# DEVELOPMENT OF 3.95 MeV X-BAND LINAC-DRIVEN X-RAY COMBINED NEUTRON SOURCE*

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*Abstract*

The existing non-destructive inspection method employed for concrete structures uses high energy X-rays to detect internal flaws in concrete structures and iron reinforcing rods. In addition to this conventional method, the authors are developing an innovative inspection system that uses a mobile compact linac-driven neutron source that utilizes neutron backscattering, to measure the moisture distribution in concrete structures and estimate the corrosion probability distribution of iron reinforcing rods.

## INTRODUCTION

### *Research Purpose*

During the period of rapid economic growth from the 1950s to the 1970s, Japanese governmental investment in infrastructural projects such as bridges and buildings expanded rapidly. However, most of the industrial and social infrastructure projects had an estimated lifetime of only approximately 50 years, so the declining strength of concrete structures has become an issue of national importance.

From a cost-performance point of view, it is better to carry out on-site non-destructive inspections regularly and repairs as and when needed, rather than demolishing or rebuilding. Non-destructive inspection methods for social infrastructures, aimed at detecting internal flaws in concrete structures and iron rods, have therefore been developed[1]. In addition to the conventional high energy X-ray method, the development of a neutron backscatter moisture detection system using a linear accelerator driven neutron source to measure moisture distribution in concrete structures is now under development. By combining the knowledge of the moisture distribution in concrete structures, the corrosion probability distribution of iron reinforcing rods can be estimated. (Figure 1)

### *Moisture Detection for PC Bridges*

About 60% of the bridges, the most important infrastructures, are concrete bridges, and about 40% of them are prestressed concrete bridges (PC bridges).

A PC bridge has cylindrical structure of iron inside the concrete, and steel wires (PC wire) with tensile stress (prestress) are passed through, thereby giving compressive stress to the entire concrete, and strengthening the whole structure. The PC wires are filled with grout filler and placed under basic conditions, so that a passive film of $Ca(OH)_2$ is formed on the surface of the PC wires that prevents internal corrosion. This passive film is destroyed by neutralization due to $CO_2$ invasion into the concrete. Corrosion of the wire is caused by moisture penetration in the grout unloaded part due to initial construction failure, leading to deterioration of the concrete (Figure 2). Therefore, it is important to acquire internal moisture distribution information for the soundness evaluation of concrete structures, but it is not yet realized in non-destructive inspection technology usable on site.

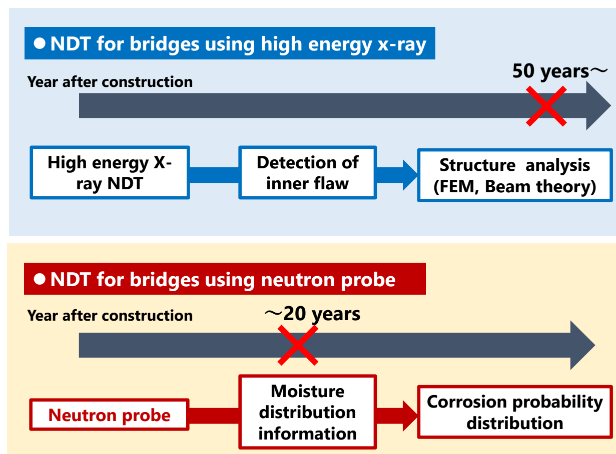


Figure 1: Applications of X-ray source and neutron source in NDT of social infrastructure.

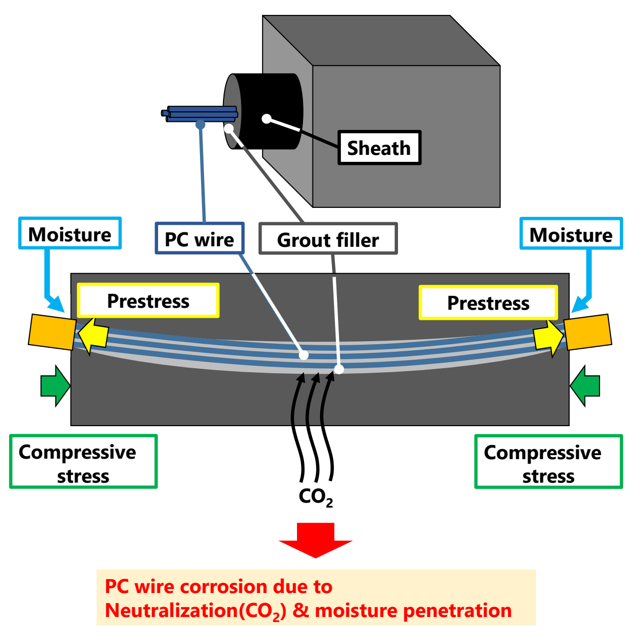


Figure 2: Description of prestressed concrete structure.

