be around 100 ns. Electron energy, macro-pulse length, power and neutron yield are ~30 MeV, 100 ns – 1 micros, <0.5 kW and $<10^{12}$ n/s, respectively. Cross section of the updated neutron target design, calculated energy spectra and fluxes by one electron with PHITS for several compositions are depicted in Fig.6. We can observe the enhancement of neutron yield by using DU. Since we want 100 ns neutron pulse, all the time responses do not affect the pulse shape. The target consists of carbon (C), void, polyethylene (PE), depleted Uranium (DU), water (W) and Beryllium (Be) for neutron generation, modulation and finally control of energy spectrum.

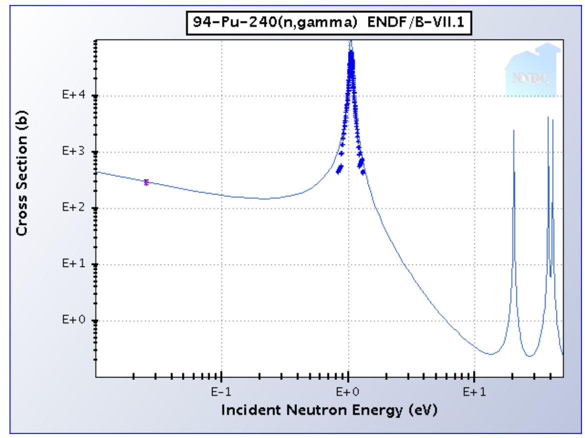


Figure 4: (n ,γ) Cross Section of 94-Pu-240 for 0.1-10 eV Neutron.

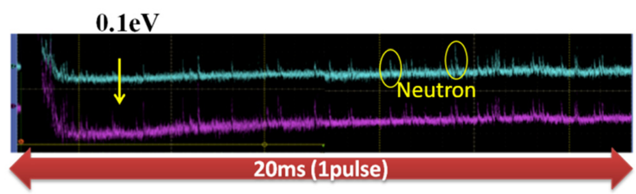
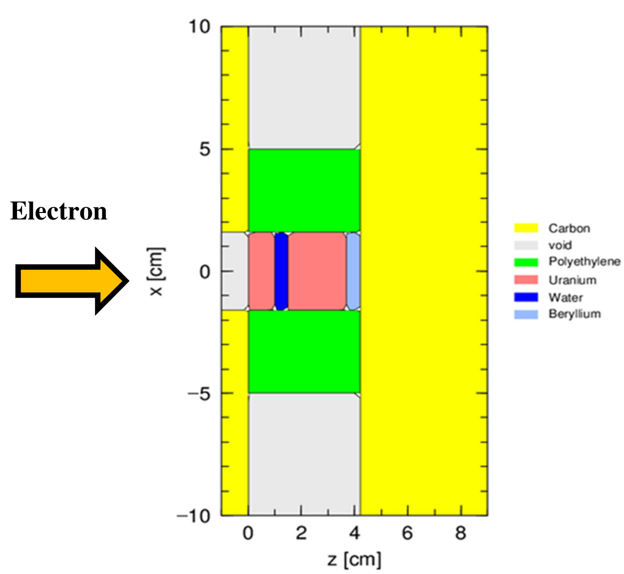


Figure 5: Example of the Time – Energy Relation of Neutron obtained by J-PARC.



(a) Cross Section of the NeutronTarget

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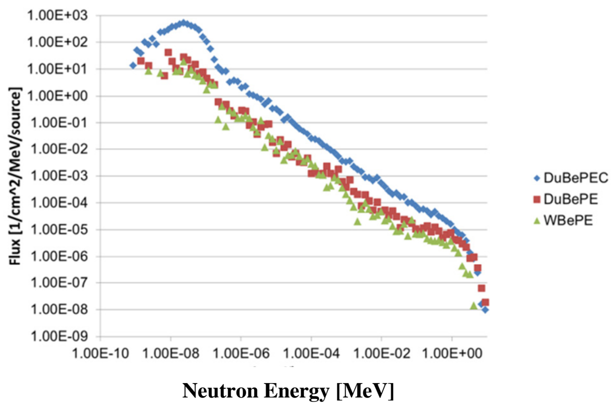
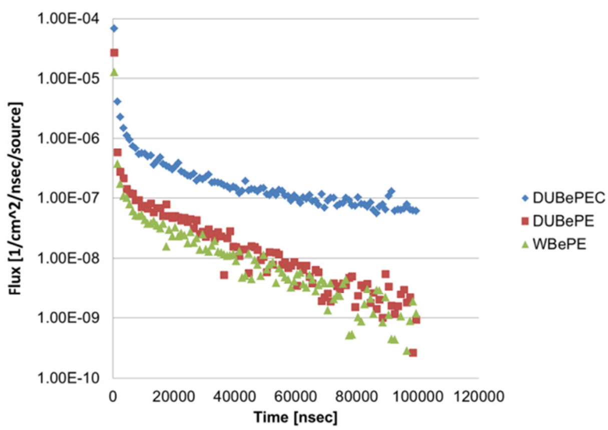


