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FROM SUPERNOVAE TO RADIOPHARMACEUTICALS: THE ENHANCED ACCELERATORS OF THE LEGNARO LABORATORIES

Understanding the processes that lead to the formation of heavy nuclei in the forging of stars is one of the scientific goals of the INFN's Legnaro National Laboratory (LNL), where the PIAVE (Positive Ion Accelerator for low VElocity ions) and ALPI (Acceleratore Lineare Per Ioni - Linear Ion Accelerator) are installed. In detail, a lead-206 (^{206}Pb) beam has been developed and accelerated at an energy of 1.2 GeV (Giga electron-volts), and then made to interact with a tin-118 (^{118}Sn) target. The lead beam was then used to investigate the reaction between heavy lead ions on tin, and the nuclei generated by this reaction were analysed using PRISMA: a magnetic spectrometer specifically designed and built at the LNL facility to measure in minute detail certain characteristics of the process that results in the production of heavy nuclei, such as the distribution of their mass, their nuclear charge and excitation energy. The nuclei produced were identified using specific detectors, mostly gas detectors, which provide the information that is needed to reconstruct the trajectory of the ions through the magnetic fields of the spectrometer. In recent times, this method has also been used successfully at the LNL facility to study the population of neutron-rich nuclei, by combining PRISMA with high-efficiency gamma ray detectors like CLARA and AGATA: this made it possible to associate the gamma rays, produced during nuclear reactions, with nuclei that had never been studied before. In the ^{206}Pb+^{118}Sn reaction, particular attention was paid to investigating the transfer of pairs of neutrons, which alters the isotopic composition of both the projectile and the target. The importance of this experiment lies in the fact that these processes, which involve pairs of nucleons, provide information about nucleon-nucleon correlations, which is fundamental in order to understand the structural properties of nuclei.
More in general, the use of lead beams and very heavy ions is important in order to study the population of neutron-rich nuclei. The detailed study of the mechanisms involved in the production of these nuclei

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and of their properties has important implications for astrophysics and for understanding the evolution of stars. In certain regions of the table of nuclides there is, in fact, strong competition between the beta decay process, which generates nuclei towards the so-called valley of stability (that contains the more stable nuclei), and the process known as "rapid neutron capture", which leads to the formation of increasingly neutron-rich nuclei in stellar structures, such as supernovae.

The beam used for the experiment was permanently generated by a 14.4 GHz cyclotron resonance source and then accelerated using radio frequency quadrupoles and quarter-wave resonators: all superconducting components, that operate at -269 °C, installed on the PIAVE and ALPI accelerators. Thanks to the combined use of PIAVE and ALPI, much of the measurement, which lasted 10 days, was performed with a beam current of more than 90 nA (nanoamperes). These measurements are the result of a major project to upgrade the superconducting RFQs, which now exceed the specifications for which they were designed and are more reliable. The system for controlling the cryostats and the cooling system of ALPI has also been modernised. The systems used to control beam radio frequency, transport and diagnostics have also been updated, and the accelerator has been aligned with laser technology so that the beam is transported more efficiently along the accelerator.

Many of these improvements have also been made with a view to using ALPI for re-accelerated exotic beams in the future multidisciplinary project at the Legnaro Laboratory, SPES (Selective Production of Exotic Species), which envisages the development of a highly innovative apparatus to generate and accelerate non-stable nuclei on fixed targets. SPES will pave the way for important research in the field of basic physics, to investigate nuclear reactions and nuclear isotopes about which little is known, as well as in other sectors such as the production of radiopharmaceuticals. ■