Exotic Radionuclides from Accelerator Waste for Science and Technology

The inaugural meeting has taken place of a collaboration that proposes to extract and use for research the radioactivity that is generated in accelerator components. The meeting, sponsored by the European Science Foundation, was organized by Dr. Dorothea Schumann, and took place at the Paul Scherrer Institute, Switzerland in November 2006.

Figure 1. *Attendees of the 1st ERAWAST meeting, PSI.*

Exotic radionuclides with comparatively long half-lives are of great interest in many research domains including astrophysics, nuclear structure, nuclear medicine, and geophysics. Radioactive beam facilities are essential tools for investigating these research areas, but using them to produce nuclides in sufficient amounts is both time consuming and expensive. Conventional techniques in commercial radioisotope production—restricted mainly to reactor-based or accelerator-driven production routes—are approaching their limitations and alternative production possibilities should be explored. One possibility is the recycling of highly irradiated particle accelerator components; such is the goal of the Exotic Radionuclides from Accelerator Waste for Science and Technology (ERAWAST) project.

Presently, the focus of this project has been one of the copper beam dumps of the 590 MeV ring-cyclotron located at the Paul Scherrer Institute (PSI). This was irradiated with average of 1.5 mA of protons between 1980 and 1992. Its central, most active, 500 g has been extracted and is now being used for the reclamation of rare isotopes. The meeting was held to provide both a forum for discussion of the many possible uses for this material, as well as an opportunity for researchers to suggest additional projects that would require the future extraction of radionuclides from new sources.

Professor Heinz Gäggeler, head of the research department "Particles and Matter" and Vice-Director of PSI, opened the meeting, describing the PSI facility and its history. With operations since 1970, and the recent development of the Swiss Spallation Neutron Source (SINQ), much radioactivity has built up in various components, such as beam dumps and targets. Just as in the nuclear energy sector, the long-term disposal of nuclear waste is a significant issue, and the possibility of usefully re-using some of the activity is a concept certainly worth exploring. PSI not only has significant quantities of activated materials, but already has fully developed remote handling equipment and some of the most advanced chemical separation expertise in the world. Future possibilities might even include the deliberate irradiation of alternative materials to allow optimized production of required isotopes.

The first session of the meeting focused on the various radionuclide production possibilities. In addition to the present work on the proton irradiated copper beam dump as well as carbon targets, the first irradiated lead targets from the SINQ will be available in the near future. Furthermore, Jörg Neuhausen (PSI) discussed extraction of radionuclides generated by proton-irradiation of mercury (part of EURISOL design study), explaining that in this instance it is necessary to extract this material to assure the target behavior. An exciting possibility is that extracted neutron-rich isotopes could be further exposed to an

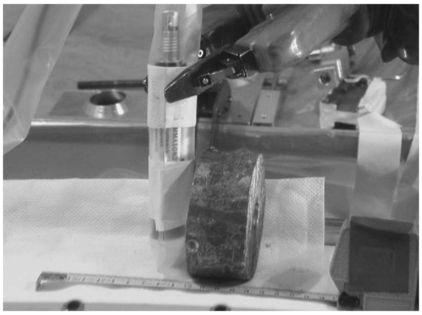

Figure 2. *Part of the copper beam dump from which long lived radioactivity is extracted. The high radiation means remote handling is necessary.*

intense neutron flux at the ILL high-flux reactor. Ulli Köster (ILL) presented the facility, exposures that might be obtained, and instruments that might be used for experiments.

After lunch, the discussion turned to the chemical separation techniques that must be employed. An important precursor to this is an understanding of what radioisotopes are being generated, where they are in the irradiated material, and with what activity they are present. Michael Wohlmuther (PSI) described the development of detailed Monte Carlo models of hadronic showers and secondary neutron irradiation, coupled to a program of experimental validation of results.

Once candidate material has been identified, it is necessary to extract the useful component. Dr. Schumann described how this is achieved by chemical separation, with each case needing to be tailored to the specific application, chemical properties of the isotope of interest, and the material within which it is embedded. Luis Fraile (CERN) discussed the progress on mass separation being made at ISOLDE. Susanta Lahiri (Saha Institute) made a presentation of the possible role of the Saha Institute for Nuclear Physics in the ERAWAST project.

The variety of applications for which these isotopes are to be used clearly illustrates the multidisciplinary nature of this project. The first area discussed was that of nuclear and basic physics. The properties of light exotic nuclei are a major source of interest in nuclear physics research. Recent progress in the production of short-lived nuclei and in the development of radioactive nuclear beams has given this field the necessary tools for detailed studies of some fascinating exotic nuclei. For example, one of the more exciting features of light drip-line nuclei is that they may form a neutron or a proton halo with a dilute mass distribution extending far outside the core of the nucleus. Christopher Geppert (GSI) explained how access to long-lived nuclei from ERAWAST would open new opportunities to explore this promising research area. Angel Sanchez-Benitez (UCL) described efforts to obtain ^{10}Be for acceleration as a beam to explore exotic nuclear structure, whereas Attila Krasznahorkay (ATOMKI) discussed possible studies of loosely bound protons in excited states of ^{44}V and ^{44}Sc.

