12. PARTICIPATION IN THE FUSION TECHNOLOGY PROGRAMME

C.A.F. Varandas and J.C. Soares (Heads), E. Alves, L. Alves, N. Cruz, A. Paul, R.C. Pereira, M.F. Silva, M.R. Silva

12.1. INTRODUCTION

The participation in 2001 of the Association EURATOM/IST in the Fusion Technology Programme included the following Projects:

- Fusion materials characterization and surface ion beam modifications;
- Monitoring system for a laser in-vessel vision system;
- Development of Be pebble beds;
- Characterization of SiC/SiC composites;
- Development of ceramic breeders;

carried out in the frame of Underlying Technology (the first Project) and of Technology Tasks (the last four Projects) by "Instituto Tecnológico Nuclear" (the first and the last three Projects) and by "Centro de Fusão Nuclear" (the second Project).

12.2. MONITORING SYSTEM FOR THE ITER-FEAT IN-VESSEL VISION SYSTEM (Task TV-018.2)

12.2.1. Introduction

The following main activities were performed in 2001:

The Project aims the development and test of the VME monitoring system for the ITER-FEAT in-vessel vision system (IVVS).

- Finalization of the development of the hardware and software
- Test of the system in Portugal
- Implementation of the system at ENEA-Frascati
- Elaboration of the final report

12.2.2. High data transfer rate VME system for TCP-IP remote real-time control

The IVVS control and data acquisition system (CADAS) is composed by a supervisory workstation connected by a 100 Mbit/s Ethernet channel to a 12-slot backplane (P1, P2) VME crate, housing a PowerPC604R based CPU, with 64 MB RAM, 9 GB hard disk and running LynxOS, as well as two on-site developed modules:

- The intelligent control and data acquisition (CADA) module, dedicated to control the laser operation for the in-vessel scanning and to acquire and store the invessel image;
- The intelligent monitoring module, dedicated to monitor external variables and to signal predefined error situations.

Figure 12.1 depicts a block diagram of the VME system. LynxOS is an UNIX compatible, POSIX-compliant, operating system, used in time critical applications where predictable real-time response is necessary.

For CADAS three levels of software were developed:

- A lower level software that runs in the two on-site developed modules hosted by the 32 bit, 50 MHz floating-point, TMS320C31 Digital Signal Processor (DSP);
- A middle level software (TCP/IP Server Application) that runs in a PowerPC board, hosted by a PPC 400 MHz microprocessor running the LynxOS operating system. Due to UNIX compatibility and POSIX compliance, migration of applications to and from this operating system (portability) is easier to achieve;
- A higher-level software (TCP/IP Client Application) that runs in a Unix Workstation.

The development of the software for these three platforms was made mainly in C language due to the facility of use, universality and portability of this type of code. In some cases DSP assembler is being used for performance reasons.

For future development and integration in new Unix Workstation, a software library was developed.

The main features of the control and data acquisition module (Figure 12.2) are:

- Two acquisition channels, 16-bits ADCs (LTC1605ACG) with sampling frequency up to