(b) Neutron Energy Spectra



(c) Relative Neutron Fluxes Calculated by PHITS

Figure 6: Neutron Target Design and Calculated Relative Flux.

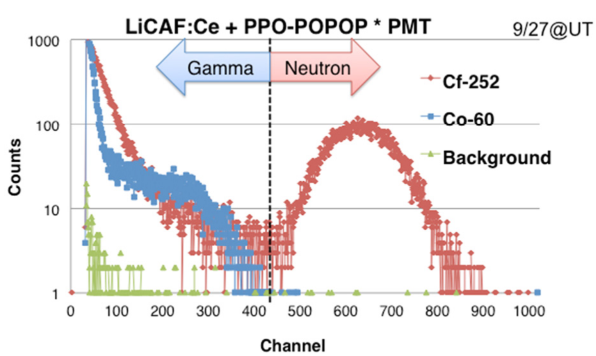


Figure 7: Signals from for Neutrons from Cf-252 and γ–rays from Co-60.

Since the neutron yield for 100 ns short pulse is rather limited, we have to design highly sensitive detector. For the purpose, we adopt Ce:LiCAF as a scintilator. We are developing its detector system. One example of the signals for neutrons from Cf-252 and γ–rays from Co-60 are shown in Fig.6. Moreover, we plan to form a large detection area to enhance the signal intensity. Finally, we expect to realize ~10 times more signal-to-noise ratio compared to a conventional BF_6 detector.

This project has been approved by the Japanese government and funded for 2013 – 2015. Now all components are designed and prepared. Installation, commissioning and measurement starts in 2014. Detailed design and way how to contribute to the analysis of the Fukushima nuclear plant accident will be presented

SUMMARY AND SUBJECTS

We are going to compose the X-band linac based neutron source at the decommissioned experimental reactor "Yayoi" area and start the nuclear data acquisition for Fukushima nuclear accident analysis. Furthermore, 50 kW 30 MeV S-band linac (see Fig.8) is also designed for the on-site neutron active method analysis in Fukushima in future. Expected neutron transmission analysis result by using the precise nuclear data is also attached in Fig.9 [4,5].

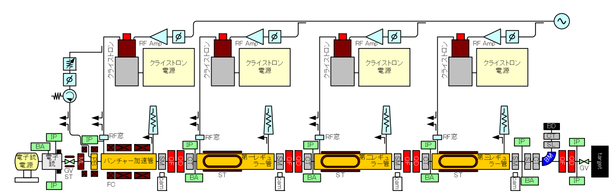


Figure 8: Layout of 60 kW 30 MeV S-band Linac for On-site Neutron Active Method Analysis in Fukushima.

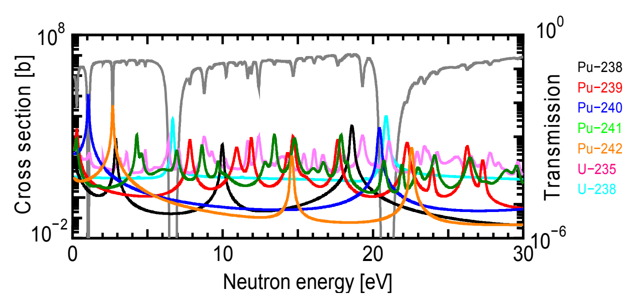


Figure 9: Expected Neutron Transmission Result by Using the Precise Nuclear Data.

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