## DESCRIPTION OF NEUTRON SOURCE

### *Target Design*

Beryllium $^9$Be, having the lowest threshold energy for photo-nuclear reaction $^9$Be(γ, n)$^8$Be$^*$, is used in a mobile linac-driven neutron source, as designed by an Italian group in the previous study [2]. A beryllium photo-neutron target has been combined with a lead beam collimator, a boric acid resin layer for neutron shielding, and a lead layer for γ-ray shielding (Figure 3). The $^9$Be target and the 3.95 MV mobile X-ray source together comprise the mobile neutron source system (Figure 4). Since mainly fast neutrons are used in the neutron source, a beam line using a high-Z material that does not moderate the neutrons is used. Optimization of the beryllium target size and neutron/γ-ray shielding simulation is performed using the Monte-Carlo code.

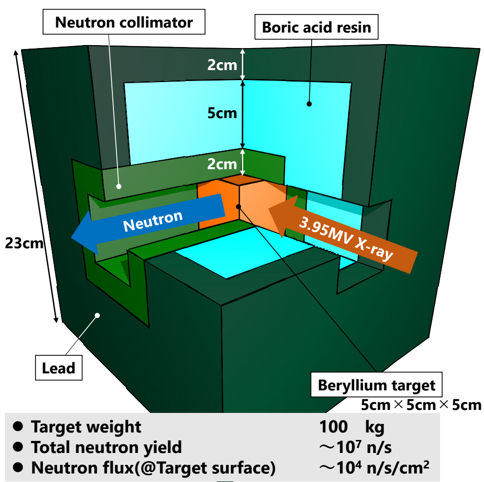


Figure 3: Description of neutron source.

### *Neutron Yield and Energy Distribution*

The calculated neutron yield in the neutron source is approximately ~$10^7$ n/s. The target weight is about 100 kg, which is manageable by manpower. Radiation safety is satisfactory as well. The distribution of neutron energy produced is shown in Figure 5.

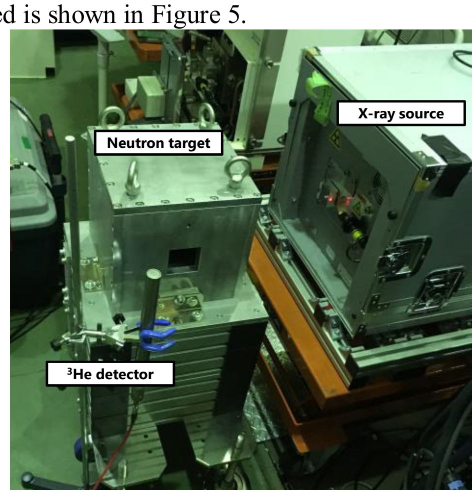


Figure 4: Neutron source setup.

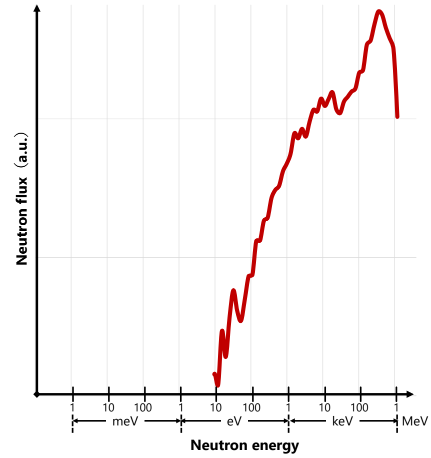


Figure 5: Produced neutron energy distribution.

## MOISTURE DETECTION USING BACKSCATTER NEUTRON

### *Detection Principle*

Moisture detection using neutrons is performed by irradiating concrete with fast neutrons and detecting backscattered moderated neutrons due to multiple elastic scattering with light elements especially hydrogen nuclei.

The substance used for neutron detection including $^3$He has a high reaction cross section with neutrons in the thermal region, and therefore the count of detectors increases with the existence of moisture (Figure 6).

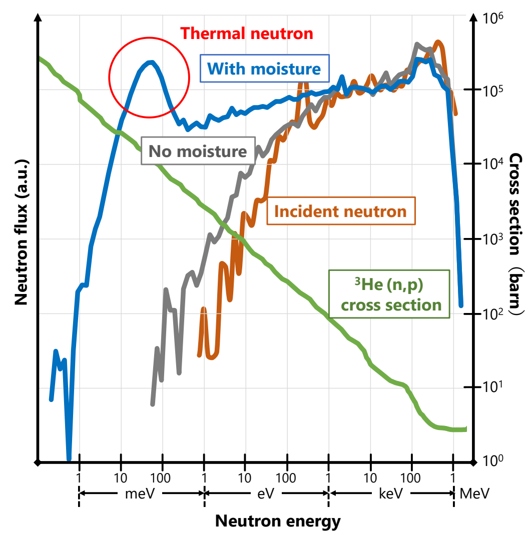


Figure 6: Backscatter neutron energy (with and without water), incident neutron energy and $^3$He(n,p) cross section.

### *Moisture Detection Experiment of PC Concrete Sample*

Moisture detection experiments simulating immersion of PC wire duct in bridges were also conducted (Figure 7). 100 g of water was placed in a concrete sample having a cylindrical sheath structure at a depth of 10 cm in the concrete, and the measurement was performed. As a result, the measurement was successful with accuracy of 3σ (Figure 8).