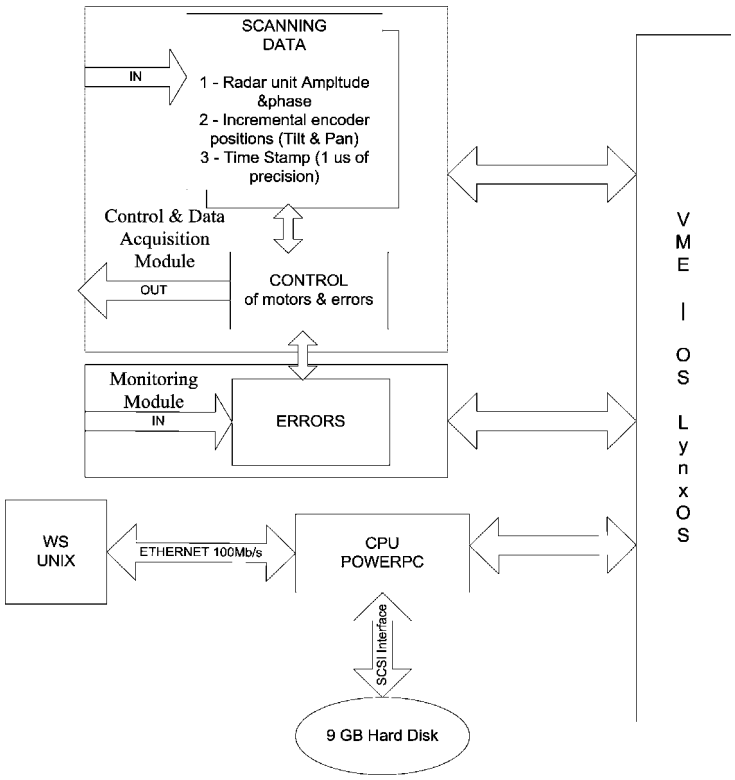

Figure 12.1 – Block diagram of CADAS

100 kSPS and an input range that can be chosen between ± 10 V or ± 2 V, for the analog amplitude and phase information;

- Four acquisition channels, 16-bit ADC, ADS7815 with sampling frequency up to 250 kSPS and an input range of ± 5 V;
- Buffer Memory per each 32-bit word is 64 kword making a total of 256 kbyte, with the possibility to extend;
- Local TMS320C31, with 512 kword of memory for data processing;
- Logic control of the module is done with Mach5 and Mach211SP.

The main features of the monitoring module are:

- Eight acquisition channels, 16-bit ADC, ADS7815 with sampling frequency up to 250 kSPS, with an input range that can vary between ± 2.5 V and ± 2.5 mV, also used in the CADA module;
- Buffer Memory per channel up to 64 kbyte;
- Local TMS320C31, the same DSP used in the CADA module, with 512 kword of memory for data processing.

The VME P2 connector performs the interface between the modules installed in the same crate. When more than one monitoring module is needed, the CADA module is able to decide which one is going to read using a special developed 3-bit (sent through P2) addressing mode.

The DSP reads the ADCs information through the respective FIFOs. Afterwards if the value is not under the right parameters, it will force an interrupt in the CADA module that will take the necessary actions.

The typical acquisition rate of these signals is 10 SPS, although 250 kSPS acquisitions would be possible with this hardware and the same structure of software.

Three levels of software communicate with each other in two different ways:

- The Workstation communicates with the VME crate with standard TCP-IP protocol over the Ethernet connection (Internet can be used if bandwidth is enough);

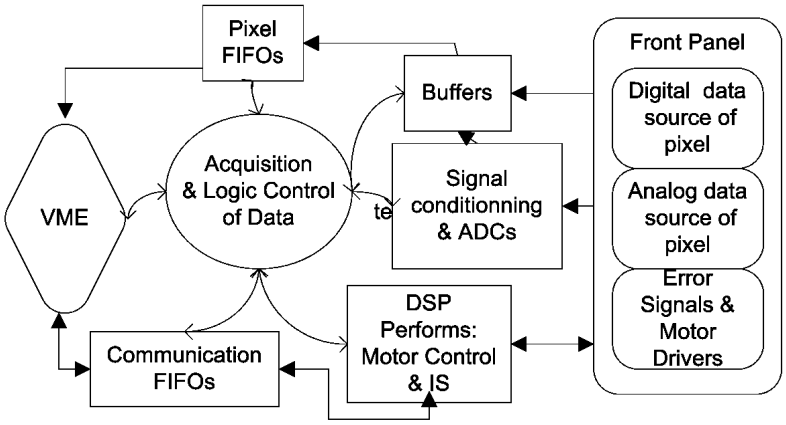

Figure 12.2 – Block diagram of the control and data acquisition module

- The VME main board controls the DSPs through the FIFOS using a specially developed dedicated communication protocol.

The TCP-IP communication software is based on a client/server architecture, which is divided in two programs that run over an Ethernet connection. The server application runs in the VME crate, while the client application runs in the Workstation. The server program acts as a bridge between the VME modules and the client program.

The communications between the client application and DSPs is also based on client/server architecture. The DSPs act as servers and are always ready to execute commands sent through the FIFOS.

12.3. DEVELOPMENT OF Be PEBBLE BEDS (TW1-TTBB-007)

12.3.1. Introduction

The Association EURATOM/IST has been responsible by the investigation of the electrical resistivity of Be pebble beds for different loads and temperatures (Deliverable 10).

