TESTS IN THE UCN PROJECT

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*The UCN (**U**ltra **C**old **N**eutrons) research facility comprises several critical components from the standpoint of thermo-mechanics (strength of materials and heat transfer) as well as from neutron physics. Tests with various engineering materials should help to find the optimal equilibrium of the ultra cold neutron yield and sufficient safety and reliability of critical parts during their life cycle of approximately 20 years. The UCN project at PSI is a pioneer project and the UCN team has to find new technical solutions without the possibility of copying or learning from any existing UCN facilities. First of all, transmission tests with zircaloy and aluminium alloys were carried out at the Institut Laue-Langevin (ILL) in Grenoble, France followed by mechanical tests with a mock-up condensation vessel made of copper. Mechanical and transmission tests with further materials and components are in preparation to be carried out in 2005.*

INTRODUCTION

The function and the principal components of the UCN research facility in the state of construction are described in the UCN safety report [1]. The main system, from the viewpoint of thermo-mechanics, is the UCN vessel. This is a cylindrical double chamber tank, which can be seen in Fig. 1. The upper section is a vacuum chamber enclosing the neutron shielding, the cryo pump, the thermal shield, the UCN storage tank and the shutter mechanism suspended on the central cold pipe. The vacuum should be better than 10^{-8} mbar. The bottom chamber is the D_2O-moderator vessel containing a thin-walled cylinder called the “Fingerhut” or thimble surrounded by D_2O at a design pressure p_{abs} of 3 bar. This is a protrusion of the vacuum chamber into the D_2O tank. The “Fingerhut” contains the extensions of the thermal radiation shield and the UCN converter vessel suspended on the central cold pipe.

During normal operation, there is a block of approximately 30 dm^3 of solid D_2 in the UCN converter vessel, which slows down the thermalized neutrons to velocities smaller than 9 m/s.

Besides the UCN tank, there are four systems necessary to produce UCN’s for research purposes:

- The proton beam system
- The horizontal spallation target
- The ultra-cold D_2 system (4 – 8 K)
- The D_2O cooling and moderator system

From the view point of thermo-mechanics, the UCN research facility comprises several critical components. There is some risk of failure of components before the end of their design life-cycle. To minimise such hazards, the design of the UCN facility is carried out with the application of modern scientific methods and quality assurance.

The following categories of validation tests are ongoing or will take place at the appropriate time:

- Tests for the evaluation of engineering materials and production technologies
- Function tests of subsystems
- Validation tests of finite element calculation based design results with mock-up dummies
- Function tests with the UCN shutter mechanism in vacuum and at cryogenic temperatures
- Function tests of the subsystems in the commissioning phase

These tests have to be planned and carried out with the goal of finding hidden sources of failure before the beginning of the operation.

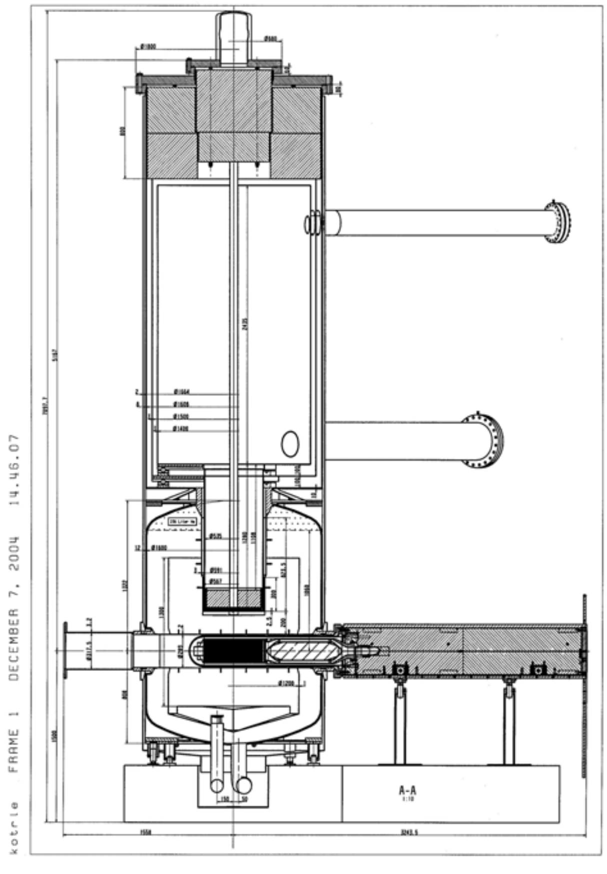

Fig. 1: UCN vessel with UCN guides and spallation target.

