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JESSICA, the ESS-like target/reflector mock-up and cold moderator test facility

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Abstract

JESSICA is designed for prototyping experiments on the optimisation of a target/reflector/ moderator system of the European spallation source (ESS). A full-size liquid Hg target is placed in a short pulsed proton beam of the COSY accelerator at Jülich to produce spallation neutrons. The neutronics and technical feasibility of advanced cold moderators will be investigated by means of n-TOF diffraction technique and the aim is to validate complex simulation methods of particle interaction and transport (mainly HERMES, MCNP-X, CALOR, LCS etc.) and to optimise the technical layout of an ESS-type target-reflector-moderator system.
The JESSICA experiments shall result in: i) nuclear spallation physics data, the neutronic performance and optimised geometry of the ESS-type liquid Hg target system, ii) a rank list of feasible advanced cold moderators, iii) experimental validation of simulation models.
The installation of JESSICA is complete and just recently the l-Hg target has produced the first water moderated neutrons from a pulsed proton beam (pulse width $\Delta t \approx 300$ns) at 1.3 GeV with approx. $5 \cdot 10^8$ protons per pulse at a repetition rate of 0.1 Hz. The bottom line is that JESSICA has become operational, recently. Commissioning tests and first real experiments are about to commence.

1. Introduction

An international collaboration among 12 neutron research laboratories (ANL, FLNP, FZJ, JAERI, KEK, LANL, ORNL, PSI, RAL, Soreq, TU Graz, U Hokkaido) was formed for joint efforts and support of the JESSICA facility (Jülich Experimental Spallation Target Set-up In COSY Area). JESSICA [1,2] is designed for studying science and engineering aspects of high-power pulsed neutron spallation targets, namely for neutron intensity and pulse shape optimisation upon varying the target and reflector material, geometry, moderators and proton beam energy. The JESSICA set-up at the Jülich cooler synchrotron facility COSY provides a unique opportunity for neutronic performance experiments on advanced cold moderators with a realistic 1:1 sized ESS-type target-reflector-moderator mock-up. The vast importance of

developing advanced moderator concepts is reflected by the request of typically 80% of all new instrument proposals for cryogenic moderators at the next generation spallation neutron sources, such as SNS or ESS.

However, there is a number of other goals tracked by the current installation of the JESSICA facility at the research centre Jülich, namely to obtain

i. a valuable and unique data set of nuclear transport and neutronic performance of an ESS-type liquid mercury target / moderator / reflector system and its individual components,
ii. experience for an optimised geometry of the assembly, i.e. the target to moderator and target to reflector position and
iii. neutron spectra and neutron time distributions to validate MCNP-X coded simulation models of target station concepts and scattering kernels for cold sources,
iv. and, last not least, a rank list of recommendable candidates of advanced cold moderators with well determined neutronic parameters and considerations on their technical feasibility.

2. Set-up of JESSICA

The COSY accelerator is employed in a modified mode [3] to produce short ($\Delta t<1\mu s$) proton pulses of a variable energy (0.3-2.5 GeV). In fact, the "rather weak" COSY pulse intensity of some $10^8 - 10^9$ ppp (protons per pulse) is regarded as an advantage: It allows investigating the neutronic performance of both the target/reflector assembly as well the moderator intensity and time structure in much detail and without any hassle of radiolysis, activation levels or shielding problems. Of course, COSY cannot provide for any high power beam tests, which are performed either at AGS or IBR-2.

JESSICA consists of the following main components:

i. Pulsed proton beam injection tube with all necessary beam diagnostics and vacuum systems.
ii. A stationary liquid mercury target of 10 x 30 cm² front-end cross-section and 965 mm length surrounded by a lead reflector of many 30 mm diameter lead rods packed into a modular sandwich-like support structure (fig. 1 in [2]).
iii. Referring to the ESS design, there is space for four individual moderators, one filled with life the others are dummies. Experiments on the neutronic performance of a number of moderator types are anticipated: the use of ambient water or liquid hydrogen moderators for reference purposes and, ultimately, advanced cryogenic