The 2001 activities included impurity and resistivity measurements.

12.3.2. Impurity measurements

Several 1 mm NGK pebbles were characterised with respect the oxide scale and impurity distribution. In order to investigate in detail the surface composition avoiding the influence of the curvature of the pebbles on the analysis we studied the pebbles using the ITN microprobe. A 1.5μm H^+ beam was used to scan the pebbles surface and the backscattered particles and x-rays were collected with a surface barrier and Si(Li) detectors, respectively. For the elemental composition of the beryllium pebbles both broad beam and microbeam ion analysis were used. Acid digestion of six different pebbles was performed and broad beam PIXE used for quantitative analysis of Ti, V, Cr, Mn, Fe, Ni and Cu. Using the Fe content as an internal standard, μPIXE was used on six different pebbles to extract information on the Mg, Al, Si, Zr, Au and U contents. The average and standard deviation results obtained in the analysis are reported in Table 12.1.

Element	Concentration (μg/g)		
Mg	116	±	30
Al	376	±	35
Si	305	±	27
Ti	42	±	9
V	19	±	3
Cr	102	±	12
Mn	104	±	13
Fe	1050	±	122
Ni	153	±	27
Cu	113	±	51
Zr	31	±	9
Au	20	±	2
U	103	±	28

Table 12.1 – 1 mm Be pebbles elemental concentration. The reported errors refer to the standard deviation value obtained in the analysis of six independent samples.

12.3.3. Resistivity set-up development and measurements

A new experimental set-up was designed for the resistivity measurements allowing the gas flow and compatible with irradiation experiments of the pebble bed column in the Portuguese Research Reactor. The pebbles are enclosed in an insulating alumina tube with a diameter (D) of 10 mm and a length of 20 mm. This guarantees a value of D/r of 20, much higher than the value of 7 needed to eliminate the influence of geometric parameters (r is the pebble radius). During the filling process the bed was vibrated to obtain a high packing factor. The force is applied by a pneumatic lift through a pressure gauge, which is used to measure the pressure. A thermocouple in contact with the pebbles monitors continuously the pebbles temperature. The drawing of the experimental set-up is shown in Figure 12.3.

This new set-up will allow us to heat the pebble using a heating coil surrounding the alumina tube. A constant current of 180 mA was applied and the voltage drop along the Be pebble bed column measured for different applied loads. The flux of the purging gas mixture (He+0.1%H_2) was kept at a rate of 50 l/h during the measurements. The gas was kept flowing during the heating and cooling of the pebble bed.

During the resistivity measurements up to 800°C the measured oxide scale remained stable under the reducing atmosphere of He+0.1%H_2. The resistivity reveals a drastic decrease after applying the first load due to the mechanical allocation of the pebbles. Further load lead to a linear regime due to the increase of the contact area (Figure 12.4).

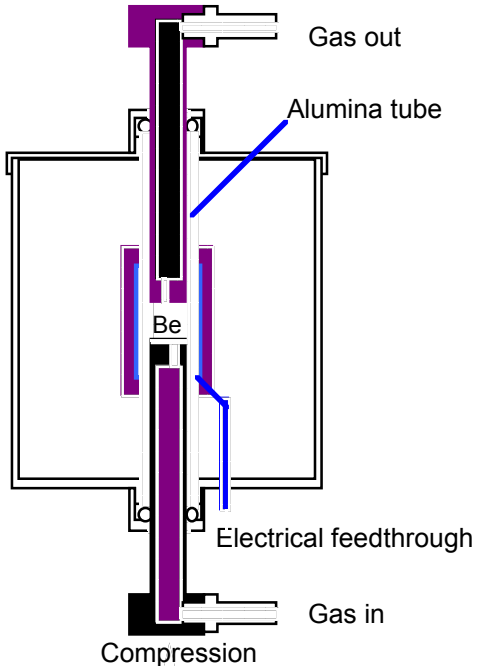

Figure 12.3 - Experimental set-up for the resistivity measurements with flowing gas.

The lower value of the resistivity, 4×10^{-4} Ω.m, is nearly independent of the temperature up to 800°C and was achieved for an applied load of 10 MPa. Although it is impossible to reproduce the envisaged conditions of the fusion power reactor our results are in agreement with the trends foreseen by theoretical calculations. According to our study the resistivity of the Be pebble bed will be higher enough to prevent any current flow in case of plasma disruptions considering the Eurofer as the structural material (ρ= $(1\text{-}4)\times10^{-7}$Ω.m).