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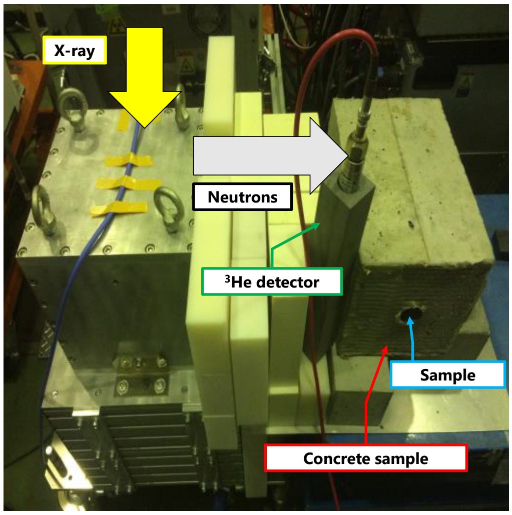


Figure 7: Experiment simulating immersion of PC wire duct.

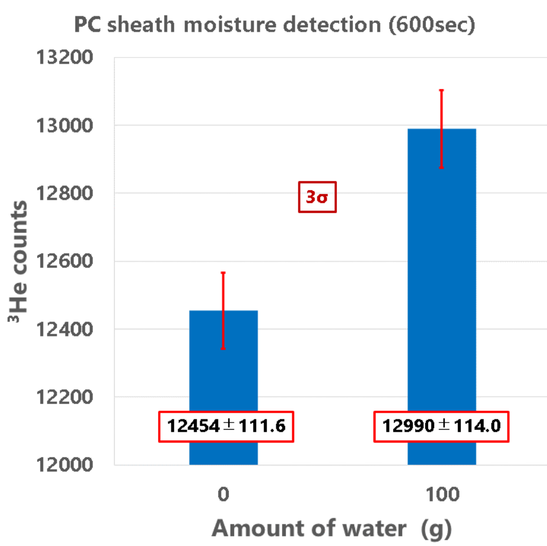


Figure 8: Result of PC sheath moisture detection experiment.

### *Concrete Moisture Content Measurement*

Concrete moisture content measurement experiment was conducted as a fundamental study for measurement of moisture distribution in concrete structures(Figure 9). Each concrete sample with a water cement ratio (W/C ratio) of 36% and 50% was adjusted to 0% moisture content and 100% moisture content and 600 second-measurement were carried out. As a result, even for concrete samples with different W/C ratios, the difference in neutron detector counts between the moisture content 0% case and 100% case is approximately the same, which means the moisture information is successfully acquired regardless of the formulation of concrete sample itself.(Figure 10)

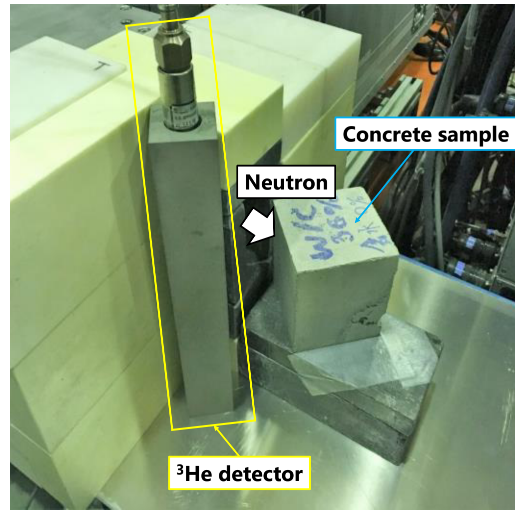


Figure 9: Concrete moisture content measurement setup.

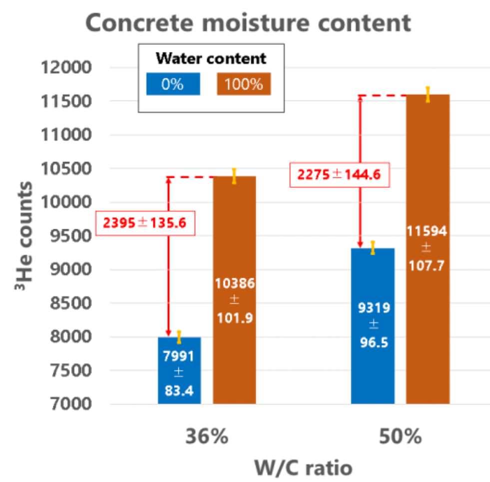


Figure 10: Result of concrete water content measurement experiment.

## CONCLUSION

An experiment simulating flood conditions in actual bridges and a measurement experiment of concrete moisture content - using a mobile linac driven compact neutron source - were carried out.

The development of a measurement system using neutron energy information by TOF to improve inspection accuracy is now under development. The first outdoor actual bridge test using an accelerator driven neutron source will also be conducted in this fall.

## ACKNOWLEDGEMENT

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