PWR Reactor Vessel In-Service Inspection according to RSEM

Yves BOUVERET, Marc ALGAROTTI, Luc HERNANDEZ, Jean Paul LANDEZ, Intercontrôle*, Rungis, France
M. LUTSEN, EDF/CEIDRE, Saint Denis, France

Abstract :
The new In-Service Inspection process provided by **Intercontrôle** has been qualified according to the RSEM standard (the French ENIQ methodology based code). Designed for high-sensitivity inspection, using immersion UT techniques, this process uses a new "MIS" Manipulator, a Saphir^{PLUS} Data Acquisition System, specific focused and focusing UT transducers and dedicated analysis software. High accuracy of crack sizing is obtained (i.e.: ±2mm for under cladding cracks whatever the surface condition is) providing reliable information to utilities and satisfying regulatory requirements.
The "MIS" Manipulator is installed on the Reactor Pressure Vessel (RPV) flange. Each inspection tool is dedicated to the examination of a specific part of the vessel. Scanning speed is as high as 300mm/s and parallel acquisitions are carried out. Because of its sturdy structure, accurate and repeatable scanning is guaranteed even when many years go by between inspections. The MIS is remotely operated from outside the containment using optical fiber. Wide use of network links has lowered the number of cables and connections; most of the cables now run inside the machine structure, avoiding contamination and keeping on with ALARA practice.
Room is left available on the machine to add other tools, either to address new safety requirements (ET has already been done) or to provide RPV maintenance capability (grinding, EDM…).
High-end analysis software developed by Intercontrôle carry out all analysis activities :
- CIVACUVE: segmentation processing for a fast and reliable characterization and sizing of defects with partially automatic analysis process and data reporting,
- CIVAMIS: on-line processing tools (modeling, crack tip diffraction analysis, phase analysis…) to support defect expert appraisal.

1. Introduction

AREVA NP experience in the examinations of reactor components began in the 1970's. Since then, each unit (American, French and German companies) developed automated NDT inspection systems and carried out pre-service and **I**n-**S**ervice **I**nspections, (ISI) using a large range of NDT techniques to comply with each utility expectations. These techniques have been validated by the utilities and the safety authorities of the countries where they were implemented. Notably AREVA NP is fully qualified to provide full scope ISI services to satisfy ASME Section XI requirements, through automated NDE tasks including nozzle inspections, reactor vessel head inspections, steam generator inspections, pressurizer inspections and **R**eactor **P**ressure **V**essel (RPV) inspections.

* *Intercontrôle, subsidiary of AREVA NP, an AREVA and Siemens company*

INTERCONTROLE (AREVA NP subsidiary dedicated in supporting ISI) is one of the leading NDT companies in the world. Its main activity is devoted to the inspection of the reactor primary circuit in French and foreign PWR Nuclear Power Plants: the reactor vessel, the steam generators, the pressurizer, the reactor internals and reactor coolant system piping. NDT methods mastered by Intercontrôle range from ultrasonic testing to eddy current and gamma ray examinations, as well as dye penetrant testing, acoustic monitoring and leak testing. To comply with the high requirements of the company customers, specific techniques and tools are developed whenever deemed necessary: manipulators, probes, pusher-pullers, transducers and software products.

INTERCONTROLE has performed more than **280** reactor vessel pre- and in-service inspections in France and abroad:

- Reactor vessel examinations in France since 1974, including more than 240 vessel pre- and in-service inspections (Figure 1).
- PSI and first ISI of Daya Bay (China) RPV. The contract has been awarded for the Daya Bay first 10-year RPV ISI, to be carried out in 2005 for the unit 2 and in 2006 for the unit 1.
- Reactor vessel examinations in accordance with ASME Sections V and XI since 1981, which include 41 inspections.
- ISI of KRSKO (Slovenia) : RPV (full and partial scope), following ASME code requirements.

Every year Intercontrôle performs the inspection of more than 10 RPV worldwide.

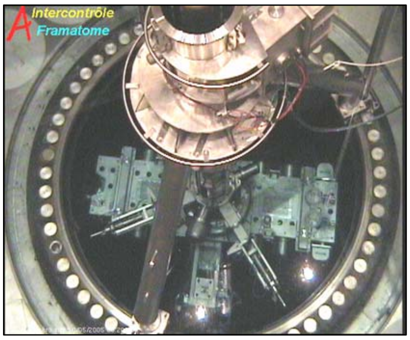

Figure 1 : MIS 7 in the Reactor Vessel

2. Customer requirements for PWR reactor vessel in-service-inspection according to RSEM

The contract awarded to Intercontrôle by EDF in 2003 for PWR ISI required:

- Qualification according to RSEM
- Reduction in the VOT (Vessel Occupation Time)
- Increased NDT sensitivity & accuracy
- Consistency with previous NDT processes to enable easy and reliable comparison
- Easing set-up & rigging… to improve safety and ALARA practice

For a standard RPV inspection following the RSEM rules, the areas to be examined by ultrasonic testing (UT), radiographic testing (RT), are highlighted on Figure 2:
In addition a visual examination (VT3) in carried out over the whole cladding surface of the vessel and the nozzle bore as weld as the bottom head instrumentation welds.