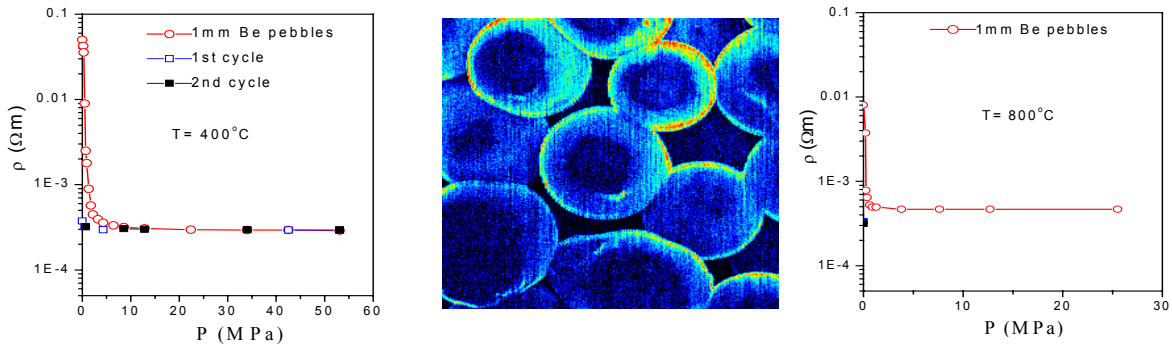

Figure 12.4 - Secondary electron image of a Be pebble annealed at 800ºC and resistivity of the pebble bed at different temperatures as a function of the applied load.

12.4. CHARACTERIZATION OF SiC/SiC COMPOSITES (TW1-TTMA-001)

12.4.1. Introduction

The Association EURATOM/IST has been responsible by the characterization of corroded surfaces and impurity mapping (Deliverable 7).

12.4.2. Characterization of corroded surfaces and impurity mapping

New SiC/SiC_f composite materials have been produced at ENEA by the Polymer Impregnation and Pyrolisis (PIP) process aiming at reducing porosity problems while maintaining good mechanical properties at high temperatures. Two different types of this SiC composite reinforced fibres were obtained, one of them presenting an extra SiC coating created by CVD deposition. Both kinds of SiC/SiC_f were placed inside a Be pebble bed and the whole set-up annealed at 800ºC for 550 h in a reducing atmosphere composed of He+01%H, thus simulating fusion reactor conditions. The whole experimental set-up was designed and built to fit the particular needs of this experiment and installed in a glovebox.

The original virgin samples and the annealed ones were analysed using the nuclear microprobe installed at the 2.5 MV Van de Graaff accelerator of ITN, both for determining the surface impurity contents and for investigating the chemical reactions occurred during the annealing process.

A 2.0 MeV proton beam focused down to ~3μm was used in the nuclear microprobe and elemental maps and depth distribution obtained respectively by PIXE (Particle Induced X-ray Emission) and RBS (Rutherford Backscattering Spectrometry) techniques. Topography contrast was also obtained constructing maps with secondary electrons (Secondary Electron Image-SEI). As can be seen in Figure 12.5, the coated virgin samples present only vestigial amounts of Cl, K, Ca and Fe, whereas the uncoated virgin samples show other type of contaminants such as Cr, Fe and Ni apart from larger amounts of Cl, Ca and the presence of S. Nevertheless, the RBS analysis shows that all these impurities are on the surface and probably due to handling. As a whole, these samples also presented a lower degree of contaminants than the SEP SiC 4D material.

After the annealing procedure, the uncoated samples show that surface oxidation occurs which is accompanied by a strong C depletion and a Be diffusion while for the coated samples these effects are severely reduced. The coated samples even present extended regions were surface is left almost unchanged when comparison is made with the virgin samples. Complementary analysis of the samples with electron microscopy confirmed our findings.

