

Physical Startup of the First Stage of IREN Facility

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Abstract

The full-scale scientific research complex IREN will comprise a 200-MeV linear accelerator LUE-200 with a beam power about 10 kW, a subcritical multiplying target, and beam infrastructure with experimental pavilions, as well as technological, control, safety and service systems. The characteristics of the full-scale complex IREN (integral neutron yield 10^{15} n/s and pulse width 0.6 μ s) will allow it to rank among the best neutron sources of such class GELINA (Belgium) and ORELA (USA). The realization of the project is conducted in several stages. The first stage includes the construction of the LUE-200 linear accelerator and nonmultiplying target. This will make possible to carry out experiments which require precision neutron spectroscopy in the energy range from fractions of eV to hundreds of eV already at the first stage of IREN. The results of the physical start-up of the first stage of IREN facility at the Frank Laboratory of Neutron Physics of the Joint Institute for Nuclear Research are presented. General scheme and current status of the electron linac are described. Achieved parameters are: pulsed electron beam current – 2.0 A; electron energy – 30 MeV; pulse width – 100 ns; repetition rate – 25 Hz; integral neutron yield $(3\div 5)\cdot 10^{10}$ n/s.

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1. Introduction

Linear electron accelerator LUE-200 [1, 2] was designed at the Budker Institute of Nuclear Physics of Siberian branch of RAS (Novosibirsk) as the driver for intense resonance neutron source IREN [3].

Accelerator consists of the pulsed electron gun, accelerating system, RF power supply system based on 10-cm range klystrons with modulators, beam focusing and transport system including wide aperture magnetic spectrometer and vacuum system. Accelerator is allocated vertically inside 3-floors building (Figure 1). Its designed parameters are listed in Table 1. The realization of the project is conducted in several stages. The first stage includes the construction of the LUE-200 linear accelerator and nonmultiplying target. This will make possible to carry out experiments which require precision neutron spectroscopy in the energy range from fractions of eV to hundreds of keV already at the first stage of IREN.

The first stage of IREN facility now is putting into operation. At the beginning the nonmultiplying neutron producing target will be used.

Table 1. LUE-200 designed parameters

Parameter	Value
Maximal electron energy, MeV	200
Pulse beam current, A	1.5 – 2.0
Accelerated electron pulse width, ns	≤ 250
Repetition rate, Hz	150
Accelerating rate, MeV/m	35
Beam power, kW	9 – 12

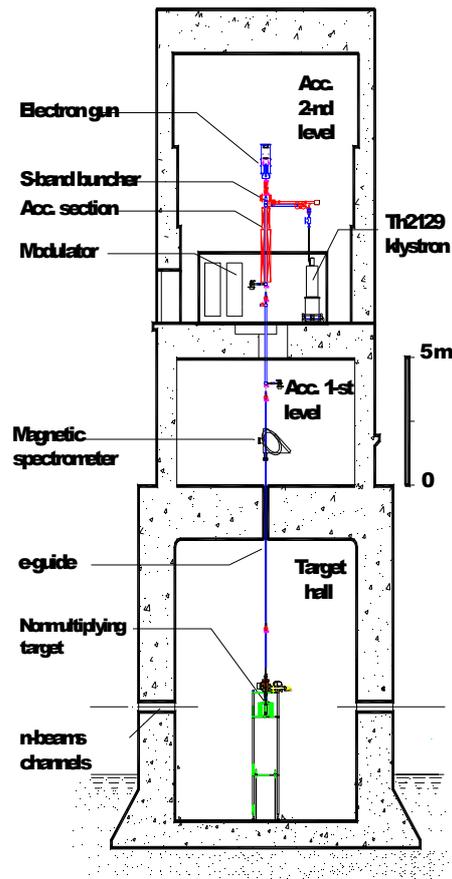


Figure 1: IREN first stage general layout

2. IREN facility components

2.1. Electron source

LUE-200 electron source is the 2-electrode electron gun with 12 mm diameter oxide thermocathode. Cathode is fed by 200 kV pulsed transformer. The anode – wall of the vacuum chamber with hole 43 mm in diameter closed with wire frame made of stainless steel. Electron gun provides pulsed electron beam with 8 A peak current, 250-300 ns duration, 50 Hz repetition rate and $\leq 0.01 \cdot \pi \cdot \text{cm} \cdot \text{mrad}$ emittance.