Specific examination procedures of repaired zones in Alloy 600 in the nozzle bore may be carried out in complement to the standard ISI program using Eddy Currents (ET) examination (flaw detection) and UT techniques (flaw characterization and sizing) .

The UT procedures implemented for the ISI are mainly based on immersion technique using focused or focusing probe.

The RT examination of the dissimilar metal welds (DMW) and the safe-end to primary piping welds is carried in panoramic exposure. The Iridium 192 source (7.4 Tbq - 200 Ci) is located on the axis of the nozzle bore with high positioning accuracy (±5 mm) and a set of 8 cassettes are supported by a metallic ring fixed on the outer surface insuring a fine positioning of RT indications. According to type of the RPV to be examined, three or two radiographic exposures are implemented for each nozzle (6 nozzles for 900 MW PWR, 8 nozzles for 1300 or 1450 MW PWR).

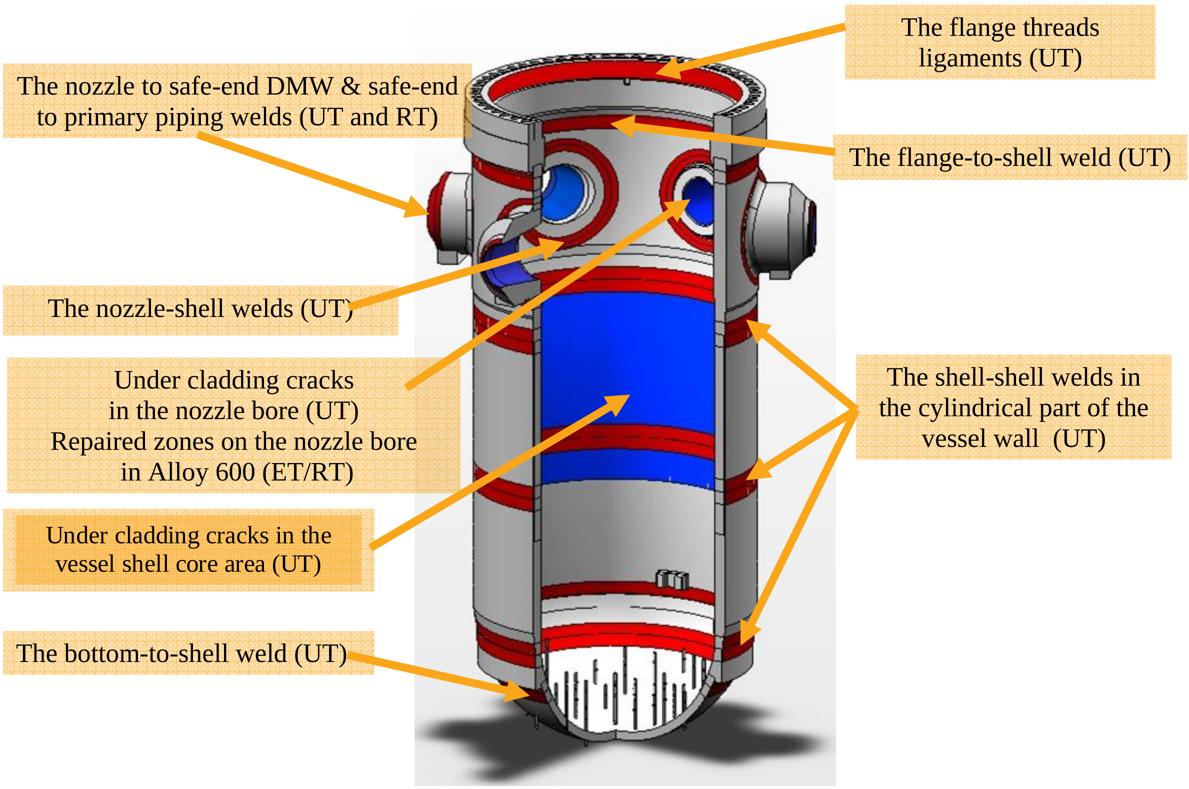

Figure 2 - Target area for RSEM inspection

3. Qualification process

In compliance with the French regulation, the ISI techniques implemented for the RPV examination have to be qualified according to the RSEM code fully compliant with the ENIQ methodology. EDF technical specification defines the type of qualification to be applied for each NDE procedure:

1) UT procedures submitted to a conventional qualification (no defect expected)

- The flange to shall weld (UT);
- The shell to shell welds;
- The bottom head to shell welds;
- The nozzle to safe end welds and the safe-end welds to primary piping (UT and RT);

2) UT procedures submitted to a general qualification (postulated defect) or to a specific qualification (eventual existing defect)

- Bimetallic welds (UT and RT)
- The core area of the RPV and the nozzle bore for the detection of under-cladding cracks (UT).