DESIGN VERIFICATION

Many parts or components of the UCN research facility are designed with help of FE-analysis based methods. Most mechanical parts and components can be classified as uncritical from the viewpoint of mechanical engineering and they do not have to undergo further testing. The design of some parts and components includes aspects which can not be predicted in advance, e.g. He-leak rates according to specifications. Final tests will prove if corrections are necessary.

The goal of the optimising process of some key components is primarily to maximise the UCN yield. For this purpose, engineering materials with high UCN transmission and at the same time good mechanical properties (yield strength, high strain rates at cryogenic temperatures) have to be evaluated. The transmission of UCN's decreases exponentially with the thickness of sheets or foils. Therefore, all materials in the UCN path should be as thin as possible. A limitation is given by buckling effects that may lead to damage of some thin-walled and therefore critical components, e.g. the D_2 moderator vessel, the "Fingerhut" or the proton beam pipe, if they were not carefully designed, precisely manufactured and tested according to the highest safety standards.

TESTS FOR THE EVALUATION OF ENGINEERING MATERIALS AND PRODUCTION METHODS

To minimise the absorption of neutrons percolating the walls of the "Fingerhut" as well as the walls of the D_2 moderator tank, materials must be applied with sufficiently small absorption to produce a high UCN density in the UCN storage tank. Several aluminium alloys and hafnium-free zircaloy are suitable alloys for the manufacturing of the D_2O tank and the D_2 moderator vessel. The procurement of hafnium-free zircaloy proved to be very difficult. There are only a few suppliers world wide and they mainly produce for the nuclear power plant industry. Their spectrum of semi-finished products covers a rather small selection of sheet or piping material. Times of delivery and prices per kg are extremely high. 1 kg zircaloy in the free market costs about US$ 500.- (price in December 2004). Due to these boundary conditions, transmission tests with hafnium-free zircaloy, normal zirconium and various aluminium alloys at the Institute Laue- Langevin in Grenoble were planned, prepared and carried out in July 2004.

More than 100 samples of aluminium alloys, zircaloy alloys and zirconium were measured. Most of the samples were disks with a diameter of 80 mm and wall thicknesses of 1, 0.5, 0.4 and 0.3 mm. The measurements showed that some of the aluminium alloys provide transmission values as high as those measured with the zircaloy specimens. In addition to the discs, spherically shaped caps of Zr 125 and Zr 110, provided from Gachina, Russia were measured. The higher the degree of deformation, the lower was the transmission rate measured.

TESTING THE FUNCTIONS OF SUB-SYSTEMS

There are three main circuits to handle the necessary gas and liquids for the operation of the UCN source:

The D_2 circuit is used as the process gas circuit with a piping and valve control system.

The liquid Helium circuit is used as the cooling system for the D_2 converter and the thermal radiation shield.

The D_2O heavy water circuit is used as a cooling system for the spallation target and as a moderator to thermalise fast neutrons.

All these circuits will be carefully tested during the commissioning phase of the UCN facility and before starting the production of UCN's.

VALIDATION TESTS OF STATIC AND BUCKLING ANALYSIS WITH SOME CRITICAL COMPONENTS

The vacuum pipe for the proton beam, the "Fingerhut" and the D_2 converter are examples for critical parts. According to the load cases, all of these three extremely thin-walled shell structures are exposed either to exterior or to interior pressure. The fact that these shells are connected to adjacent parts with welds makes the situation more difficult. Welded aluminium joints are locations of reduced mechanical strength when the welded alloy cannot be heat treated after welding (This means that welded shell structures are locally weakened if aluminium alloys are applied that cannot be re-annealed after welding).

Real shell structures normally deviate more or less from the ideal shell structure (e.g. from the idealised FE analysis geometry). In reality, the shape of a pipe is not necessarily a geometrically perfect circle. It rather has an "oval" shape. Deviations from the ideal geometry applied in the finite element analysis are called imperfections. In most cases, it is impossible to build in imperfections into the structural analysis model for the finite element analysis because of a lack of information to estimate the real shape before it is built.

Imperfections can easily reduce the critical buckling pressure in the order of 50 % or more.

FUNCTION TESTS OF THE UCN SHUTTERS

The UCN storage tank can be closed with shutters, separating the "Fingerhut" and the neutron guides leading to the experimental areas. The shutters and their actuators operate in high vacuum and at cryogenic temperatures. During their life cycle, all shutters make a high number of open-close moves in the order of several 100'000 operations. For safety reasons, mock-up shutters will be built and tested under realistic conditions in vacuum and at the low operational temperatures.

FUNCTION TESTS DURING THE COMMISSIONING PHASE

Before regular operation and the production of UCN's, all the sub-systems of the facility, including the control system, will be tested.