2.2. Accelerating system

Accelerating system consists of the RF buncher and 2 short (3 meters long) accelerating sections with high acceleration rate. Accelerating sections were designed and manufactured at BINP (Novosibirsk). Accelerating section represents the circular blinded waveguide with constant impedance fed by RF power. RF power comes from klystrons – RF power amplifiers of 10-cm frequency range (2856 MHz). The prototype of the accelerating system was tested at foreinjector of the VEPP-5 complex of BINP. During the tests the maximal electric field 45 MV/m and average accelerating rate 35 MeV/m were achieved [4].

Full scale accelerator project foresees two accelerating sections. At present one accelerating section is used the second one is replaced with drift section surrounded by two quadruple lenses doublets.

2.3. RF power supply

As the optimal RF power supply for LUE-200 accelerator the SLAC 5045 were chosen providing peak RF power 60 MW at average level 45 kW. RF power compression system is introduced to provide 3-4 times gain in RF power transfer to the accelerating section providing average accelerating rate up to 35 MeV/m. Main components of the RF system of the accelerator are: two-channel high frequency driving generator with possibility to set 180 degrees phase shift between channels and fast phase reversal; two RF preamplifiers for klystrons actuation; two power compression systems; waveguides, couplers etc.

At present due to the absence of SLAC 5045 klystrons only one accelerating section was put into operation with TH2129 (Thomson) klystron providing 20 MW peak power.

2.4. Beam focusing and transport system

Beam focusing and transport system provides beam transporting and trajectory correction on the way from electron gun to the nonmultiplying neutron producing target. From electron gun to the RF buncher 3 short solenoidal magnetic lenses are focusing electron beam. Inside RF buncher and first accelerating section the beam transports due to the continuous solenoidal magnetic field provided with “short” and “long” solenoids enveloping accelerating section.

Beam transportation from the exit of accelerating section to the nonmultiplying target is provided with one separate quadruple lens, four doublets of the wide-aperture quadruple lenses and six correcting magnets distributed along the electron guide.

2.5. Nonmultiplying neutron producing target

Neutron producing target is produced with tungsten based alloy and represents cylinder 40 mm in diameter and 100 mm height spaced within aluminum can 160 mm in diameter and 200 mm height. Distilled water is circulated inside can, providing target cooling and neutron moderation. Water layer thickness in radial direction is 50 mm. Target dimensions and water moderator thickness were optimized with Monte Carlo simulation. Simulation result for neutron flux density at 10 meters flight path is shown at Figure 2.

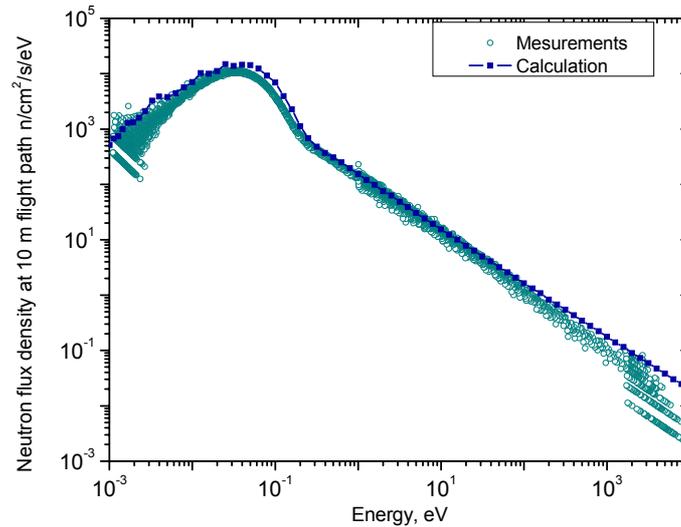


Figure 2: Neutron flux density at 10 m flight path of IREN source. Calculated (solid squares) and measured (open circles).

Accelerated electrons are penetrating inside the can through beryllium window 1 mm thick and hit the top surface of the target cylinder. One thermocouple is placed in the center of the exposed face of the target.

Neutrons are produced in the target with double stage process. At the first stage accelerated electrons stop in the target producing Bremsstrahlung gamma quanta. Energy spectrum of the gamma quanta is limited from above with the maximal energy of the accelerated electrons. At the second stage gamma quanta interacting with tungsten nuclei and neutrons are produced in reactions ${}^A W(\gamma, n) {}^{A-1} W$, ${}^A W(\gamma, 2n) {}^{A-2} W$, ${}^A W(\gamma, 3n) {}^{A-3} W$.

3. Beam adjustment and transportation

Accelerator startup was carried out by subsequent adjustment of the electron gun, components of beam focusing and transportation system and accelerating system.