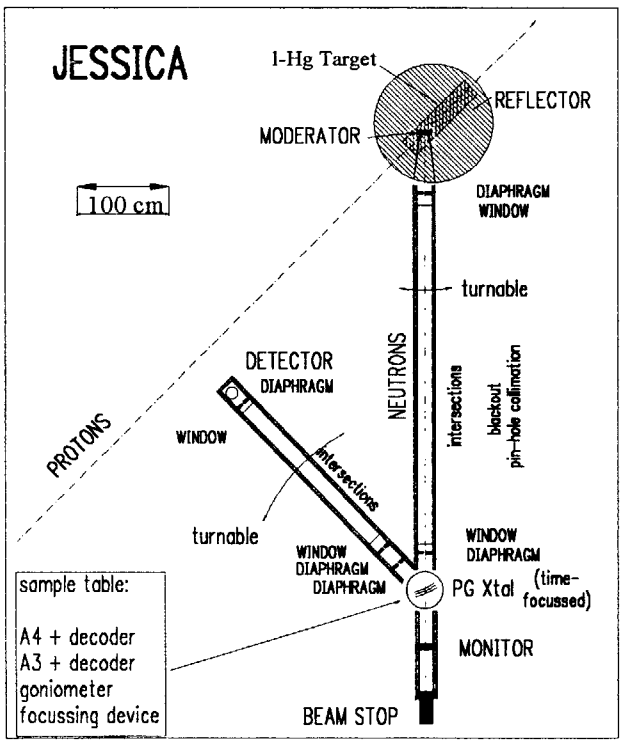


fig. 1: sketch of JESSICA

moderators, e.g. made of pelletised solid methane in liquid hydrogen, clathrates etc. is planned. There is sufficient space to alter the surface shape or angular position of the moderator. The effect of coupling/decoupling or even pre-moderation with a water cushion between the target and the moderator can be investigated, too.

iv. The target itself is mounted on a sledge for axial position optimisation.

v. The integral intensity and spectral distribution of the pulsed neutron beam emerging from the moderator is monitored with a direct view back-end detector.

vi. A single crystal probe in the neutron beam allows for standardised Bragg diffraction studies of the peak profiles and time distribution function of the neutron pulses (cf. fig. 1). The viewing angle to the moderator is adjustable like both the in-pile and reflected beam tubes are kept adjustable for optimised focussing conditions. The probing crystal is pyrolytic graphite.

3. First results

The preparation of the JESSICA experiment hall had commenced in early 2000. The stainless steel reflector vessel was filled with some thousands of lead rods with no D_2O or polyethylene filling the intersecting gaps. The target is filled with 35 litres of liquid mercury and for the purpose of JESSICA no target cooling or a l-Hg pumping loop is required. The mercury filling level is interlocked with the COSY safety system and the axial target position is adjustable within 670 mm from its nominal zero position. An ambient water moderator was installed as a reference for the time of the start-up experiments. The operation licence was granted in spring 2000.

At present a provisional neutron flight tube was installed with a Ce-doted LiJ single crystal neutron detector directly viewing the moderator at 5.4 m distance. The tube will be replaced later this year by a properly shielded and evacuated flight tube, manufactured and delivered by ISIS. The probing crystal and its lign-up equipment will be ready for mounting by the end of 2000.

Meanwhile the provisional set-up was used to monitor the first neutron time-of-flight spectrum of an ambient water moderator at the first beam-to-target event in August 2000.

It was a significant step forward to develop the COSY proton accelerator towards a pulsed mode of operation and, in fact, the machine was stretched to its present technical limits. Details of the COSY pulsed beam development will be reported elsewhere [3]. However, the important beam parameters for the JESSICA application where achieved after some periods of beam development tests:

table 1: JESSICA proton beam parameters

proton energy	tunable up to 1.34 GeV (2.1 GeV/c)
beam intensity	up to $9 \cdot 10^8$ protons per pulse (exp. achieved)
pulse width	$\Delta t \approx 300$ ns
repetition rate	0.1 Hz
beam size	≈ 4 mm (in diameter)

The COSY proton beam parameter set-up is reproducible by software and, thus a previous set-up can be recalled easily.

