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Status report on the Jülich ESS related activities

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Introductory remark

The ESS related work being performed at Forschungszentrum Jülich (Research Center Jülich) or by its contractors more or less comprises the entire field of research starting from the ion source of the accelerator down to the neutron scattering instruments. The major topics are:

- accelerator physics and technology
- materials problems with target and moderator systems
- liquid metal target engineering
- spallation related nuclear studies and code development
- neutronics experiments with JESSICA, the Jülich spallation source
- neutron scattering instrumentation

Accelerator physics and technology

Negative hydrogen ion sources

The original requirements for the ESS were: a low noise level, low emittance, high reliability source delivering 1.2 ms lasting pulses at a rep rate of 50 Hz and a time average current of 70 mA H^- ions. The latter was based on the assumption that the necessary 110 mA can only be achieved by using two sources and a subsequent funneling section. Researchers at the University of Frankfurt, Germany eventually came up with the development of a single source producing 120 mA over so far 15 to 20 days of operation. This feat might even enable the omission of the funneling concept.

Superconducting linac for ESS

An attractive option for the high energy part of the ESS linac is the use of a superconducting (sc) multi cell cavity accelerator. Loss free injection into the compressor rings, however, requires rf amplitude and phase errors of each sc cavity to be less than ±1% and ±1° respectively. These errors for pulsed operation are caused by Lorentz force frequency detuning and microphonics noise. The Lorentz force detuning is due to wall deformations caused by the pulsed accelerating field. In order to investigate these problems of pulsed operation an sc test stand with a 500 MHz, $\beta = 0.75$ elliptical five cell cavity has been set up in Jülich recently. The cavities are operated at 5 MV/m minimum accelerating gradient employing a 20 kW peak rf power unit. The goal of the test program is to study the excitation of multi-cell modes up to 100 Hz rep rate keeping rf amplitude and phase oscillations below ±1% and ±1°, respectively, during every individual 1.2 ms flat top pulse with only 20% nominal rf power increase.

Materials problems with target and moderator systems

The integrity of these components will be decisive for the duration of uninterrupted operation periods of the entire facility. The extraordinary loads on the mercury target are on the container proper and its secondary enclosure, in particular the respective proton beam windows. These loads have mainly two causes. First, the stress waves, which are due to the shock-like energy deposition into the target and its multiple shells. Stress waves within the container walls are generated by the direct heating of the beam window as well as by the pressure waves due to the pulsed heating of the mercury. The second major concern is radiation damage and foreign atom production (mainly hydrogen and helium) induced by the high energetic protons and neutrons.

The stress wave problem

Experiments on the stress wave problem are being performed at the Alternating Gradient Synchrotron (AGS) at Brookhaven with the mercury target of the international ASTE (AGS Spallation Target Experiment) collaboration. A recently developed laser interferometric technique for measuring pressure waves in liquid metal targets provided reproducible results.

The comparison of experiments with results from numerical calculations (employing finite elements) of the expected stress and pressure waves within the ASTE target subject to high power proton pulses is satisfactory only for the time interval between power input and arrival of the pressure wave front at the target container wall. For a quantitative description of the pressure wave at later times a more sophisticated modeling of the pressure sensor is needed and being developed.

Numerical calculations show that the time dependence of the pressure wave within a mercury target for a given total energy deposition strongly depends of the proton beam profile. This way may offer a means of mitigating the impact of pressure waves on the target structure.

Radiation damage

Radiation damage and foreign atom production are investigated with proton accelerators. Life time estimates of components are made by analyzing long term irradiated targets and proton beam windows of already operating medium power spallation sources (LANSCE, Los Alamos and ISIS, Rutherford Appleton Lab).

The mechanical tests and micro-structural investigations of samples cut from components of existing spallation sources are nearly finished. The results show a remarkable strengthening and embrittlement with all three investigated materials classes (austenitic and martensitic steels as well as nickel-based alloys). The residual ductility observed with specimens subject to the highest available dose of 10 dpa (corresponding to about 2 months of operation of ESS) are, however, sufficient for being employed as structural materials of ESS targets.

Cryogenic moderator development

Cold moderators have gained increasing importance in the past. Quality and quantity of neutrons produced with a pulsed source can be particularly improved, if cold moderators can deliver and sustain short pulses over a broad energy range. The ideal slowing down medium for that purpose is methane because of its high proton density and many low lying rotational vibration modes. Unfortunately, in the radiation field of a target, highly active radicals are formed in methane, in particular CH_3^- und H^+. In liquid methane (100-K-moderator) this gives rise to the formation of higher alkane homologues, which is eventually clogging the piping. In its solid state (20-K-moderator), in addition to radiolysis, crystal defects like interstitials are generated. The stored energy together with recombination of radicals can lead to spontaneous energy release ("burping"), which in turn may destroy the moderator vessels.

Within the present ESS R&D phase several paths for developing radiation resistant or at least better manageable cold moderators are being followed. One way is the production of small methane pebbles (2 to 3 mm diameter), which as a bed are cooled by flowing liquid hydrogen. A second possibility is the inclusion of methane in porous substances (e.g. zeolites) or clathrates (e.g. from water ice), both again as small pebbles. Radiation damage and energy release will thus be restricted to small particles. A timely and regular exchange of the pebble beds would prevent the destruction of the vessel and sustain the neutronic quality of the moderator. A third way would be the utilization of different hydrocarbons (with many freely rotating methyl groups), which do not exhibit the unfavorable radiolysis behavior of methane.