During accelerator startup the beam parameters were tested at five diagnostic stations distributed along accelerator: after the electron gun, on the exit from accelerating section, at the end of the drift section, after magnetic spectrometer and in front of the target. Each diagnostic station includes: magnetic induction sensors of the beam current – Rogowski loop; beam viewer – luminescent screen with CCD camera; secondary emission wire frame profilometer. These tools let one to measure beam current and its position in each pulse.

As a result of the optimization of the operational modes of the accelerating and focusing systems at 5 A peak current from electron gun the peak current on the exit from accelerating section reaches 2.2 A and peak current on the target on the level 1.6 A.

4. Measurements of the accelerated electrons spectra

To measure the spectra of the accelerated electrons the broadband magnetostatic analyzer with magnetic field perpendicular to the beam direction was used. Magnet E-core with the variable magnetic rigidity 0.166 – 0.7 T·m is placed after the drift section. Electron beam in the spectrometer magnetic field is turned up to 90 degrees and extracted from the spectrometer vacuum chamber through 50 microns stainless steel window. Thereupon turned electrons hit the position sensitive detector which make it possible to measure electron energy with accuracy $\frac{\Delta E}{E} \leq 5\%$.

Electron spectra were measured at different modes of operation of the electron gun and RF power compression system. Peak current on the exit from the accelerating section varies from 0.7 A up to 2.6 A. It was found that when RF power compression system is off the maximum of the accelerated electron spectra is between 18 MeV and 20 MeV. When RF power compression system is on the maximum of the accelerated electron spectra is between 27 MeV and 31 MeV. Typical beam spectrum is visualized at Figure 3.

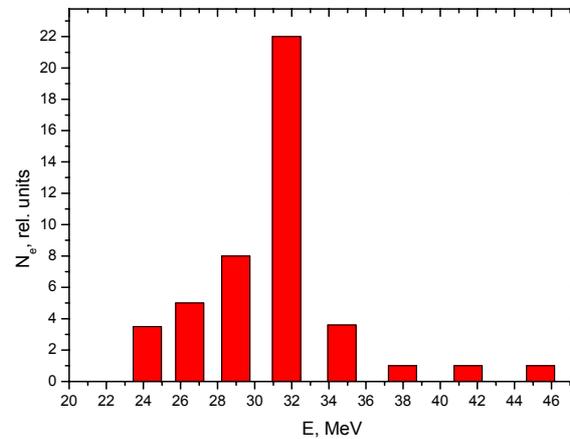


Figure 3: IREN electron beam spectra. Electron gun peak current 4 A, accelerated beam current 1 A, power compression system is on.

5. Estimation of the neutron yield and extracted neutron beam parameters

Actual beam parameters achieved at the middle of 2009 were: average energy of the accelerated electrons – 30 MeV; peak beam current – 1.5 A; electron pulse width 100 ns; repetition rate 25 Hz.

Estimation of the integral neutron yield realized by measurements of the neutron flux density at 10 meters distance from the target by means of the ³He gaseous proportional counter SNM-16 (see Figure 2) and also with the set of activation detectors positioned on the side surface of the target can. The pressure of the ³He in SNM-16 was measured beforehand by the method of transmission of the collimated neutron beam through the counter and amounts 4.3 bar. The results of the estimation of the neutron yield for abovementioned parameters obtained with two methods are in a good agreement and amount to the value of neutron yield $(3 - 5) \cdot 10^{10}$ n/s. Corresponding neutron flux density at 10 meters from the target (shortest flight path) amounts $(2.4 - 4) \cdot 10^3$ n/cm²·s.

To estimate the parameters of the extracted neutron beam the experiment on transmission of the neutrons through tantalum and indium filter samples 2 mm thick was performed. These elements have strong resonances in total cross sections in the energy region from eV to keV. Neutrons passed through the samples were detected with SNM-16 counter and another ³He detector SHVAPS 38 cm in diameter and 53 cm long with 1 bar ³He pressure. Time of flight spectra were registered by the DAQ system with minimal time channel width 20.83 ns. The results are presented at Figure 4.

