NSC KIPT NEUTRON SOURCE ON THE BASE OF SUBCRITICAL ASSEMBLY DRIVEN WITH ELECTRON LINEAR ACCELERATOR

A. Y. Zelinsky, O. Bezditko, P. O. Demchenko, I. Karnaukhov, V. Oleinik, F. Peev, I. Ushakov, O. Vodin , NSC KIPT, Kharkov, Ukraine
Y. Gohar, ANL, Argonne, IL 60439, USA

Abstract

National Science Center "Kharkov Institute of Physics and Technology" (NSC KIPT, Kharkov, Ukraine) together with Argonne National Laboratory (ANL, USA) developed the conceptual project of a neutron source based on the sub-critical assembly driven by electron linear accelerator. The main functions of the subcritical assembly are support of the nuclear industry and medical researches. Reactor physics and material researches will be carried out at the facility. For subcritical assembly design proven techniques and practices are used to enhance its utilization. The goal of the development is to create in Ukraine the experimental basis for neutron research based on safe intensive sources of neutrons. The main facility components are an electron linear accelerator, a system for electron beam transportation from linear accelerator to the neutron production target, subcritical assembly, biological shield, neutron channels and auxiliary supporting systems.

INTRODUCTION

An experimental nuclear facility the neutron source (NS) on the base of subcritical assembly driven with linear electron accelerator is under design and construction in NSC KIPT, Kharkov, Ukraine as an international collaborative project of NSC KIPT and Argon National Laboratory (ANL), Chicago, USA. The source is oriented at scientific investigations and applications in nuclear physics, solid state physics, biology, generation of medical isotopes, radionuclide transmutations.

The very principle of intense neutron flux generation in the facility is the multiplication of the initial source neutrons in a medium of a fissionable material. A geometry and mass of the material is chosen to provide neutron multiplication constant value k_{eff} less then 0.98 (k_{eff}≤0,98) at any initial event. So, the multiplying medium is *subcritical assembly* (SA). The value of the neutron flux Φ (n/cm^2·s) in the NS can be changed with intensity of initial neutron source Q_0 (n/s) and the total number of generated neutrons per second is $Q_0/(1-k_{eff})$.

The photonuclear source was chosen as an initial neutron source of the SA. In the source neutrons are generated at irradiation of heavy metal target (*W, U*) with hard γ-radiation with quanta energies above the edge of the photo-nuclear reactions ((γ,n), ($\gamma,2n$), ($\gamma,3n$), (γ,f) etc). To generate initial neutrons one uses the γ-radiation of an 100 MeV electron linear accelerator beam with average current of 1 mA that bombards the target. During the bombarding of uranium target, the output of the neutrons is about δ_n≈5% per one bombarding electron. For the tungsten target the efficiency of the neutron generation is as much as twice lower.

The electron linear accelerator, driver of the SA, is under manufacture in Institute of High Energy Physics (IHEP), Beijing, China [1].

The main NS characteristics are presented in Table 1.

Table 1: NS Characteristics

Parameters	Value
Electron energy, MeV	100
Electron beam average power, kW	100
Neutron generating target	U, W
Target photo neutron output, n/s	3,01·10^{14} (U-target) 1,88·10^{14} (W-target)
Neutron multiplication constant k_{eff}	Not more then 0,98
Fissionable material of the core	Low enriched uranium with 19,7% of ^{235}U isotope
Neutron reflector	Two zone: intrinsic zone is beryllium, outside zone is graphite
Moderator, coolant	Demineralised water (H_2O)
Neutron flux at the core, n/cm^2·s	1,95·10^{13} (U-target) 1,14·10^{13} (W-target)
Energy release, kW	192 (U-target) 131 (W-target)

The SA core is a set of fuel elements of WWR-M2 type by the TVEL corporation production (Russia) of low enriched uranium (19,7% ^{235}U). The fuel is finely dispersed uranium dioxide UO_2 that is uniformly distributed in aluminium matrix. The main fissions of actinides are produced with thermal neutrons.

NS DESIGN

The described Neutron Source involves the complex of buildings and constructions for the technological equipment for generating and use neutrons, operation and scientific personal. The facility consists of:

- Linear accelerator,
- Electron beam transportation channel;
- Neutron generating target.
- Subcritical assembly,
- System of the neutron channels,
- Technological systems and equipment.

Below the main technical characteristics and features of the systems and main design solutions are presented.

ISBN 978-3-95450-122-9

Electron Linear Accelerator

The main design characteristics of the accelerator are presented in Table 2 [1, 2]

Table 2: Accelerator Parameters

Parameter	Value
Electron energy, MeV	100
Average beam current, 1 mA	1
RF frequency, MHz	2856
Repetition rate, Hz	625
Pulse duration, μs	2,7
Pulse current, A	0.6-0.8
Energy spread, %	1-3
Emittance, m·rad	$5{\cdot}10^{-7}$
Pulse/average klystron power	30 MW/50 кW
Accelerating wave type	2π/3
Accelerating section length, m	1,33
Number of accelerating sections	10
Total accelerator length, m	24,5

The accelerator includes the injector part with triode electron gun of 120 keV beam energy and up to 2 A pulse current, pre-buncher, buncher and injector accelerating section, 4-magnet chicane and 9 accelerating sections with focusing triplets between each two sections.