TRANSMISSION TESTS WITH ZIRCALOY AND ALUMINIUM SPECIMENS

The difficulties in the procurement of Zircaloy sheet material forced the project team to evaluate alternative more easily available materials and with a larger spectrum of dimensions. Aluminium alloys have low cross sections in the order of Hafnium-free Zircaloy.

For the precise measurement of flat disc specimen and spherical shaped shells, transmission tests were carried out at the Institute Laue-Langevin (ILL) in Grenoble. The setup for the experiment was as follows: UCN's from a turbine fly into a chopper. The chopper is a three disk rotational shutter with a rotation frequency of 1.1 Hz opening on each turn for 4 ms. The chopped UCN beam passes through a drift tube containing the test specimen at a distance of 1.8 m before flying into the detector according to the scheme shown in Fig. 2. The detector used was a ^{3}He microstrip detector provided by the ILL.

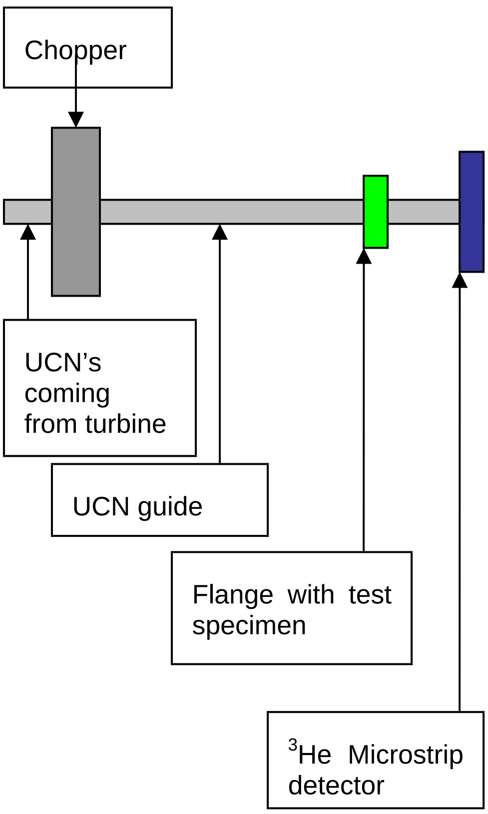

Fig. 2 Experimental Set Up for the Transmission Measurements at the ILL.

Together with the trigger signal from the chopper, its signal is fed into the data acquisition system.

A total of 104 samples of aluminium alloys, zirconium and Zircaloy were measured.

Samples: The sample thickness varied between 1.0 and 0.1 mm. There was no specific surface treatment applied. The specimens were rolled, milled or cut by electric discharge milling. The samples were degreased and dried before the measurement. Some of the specimens were polished with sand paper to investigate the effects of surface roughness on the transmission.

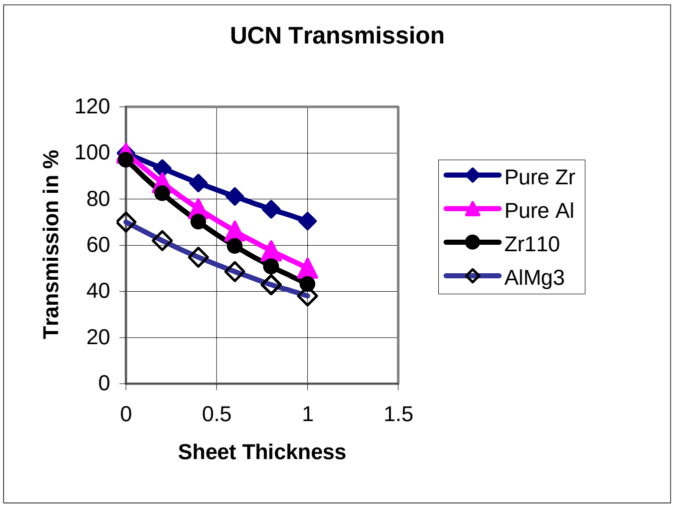

Fig. 3 Summary of results from transmission measurements at the ILL.

CONCLUSIONS AND OUTLOOK

To verify the results from the first measuring campaign at the ILL and to get better information on suitable aluminium alloys, more than 100 additional aluminium samples are in preparation.

A new measuring campaign is planned in early 2005.

Material tests and further tests will be continued according to the project time schedule.

REFERENCES

[1] Ch. Perret, *Sicherheitsbericht zur Experimentier-anlage mit ultrakalten Neutronen an der Beschleunigeranlage des PSI-West,* Sicherheits-bericht, 2004.

[2] M. Daum, *UCN Transmission Through Thin Windows of Different Materials.*