Two sessions of the meeting addressed the many opportunities that ERAWAST will provide in nuclear astrophysics. The ^{7}Be(p,γ)^{8}B reaction plays a central role in the evaluation of solar neutrino fluxes and in understanding neutrino oscillations and neutrino masses. Michael Hass (Weizmann Institute) showed that, despite numerous measurements, there persists significant need to obtain highly accurate cross-section measurements at low energies. This would be possible with a radioactive ^{7}Be target produced from extracted material. A complementary measurement of the inverse reaction with a ^{7}Be beam could be made at REX-ISOLDE.

Radioactive nuclei are particularly important in explosive stellar environments because a large fraction of the nuclei involved are radioactive. However, meaningful studies require that measurements in the laboratory be compared to an observable astrophysical signature, such as γ-ray emission or observation of isotopic anomalies in meteorites or deep sea deposits. For example, γ-rays at an energy of 1.157 MeV indicate ^{44}Ti production, and may be used as a diagnostic of core collapse supernovae because it is thought that this isotope is formed in the region of the mass-cut—the separation between material ejected into space and that which falls back on to the proto-neutron star. Uncertainty in nuclear reaction rates such as ^{44}Ti(α,p) hinder the necessary comparisons between γ-ray flux and model and thus provides motivation for their determination. Provision of an appropriate beam of ^{44}T is difficult with present ISOL facilities, but, as Alex Murphy (Edinburgh) explained, an approach in which previously collected ^{44}Ti atoms ($t_{1/2} = 60$ yrs) are fed into an off-line ion source appears to be promising.

With a half-life 1.5×10^{6} yr, ^{60}Fe is another particularly interesting astrophysical radioisotope. It has recently been detected in deep sea sediments indicating that the Earth may have been bombarded by debris from a nearby supernova, but whether supernovae or AGBs are the main source of ^{60}Fe in the Galaxy is still an open question. Franz Käppeler (FZK) showed that it would be possible to clarify the situation with measurements of the $^{58,59,60}Fe(n,\gamma)$ reactions, possible with target samples provided by the ERAWAST project. Also, the ^{60}Fe half-life itself is rather uncertain; G. Rugel (TUM) showed that a sufficiently large sample of ^{60}Fe would allow determination of the half-life by measuring the activity of daughter ^{60}Co nuclei. Michael Heil (GSI) presented further possibilities for astrophysical studies involving (n,γ) reactions. By definition, the astrophysical s-process is slow, and so the cross-sections involved are small and the process generally follows the valley of stability. However, in a few cases the neutron capture timescale is comparable with β-decay lifetimes, leading to branching points in the path. Again, ERAWAST could provide radioactive targets in some of these cases allowing first measurements to be made. Rene Reifarth (LANL) illustrated how such material could be utilized at the Detector for Advanced Neutron Capture Experiments at Los Alamos, whereas Alberto Mengoni (Vienna and CERN) presented a proposal for an upgrade of the CERN n_TOF facility to construct a new beam-line providing neutron intensities a factor of 5,000 greater than at present. This would allow sensitivities to the level where the small but highly exotic samples from ERAWAST could be used.

The last session of the meeting looked at other applications, such as geophysics and nuclear medicine. Gunther Korschinek (TUM) discussed recent work regarding the ferromanganese crust of the Earth, itself a unique tool for the study of the paleoclime. Measurements of $^{53}Mn/Mn$ concentrations in deep ocean ferromanganese crusts allow dating in excess of 10^6 y, but accuracy is limited due to an uncertain half-life. Significant quantities of ^{53}Mn extracted from irradiated waste should allow a new accurate measurement of the half life to be made.

Frank Roesch (Mainz) explained how the demand for medical isotopes has recently been changing. New approaches in systemic radioisotope therapy require radionuclides that have different nuclear properties compared to those used for diagnostics (e.g., using positron emission tomography). There are a number of radionuclides, especially lanthanides, with great potential for therapeutic application. Additionally, some long-lived isotopes, suitable for use in generators such as $^{68}Ge/^{68}Ga$ or $^{44}Ti/^{44}Sc$, are promising from the medical point of view. Extraction and use of these nuclei was proposed.

Clearly, the ERAWAST project will involve scientists from many different areas and institutions, bound together by a common need for long-lived isotopes. A proposal has now been submitted for a Research Training Network to provide support for interaction and exchanges of personnel between European laboratories via fellowships and student exchanges, and further workshops and conferences. The abstracts, photos, and transparencies of the talks can be found at http://lch.web.psi.ch/radwaste/ workshop/.

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