The energy increasing in each section is about 10 MeV at RF power of 10 MW. The wave type in the sections is 2π/3. The length of each section is 1,33 m.

Focusing of the beam in the first injector accelerating section is made with longitudinal magnetic field of solenoids. Along the main part of the accelerator 5 sets of quadrupole triplets provide the transverse beam focusing.

RF power supply of the accelerator is provided with 6 RF-sources on the base of Toshiba E37311 klystron with RF frequency of 2856 MHz, 30 MW pulse power and average power of 50 kW. The first klystron supplies pre-buncher, buncher and the first accelerating section.

To decrease the beam losses along the accelerator and transportation channel and, therefore, the level of the equipment irradiation the four magnet dipole chicane (energy filter) with collimator is used. The chicane is installed after the first accelerating section and operates with electron beam of 12 MeV [1].

Neutron Generating Target

The design of the target was chosen on the base of numerical simulations with optimization of the target geometry, sizes and construction features. The main requirements to the target design are to get the maximal neutron output, taking into account the effect of the neutron absorption in the target; target cooling of 100 kW of the electron beam power without boiling of the coolant; thermal and vacuum strength.

In Fig. 1 the longitudinal and transverse cross sections of the uranium target are presented. The target consists of the square plate set of 68×68 mm transverse sizes and total thickness of 80 mm.

The thicknesses of the separate plates were chosen taking into account distribution of the heat release volume density at electron slowing-down in the target and the requirement to provide target cooling. The water is pumped along 2 mm gaps between target plates (Fig. 1).

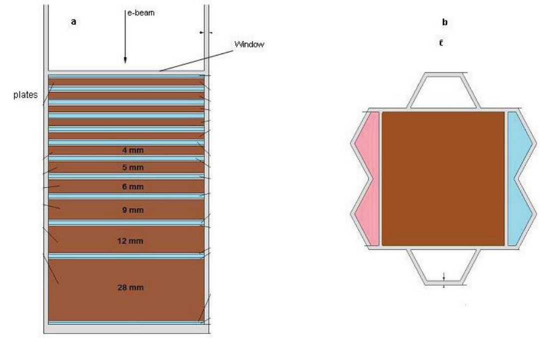

Figure 1: Longitudinal (a) and transversal (b) cross sections of the target.

To eliminate the cooling water contamination by radioactive corrosion products the target plates are covered with protection layer of aluminum of 0.2 mm thickness.

Aluminium alloy window that is cooled with water (Fig. 1) is an interface between vacuum channel of the target construction and the neutron generating target.

The housing of the target is made of aluminum alloy. The target construction is connected to the electron beam guide with flange connections.

Subcritical Assembly

The thermal neutron subcritical assembly multiplies the initial photo neutrons as a result of uranium-235 fission. The subcritical assembly includes tank, fission core, moderator, reflector, coolant.

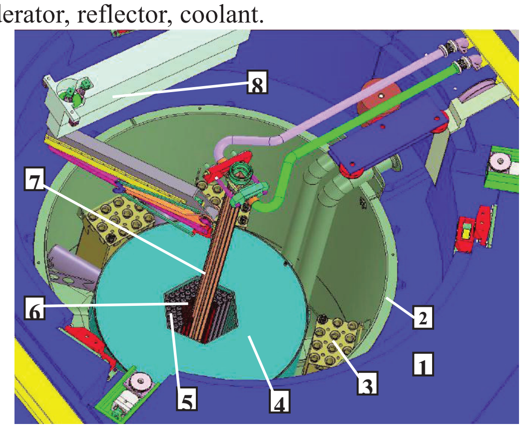

Figure 2: 3-D Subcritical Assembly model: 1-radiation shielding, 2 – SA tank, 3 - fuel shelves, 4 – graphite reflector, 5 – beryllium reflector, 6 - core, 7 - target, 8 – fuel machine.