Irradiation behavior of moderator media in particular with respect to the burping behavior are being performed at the Tandetron accelerator in Jülich and the IBR-2 reactor in Russia.

The neutronic properties (intensities and pulse shapes) of the different variants will be studied in a to scale mock-up of the ESS target-moderator-reflector module (see below).

Liquid metal target engineering

Mercury and water loops, heat transfer and computational fluid dynamics (CFD)

Strong thermo-mechanical loads are expected on the proton beam window of the mercury target container due to temperature gradients as well as transients due to accelerator tripping. Temperature gradients will arise due to the fact that the window is planned to be actively cooled only from the mercury side. Therefore, extended test programs for investigating the heat transfer conditions have been performed. Measurement techniques for determining transfer coefficients have been developed and experiments conducted, which were compared to computational fluid dynamics results. For the heat transfer experiments a mercury loop including a target test section with HETSS (Heat Emitting Temperature Sensing Surface) sensors has been employed at the Institute of Physics of the University of Latvia in Riga.

A mercury laboratory in Jülich is now under construction and will be available in the summer of 2001. A mercury loop will be installed, which is going to be used mainly for component tests and flow measurements using ultra-sonic Doppler velocimetry. Other purposes include the study of gas bubbles in streaming mercury.

In addition a water loop is being manufactured for use of flow mapping by particle image velocimetry.

Advanced welding techniques

The internal welding structure of the ESS mercury target container with its flow baffles and potential pressure wave mitigation devices is very complicated and has to sustain large stresses reliably. It seems to be reasonable to take into account sophisticated joining techniques. Therefore, an extended test program for laser beam welding of container structures to be manufactured from martensitic steels is being performed at the Forschungszentrum Jülich.

Spallation related nuclear studies and code development

Experimental studies are being performed at the cooler synchrotron COSY in Jülich within the NESSI (NEutron Scintillator SIlicon detector) collaboration. Reaction and production cross sections for neutrons, hydrogen and helium have been measured with 1.2 and 1.8 GeV protons on thin targets of Fe, Ni, Ag, Ta, W, Au, Pb and U. The data have been compared with different intra-nuclear cascade models combined with evaporation models. It has been found that the calculated charged particle production cross sections are particularly sensitive to the high energy tail of the excitation energy distribution, whereas neutron productions cross sections are less sensitive. Best agreement for production cross sections for H and He has been obtained with the INCL code, while the LAHET and HERMES codes show large deviations for heavy nuclei.

Whereas the above mentioned thin target experiments are particularly useful for code validation, neutron production measurements for thick targets are essential for the design of spallation sources like ESS. On the other hand, these data are valuable from a theoretical point of view, because the inter nuclear cascade can develop properly in those targets. The results can adequately be compared to high energy transport codes like HETC. A large number of thick targets of W, Pb and Hg with varying lengths and diameters have been measured with proton energies of 0.4, 0.8, 1.2, 1.8 and 2.5 GeV.

A careful analysis of the data taking into account the energy of the emitted evaporation neutrons has been made allowing comparison with simulations using the HERMES code system developed in Jülich. The latest development of the code were based on the above mentioned experiments. Two additional collision kernels have been implemented, parts of the existing models have been revised and the data bases and codes for radioactivity estimates have been updated.

Neutronics experiments with JESSICA, the Jülich spallation source

JESSICA (Jülich Experimental Spallation target Set up In COSY Area) has been designed for experiments to optimize the target/reflector/ moderator system of the ESS. A to scale mock-up of the ESS lead reflected mercury target has been installed in a dedicated experimental room at the COSY proton accelerator in Jülich. Moderators can be inserted into any one of four voids, two on each side of the target. A major goal of the facility is the investigation of the neutronics and technical feasibility of advanced cold moderators like pebble beds of solid methane cooled by liquid hydrogen. Another aim is the validation of simulation methods of particle interaction and transport (mainly HERMES, MCNP-X, CALOR, LCS etc.).

The installation of JESSICA is complete. Recently, with proton pulses from COSY the 300 kg mercury target has produced the first neutrons. COSY delivered 300 ns long pulses of 1.3 GeV with approx. $5 \cdot 10^8$ protons per pulse at a repetition rate of 0.1 Hz. The neutron spectrum emitted from a water moderator has been measured using a ^{6}LiJ single crystal scintillator neutron detector. The data could be well represented by a slowing down spectrum at higher energies and a Maxwell spectrum representing room temperature as expected.

Neutron scattering instrumentation

Spectrometers utilizing the continuous flux at reactors usually do not gain a lot from pulsing, in particular those instruments exploiting a broad wavelength band like small angle scattering or neutron spin echo (NSE) spectrometers. In order to nevertheless make the most of the pulsing, conceptual design studies and model calculations for pulsed NSE instruments are being performed recently in Jülich. Five different generic designs are evaluated ranging from the "classical" type with longitudinal precession coils to zero field spin echo solutions. Except with the last example, all design have to cope with the problem of developing broad band spin flippers. The wavelength dependence of the flipper operation for two of the selected designs can be solved either by synchronous ramping of the currents or employing broad band flippers. Despite the fact that at low repetition rates (e.g. 10 Hz) the useful wavelength band is larger, higher rep rates (e.g. 50 Hz, at the same average source power, of course) turned out to be advantageous due to the absence of technical complications and the possibility of consecutively utilizing the wavelength band. It turned out that either the "classical" design or a 2π-instrument with a radially symmetric field around the sample position will be the most appropriate ones.