6 - 16 Research Activities of Nuclear Safety and Nuclear Data Group in 2022

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In 2022, the main research activities of Nuclear Safety and Nuclear Data Group were focused on nuclear and radiation safety, nuclear data measurements and calculations for CiADS and medical isotopes programs, and fundamental research in heavy ion reactions. Some important results have been obtained.

The final design of radiation protection system in the civil engineering design stage for CiADS accelerator and supporting facilities has been completed. It provided technical support for drawing, bidding and construction of civil engineering construction. The radiation source term analyses for CiADS reactor-target coupling area and radioactive waste have been preliminarily finished. The technical supports for the equipment layout of CiADS reactor-target coupling area and the design of radioactive waste disposal system were provided. The environmental impact assessments of CiADS accelerator and its supporting facilities have been finished. The environmental impact assessment for the first phase of CiADS and Huizhou headquarters test area were officially approved.

For medical isotope project, during 2022, the optimization design tasks of radiation protection and radioactive waste disposal system for each stage of medical isotope project have been completed. The technical supports for the civil construction of Gansu Province isotope laboratory and the application, review and approval of the environmental impact assessment of CiADS accelerator and its supporting facilities, "14th Five-Year Plan" science and education infrastructure project were provided. The environmental impact assessment, review and approval of the medical isotope (Phase I) project after major changes have been completed.

In nuclear and radiation safety technology research, a number of research works have been carried out, including detection technologies of neutron spectroscopy and radiation dose, experimental analysis of radioactive source term, optimization of radiation shielding calculation methods, and radioactive aerosol monitoring technology. Some of the results have been published or patented.

^{99m}Tc is one of the most commonly used radioisotopes for nuclear medicine diagnostic. As the parent nuclide of ^{99m}Tc, ^{99}Mo is widely used in ^{99}Mo/^{99m}Tc generator system. ^{99m}Tc and ^{99}Mo can be produced by proton induced reactions on natural molybdenum targets. However, there are few experimental values of thick target yields for proton induced reactions on natural molybdenum. The thick target production yields of ^{94m}Tc, ^{95m}Tc, ^{95m}Tc, $^{96m+m}$Tc, ^{99m}Tc and ^{99}Mo radionuclides produced by 8.0∼18.0 MeV proton induced reactions on natural molybdenum targets were obtained[1]. The measurements were carried out at the superconducting linear accelerator of the Institute of Modern Physics, Chinese Academy of Sciences by using the stacked-foil activation technique. The obtained results were compared with the calculation of TALYS-1.95 and FLUKA.

The energy and angular distributions of thick target neutron yields (TTNY) from α-induced reactions are important for different applications, including ion therapy, shielding of accelerator facilities, and space radiation protection. However, the thick target neutron yields data from ^{4}He ions are very scarce in the energy range of about 20 MeV/nucleon. The angular and energy distributions of secondary neutrons produced from 26.7 MeV/nucleon ^{4}He ions, stopping in thick Be, C, W and Pb targets are measured by the time-of-flight method[2]. The experiment was performed on the Radioactive Ion Beam Line in Lanzhou (RIBLL) at the Institute of Modern Physics, Chinese Academy of Sciences. The GEANT4, PHITS, and FLUKA Monte Carlo simulation codes with different physics models are employed to simulate the neutron yields and the results are compared with the experimental data.

Intermediate energy proton induced reactions are very important for a wide range of applications including the activation study for advanced nuclear systems, such as Accelerator Driven Sub-critical systems (ADSs), medical isotope production, radiation therapy, radiation and shielding effects in space. As the basic structural material of various types of reactors and accelerators, stainless steel with iron as the main component is an ideal material in terms of utilization, physics, chemistry, and mechanics. In particular for ADS, stainless steel is widely used in accelerator beam tube and spallation target structural components. Lead-bismuth eutectic is considered an ideal material of spallation target for the primary neutron production. Excitation function of proton induced reactions on iron in the energy range 85∼100 MeV[3], activation cross-sections of proton induced reactions on natural molybdenum within 75∼100 MeV[4], excitation functions of ^{nat}Ni(p, x) reactions in the energy range of 75∼100 MeV[6] and activation cross sections of proton induced reactions on bismuth in the energy range 73∼100 MeV[6] were obtained. The irradiation experiments were carried out at the separated sector cyclotron of the Heavy Ion Research Facility in Lanzhou (HIRFL) by using foil activation methods. Besides, theoretical result of TALYS-1.95 code with default models and evaluated nuclear data of the ENDF/B-VIII.0, PADF-2007 and JENDL-4.0/HE libraries were compared with experimental values.

Neutron induced reactions are very important for ADS and radiation safety. Metal tin or tin alloys play important roles in the application of nuclear technology. Tin is the potential structural material of first wall for a fusion tokamak reactor (Budaev, *et al.*, 2020). Nb_3Sn is used in the superconducting radio frequency cavities due to the excellent performance in acceleration gradient and operating temperature. Cross sections of the ^{112}Sn(n, x)^{111}In, ^{114}Sn(n, 2n)^{113}Sn, ^{nat}Sn(n, x)^{117m}Sn and ^{124}Sn(n, 2n)^{123g}Sn reactions have been measured by using the activation technique at 13.6 MeV neutron energy[7]. The irradiation was carried out at the K-400 Neutron Generator at China Academy of Engineering Physics. The experimental data are compared with the corresponding evaluated nuclear data from the ENDF/B-VIII.0, JENDL-4.0/HE, BROND-3.1, CENDL-3.2 and JEFF-3.3 libraries and TALYS-1.95 calculation.

High energy density physics experiments were performed at nuclear data experimental terminal of HIRFL-CSR at IMP. APD readout $LaBr_3$ and CsI detectors were developed for the measurements of high intensity gamma rays. The energy spectra of gamma rays were measured with or without strong magnetic field (5 T) using 150 MeV/u intense Bi beam bombarded on several targets. The neutron yields were measured with or without strong magnetic field (10 T) using 430 MeV/u ^{78}Kr beam bombarded on several targets by activation method.

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6 - 17 Study on Radiation Field of the Coupling Region in CiADS

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There is complex spatial structure design and radiation source in the coupling region of CiADS, which is also one of the most important areas in radiation protection design. Radiation sources term mainly includes subcritical reactor leaking particles and beam loss particles, this paper adopted "two-step method" to study the radiation field distribution of CiADS in the status of operation and shutdown. Result shows that the high dose rate area (several tens Sv/h) is concentrated in the 2 m space of the center region above the subcritical reactor during operation. Table 1 shows that the radiation dose rate distribution in the personnel detention area under three situations after 6 months continuous running of CiADS.

Table 1 The inducing dose rate (μSv/h) distribution after CiADS shutdown.

Cooling times	1s	2h	1d	7d
Don't remove beam tube and don't increase the shield	1953	1216	411	338
Remove beam tube and don't increase the shield	946	541	77	59
Don't remove beam tube and increase the shield	859	523	91	70

The coupling region of the Compact Intense Accelerator-Driven System (CiADS) exhibits a complex spatial structure design and encompasses significant radiation sources, making it a crucial focal point in the design of radiation protection measures. The primary radiation sources in this region primarily consist of subcritical reactor leaking particles and beam loss particles. To investigate the radiation field distribution of CiADS during operational