The structure of the subcritical assembly is similar to a construction of research reactors on the base of thermal neutrons. The differences of subcritical assembly from research reactors are the following:

- Absence of neutron absorbers that can be mechanical removed or insert into the core during reactor start or for power regulation;

ISBN 978-3-95450-122-9

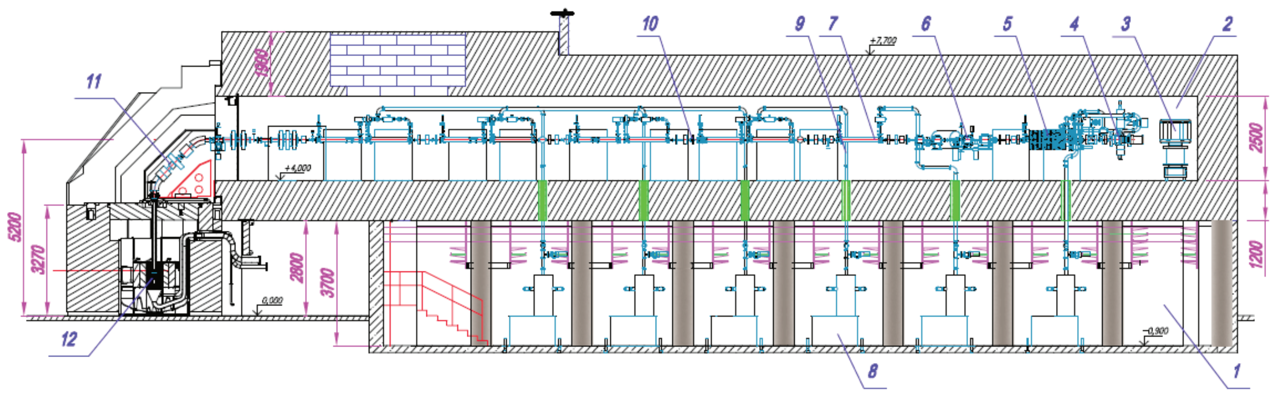

Figure 3: Layout of the accelerator and subcritical assembly systems: 1 – klystron gallery, 2 – accelerator tunnel, 3 – electron gun power supply, 4 – injector part of the accelerator, 5 – the first accelerating section, 6 - chicane, 7 – accelerating section, 8 - klystron, 9 – wave guide, 10 – quadrupole triplet, 11 - electron beam transportation channel, 12 – subcritical assembly.

- At k_{eff}≤0,98 the absence of fast neutron absorbers for alarm suppression of self sustain chain reaction (safety system);
- Neutron generating target.

3-D-model of the subcritical assembly is shown in Fig. 2. SA is assembled in tank 1 of 2 m diameter and 2.2 m height and made of aluminium alloy. The tank is filled with demineralised water.

Heat release fuel rods 6 are installed around neutron generating target 7, formatting the core of hexagonal shape.

The reflector consists of two zones. The first zone is next to core of SA. This zone is assembled with few rows of beryllium, hexagonal rods 5 with sizes of the fuel rods. The second zone is the cylindrical block 4 of reactor graphite with 1,84 g/cm^3 density. The diameter of the reflector is about 1,2 m, the height is 0,7 m. In the hexagonal will of the cylindrical reflector the neutron generating target, core and beryllium reflector are set. Graphite reflector is covered with aluminium case.

SA is surrounded with radiation shielding 1 (Fig.2) of 1.4 m minimal thickness of heavy concrete with 4,8 g/cm^3 density [2]. In Fig. 2 the layout of the target and SA cooling system pipes is shown.

The Facility Layout

The facility is constructed at NSC KIPT and has separate building that includes experimental hall, laboratory and accelerator buildings.

In the centre of the experimental hall there is SA with radiation shielding of a heavy concrete. Six neutron channels with experimental stations will be used for experiments with intense neutron beams. The experimental equipment includes the following: quasielastic scattering spectrometer, biological box, equipment of neutron-activation analysis, cold neutron spectrometer, three axes spectrometer, powder diffractometer.

The layout of the neutron generator facility is shown in Fig. 3.

At the first floor of the accelerator building there is a klystron gallery with RF power supply systems for the accelerator, power supply equipment for the accelerator magnetic elements and beam instrumentation system.

The accelerator is installed at the second floor. There is the transportation channel to pass the electron beam from the accelerator to the neutron generating target. The transportation channel includes two electromagnetic dipole magnets, six quadrupole lenses, beam scanning system to provide uniform electron beam distribution at the surface of the target, electron beam energy spread measurement equipment and other beam diagnostic elements [1].

Radiation shielding above SA is movable to provide access for the transportation channel and target maintenance.

CONCLUSION

Till now the conceptual project and working design project of the NSC KIPT Neutron Source on the base of subcritical assembly are designed and developed. The state expertise of the project has been carried out in compliance with State Ukraine Nuclear Regulation, Sanitary and Environment legislation. The construction of the Neutron Source has been started. The linear accelerator, cooling systems, elements of subcritical assembly, fuel machine and other technological systems are under manufacturing. It is supposed to start the facility operation in May 2014.

REFERENCES

[1] Y. Chi et al., “Design Studies on 100MeV/100kW Electron Linac for NSC KIPT Neutron Source on the Base of Subcritical Assembly Driven by Linac,” IPAC2011, San Sebastián, September, 2011, TUPC034, p. 1075 (2011); http://www.JACoW.org

[2] Z. Zhong et al., Nuclear Technology, 168 (2009) 871.

ISBN 978-3-95450-122-9