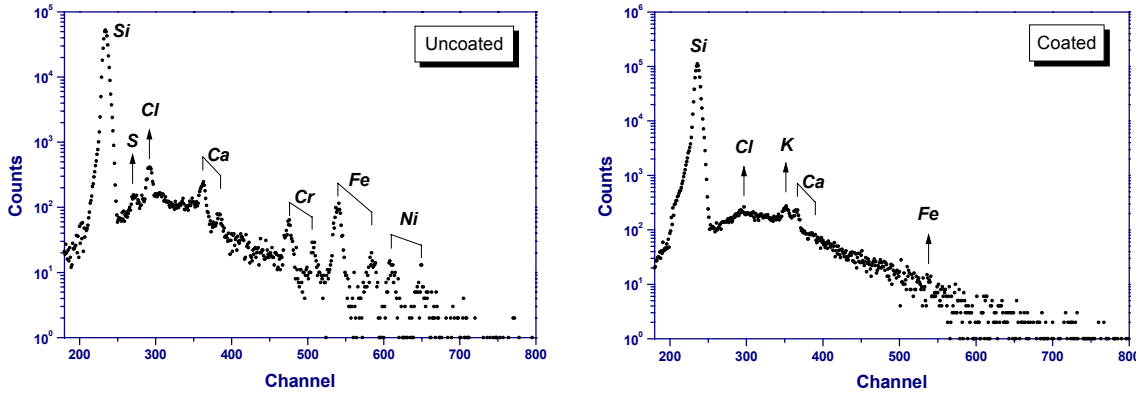

*Figure 12.5 - μPIXE spectra of virgin uncoated (left) and virgin coated (right) samples showing the main contaminants. The spectra were obtained during a beam scan of 2640*2640μm.*

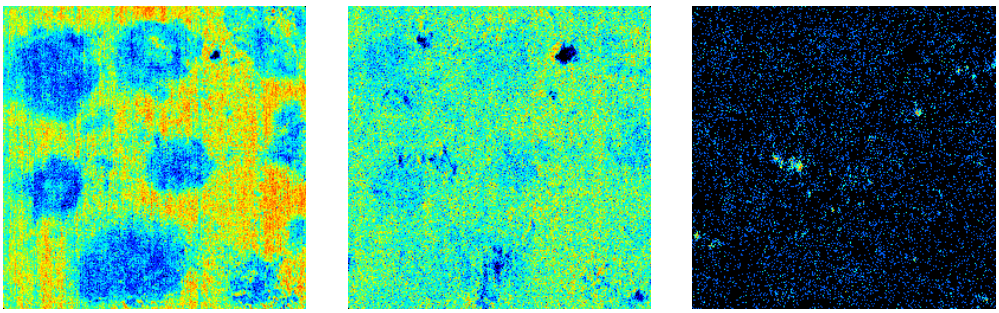

*Figure 12.6 – Nuclear microprobe images from an uncoated SiC sample after the annealing conditions referred in the text. The images were obtained from a 2640*2640 μm^2 scan, and the secondary electron image (SEI) clearly reveals the spots were the Be pebbles were in contact with the SiC material. Also shown are the Si and Cl maps.*

12.5. DEVELOPMENT OF CERAMIC BREEDERS (TW1-TTBB-005)

12.5.1. Introduction

The Association EURATOM/IST is in charge with the following activities:

- Analysis of Eurofer impurities below 10 ppm;
- Surface composition investigations of Li_4SiO_4 and Li_2TiO_3 exposed to long term annealing;
- Compability of structural and cladding materials used in irradiation tests with ceramic breeders.

12.5.2. Analysis of Eurofer impurities below 10 ppm

Due to the delay of the delivery of the samples this task is still running. The new due date is July 2002.

Several samples were cut from the Eurofer heats received and are being measured using the techniques, particle induced x-ray emission (PIXE and neutron activation to identify and determine the impurity content.

12.5.3. Surface composition investigations of Li_4SiO_4 and Li_2TiO_3 exposed to long term annealing

Preliminary results on chemical compatibility tests in fusion relevant working conditions using old ceramic breeder (not the reference material) pebbles were obtained. These studies allowed us to test the capabilities of our techniques to study this kind of specimens.

12.5.4. Compability of structural and cladding materials used in irradiation tests with ceramic breeders

The due date of these deliverables was changed due to delays on the delivery of the material for analysis. The new due date for these deliverables is August 2003.

The characterisation of the ceramic pebbles with the microprobe is running.