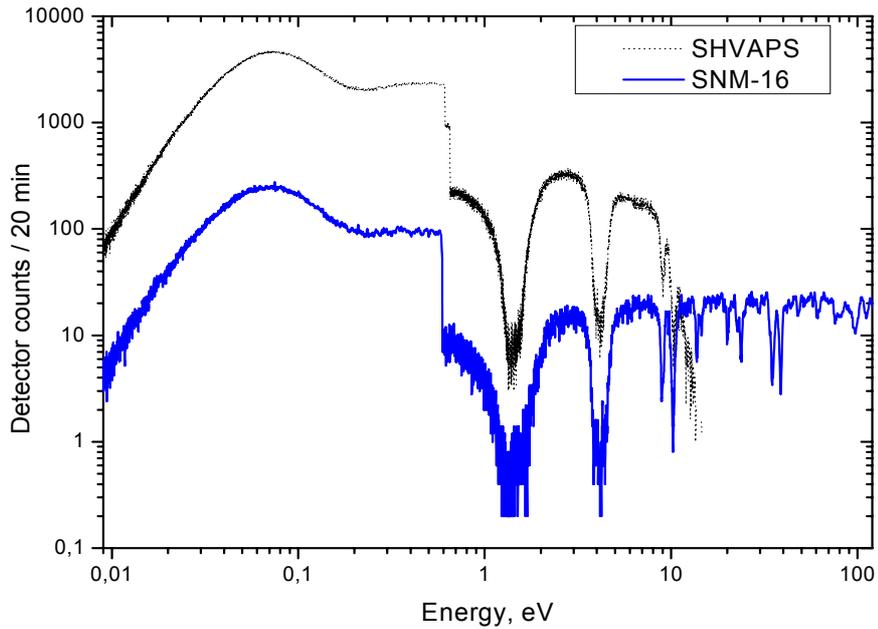


Figure 4: Transmission curves for two filters (Ta + In). Exposition – 20 minutes. Flight path – 9.3 m. Time channel widths in the energy range below 0.5 eV – 10 μ s, above 0.5 eV – 2 μ s.

To compare the energy resolution of the IREN source with our old IBR-30 + LUE-40 complex the experiment on measurements of the capture gamma quanta from tantalum was performed. Large volume liquid scintillator detector consisting of 6 sections 20 liters each was placed at 60 meters flight path. Tantalum sample was installed inside the detector. Raw experimental data are presented at Figure 5. One can see valuable improvement of the energy resolution in the neutron energy range above 10 eV.

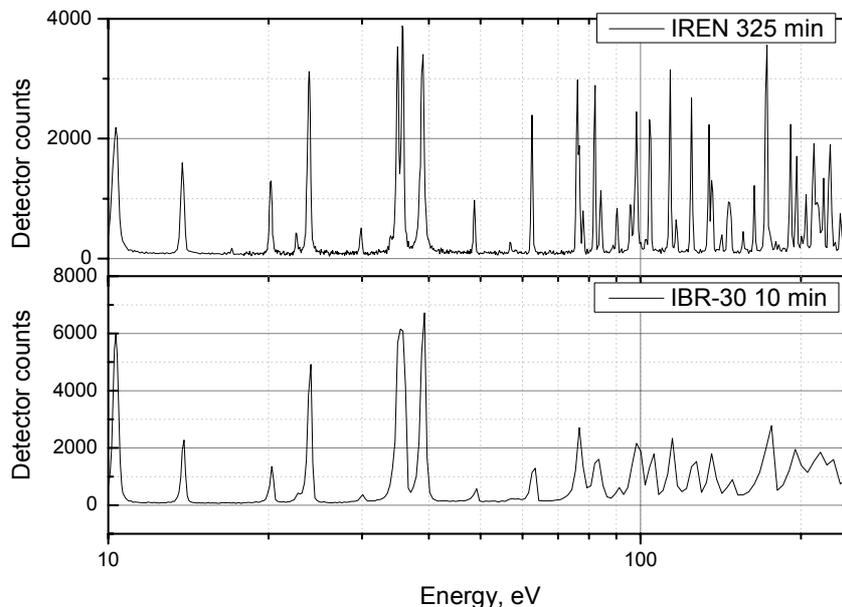


Figure 5: Liquid scintillator detector counts vs neutron energy for IBR-30 and IREN.

6. Conclusion

Physical start up of the first stage of IREN facility was performed at the beginning of 2009. Actual parameters achieved at the middle of 2009 are: average energy of the accelerated electrons – 30 MeV; peak beam current – 1.5 A; electron pulse width 100 ns; repetition rate 25 Hz; neutron yield $(3 - 5) \cdot 10^{10}$ n/s. Extracted beam parameters were estimated within the set of test experiments.

The upgrade of the facility with more powerful klystrons and modulators to reach the designed parameters is planned for the period 2010 – 2015.

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