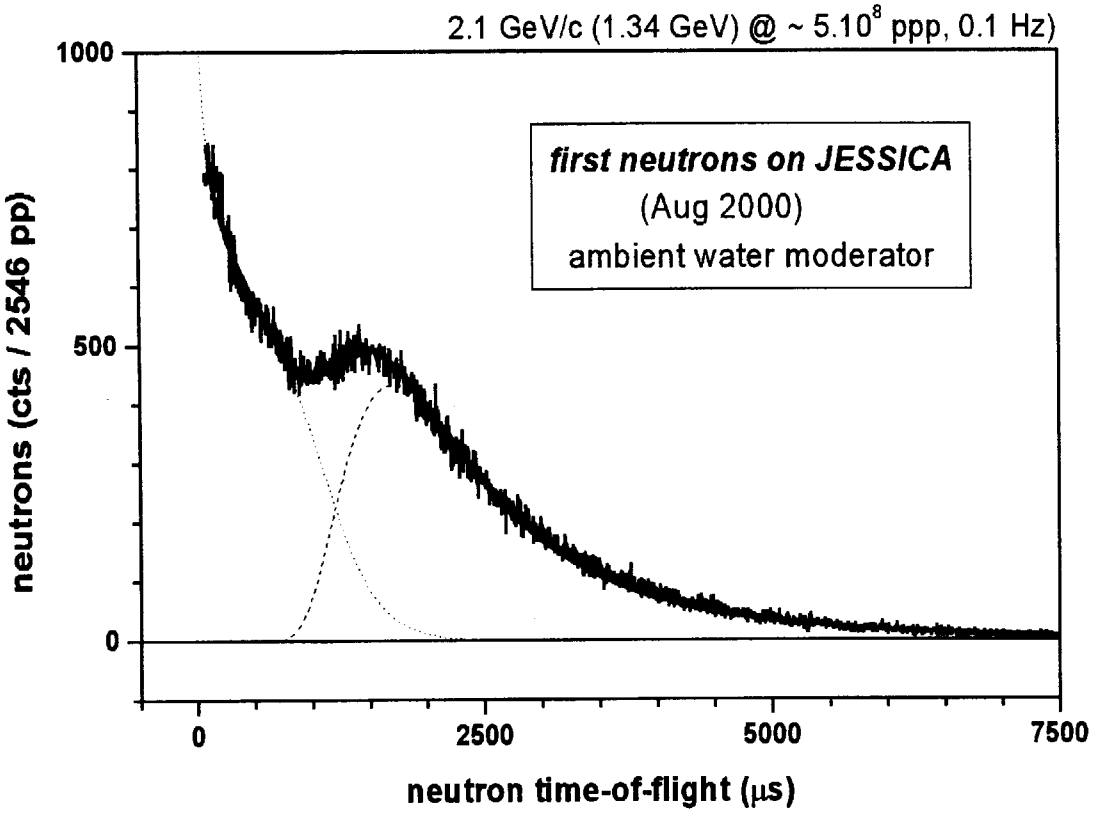
With these proton beam parameters the ambient water moderator spectrum was recorded (fig. 2) in very good agreement with Taylor's description of the ISIS water moderator [4]. Taking into account a detection efficiency $\varepsilon \sim \varepsilon_0/v_n$ the count rate is obtained from the ISIS formula [4] by rewriting for time bins, for JESSICA $\Delta t = 6\mu s$:

$$\Delta I(t) = \frac{\varepsilon_0}{d} t\left(\frac{2E_n}{t}\right)\left(J\frac{E_n}{T^2}\exp\left(-\frac{E_n}{T}\right) + \frac{1}{1+\exp\left(\frac{w_1}{\sqrt{E_n}} - w_2\right)}\frac{\Phi_0}{E_n^A}\right)\Delta t$$

with $E_n = 0.5\, m_n ((L/t)^2$. The other values are compiled in table 2.

table 2: JESSICA neutron spectrum parameters

L	5.4 m
J	398 n / sr 100 cm²
T	26.9 meV
w_1	55.2 meV $^{1/2}$
w_2	5.1 meV
F_0	161 n / eV sr 100 cm²



It may be worth mentioning that this is actually the first experimental neutron spallation from a l-Hg target with pulsed protons at 1.34 GeV of energy. However, the presented data are taken from one night of operation of JESSICA and clearly we are looking forward to established a broader data base endorsing confidence in the reproducibility and intensity / background level. The next experiments are firmly scheduled for March 2001.

References

[1] D. Filges and H. Tietze-Jaensch
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[3] J. Dietrich et al., to be published

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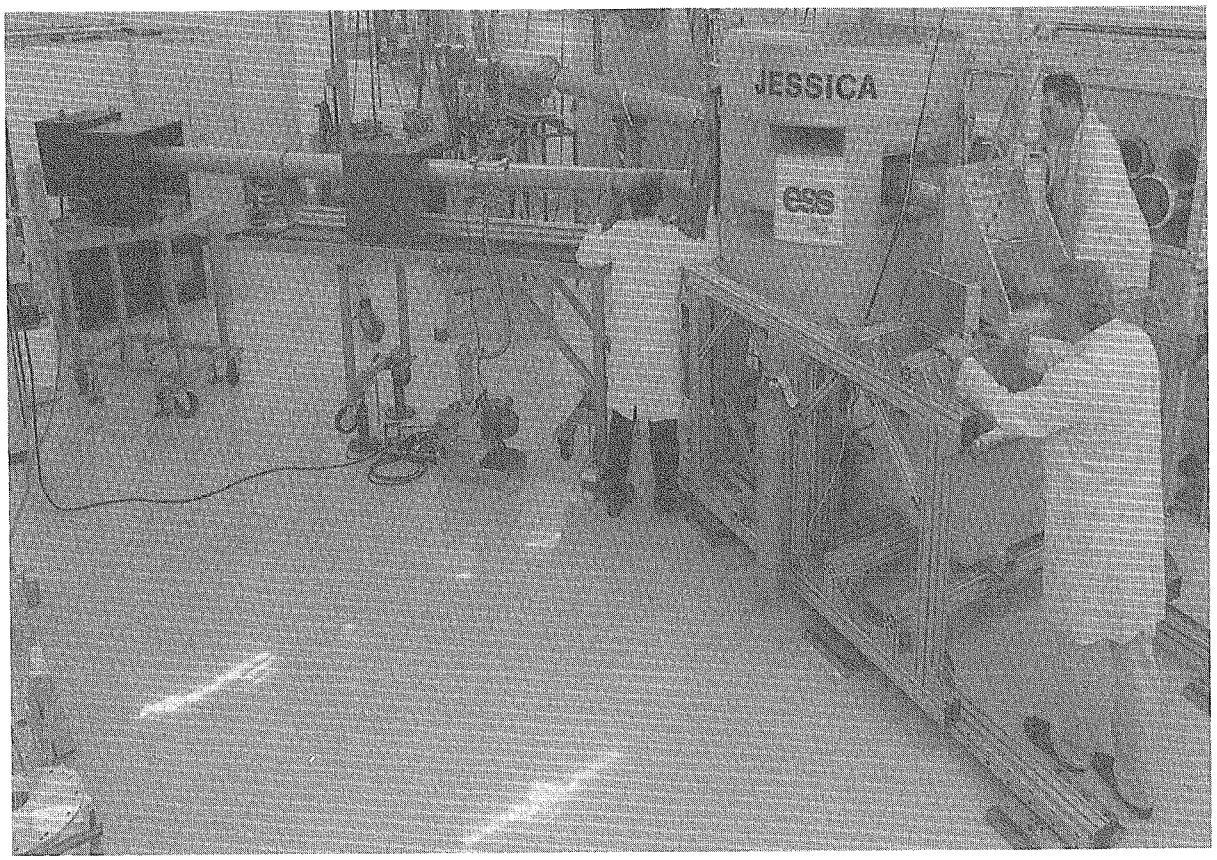
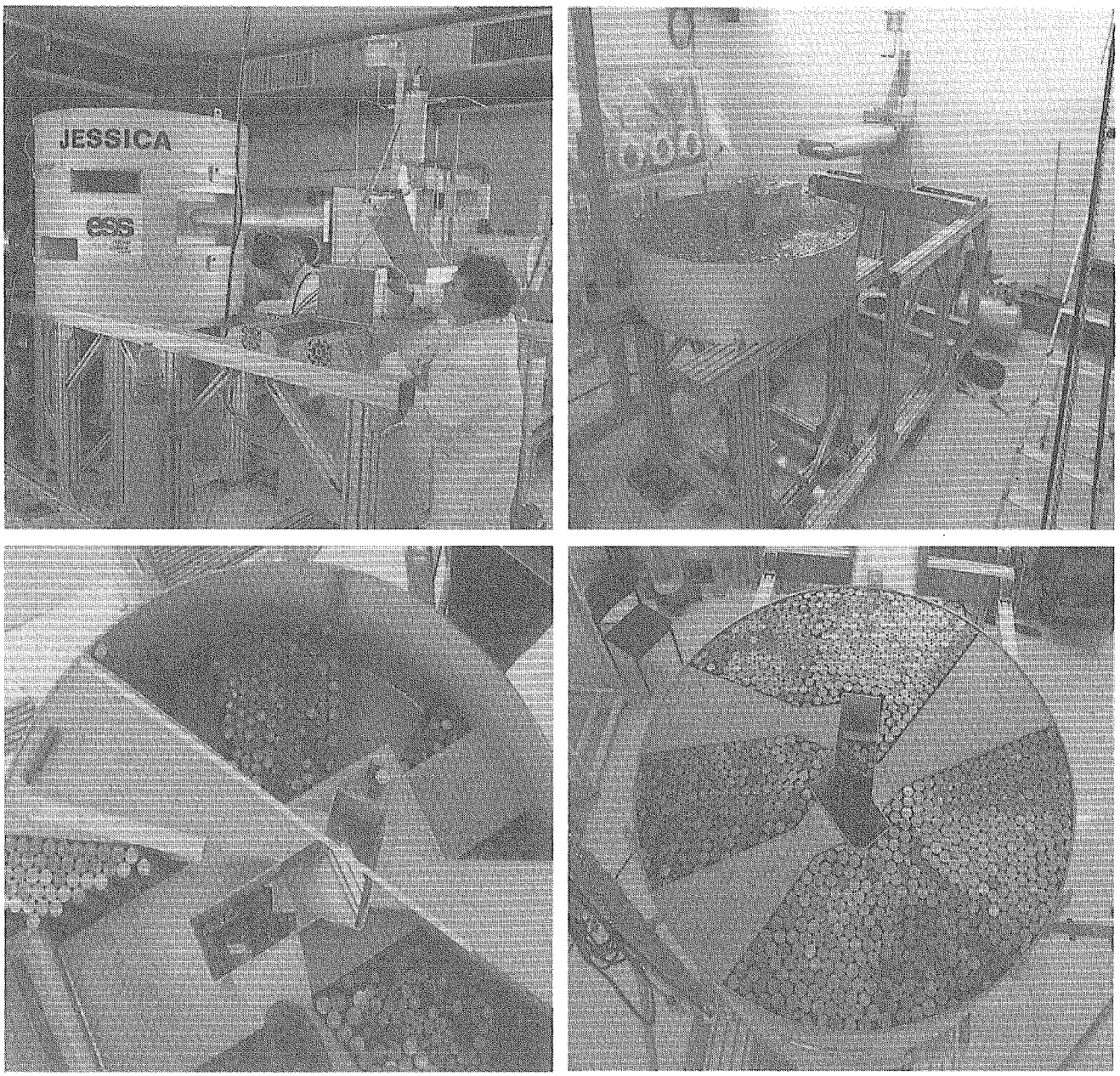
Appendix: picture series of the installation and set-up of JESSICA



The JESSICA facility: proton beam line (from top centre), reflector vessel with target and moderator and primary neutron flight path (between reflector vessel and black detector box)



JESSICA: installation process (March - August 2000)