In both cases, a qualification file has been be established by Intercontrôle composed of the main elements:

- **The technical specification** defining the location and extension of the area to be examined, the detection sensitivity (conventional qualification) or characteristics of flaws to be detected and characterized (general and specific qualification), minimum coverage, location and sizing accuracy, repeatability and reproducibility performances.
- **The Technical Justification (TJ)** : The aim of this document is to justify the parameters of the NDE procedure and to demonstrate that the detection and sizing performances reached by the NDE procedure taking into account the influential parameters actually meet the requirements of the customer. The TJ is based on physical reasoning, results of UT modelling or experimental evaluation tests on representative mock-ups with artificial or realistic flaws or feedback from previous ISI (see figure 3 below).
- NDE Procedures.
- The Personal Qualification Procedure.
- **The synthesis of the qualification process**: This document summarizes the technical specification, the characteristics of the component to be examined, the influential parameters with their nominal value and acceptance deviation limits, the summary of the Technical Justification as well as the results of the qualification tests carried out on full scale mock-ups representative of the field environment.

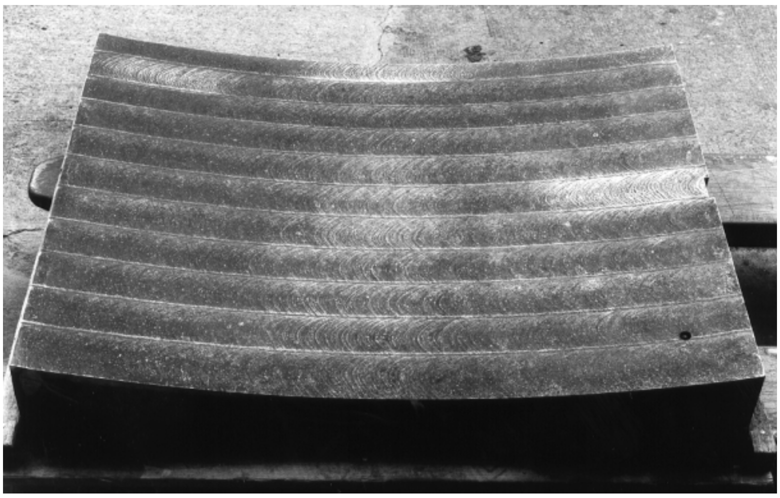

Fig. 3 : Full scale mock-up for the qualification of the UT examination procedure of the core area

At the present date, most of the NDE procedures have been submitted to the French Qualification body hosted by EDF and are presently qualified.

The full set of NDE qualified procedures according to the RSEM code were implemented successfully on site during four 10-years RPV ISI en 2005.

4. Intercontrôle solutions to comply with our customer expectations

Taking advantage from thirty years of knowledge and operational experience, the new In-Service Inspection process provided by Intercontrôle enables 40% shorter VOT (**V**essel **O**ccupation **T**ime) and has been qualified according to the RSEM code (the French ENIQ methodology based code) against a specific committee.

Designed for high-sensitivity inspection using immersion UT techniques, the process uses a new "MIS" Manipulator, a Saphir^{PLUS} Data Acquisition System, specific focused and focusing UT transducers and dedicated analysis software. The high accuracy obtained in crack sizing (i.e.: ±2mm for under cladding cracks whatever the surface condition is) provides reliable information to utilities for satisfying regulatory requirements. To enable fast acquisition, gamma radiography and ultrasonic scanning can be done at the same time. Simultaneous UT pulses target different transducers to save even more time.

Two MIS manipulators of the third generation are now built: MIS7 & MIS8. After assembly and dry system checkout, the MIS manipulator is lowered into the vessel with the building polar crane, and the scanning is then started. The new MIS performance in high-speed precision coupled with the advanced Saphir^{PLUS} UT acquisition system allows a RSEM style examination to be completed in approximately seven days for 900MW RPV, (ASME examination is substantially shorter). The innovative manipulator arrangement supports maximum weld coverage including examination of the flange surface with minimal personnel exposure. Operators are not required inside the reactor building during the complete inspection: they first supervise lowering operations then perform regular monitoring.

5. The MIS manipulator

The manipulator can support full ten-year, intermediate, and follow-up surveillance inspections with minimal disruption of outage activity. Proof of carrier accuracy is provided through thorough measurements before turning it to field work using a portable coordinate measuring machine (laser tracker as seen in Figure 4). The machine main core structure can be moved on a cart that doubles as a shipping support (Figure 5).

The "MIS" Manipulator is to be installed on the RPV flange. Its vertical mast moves up and down, from the flange to the bottom of the RPV, a device called the multi-tool on which all the inspection tools (UT, RT, VT) are attached, thus avoiding time consuming tool changes.

Figure 4 - Checking MIS7 with laser tracker

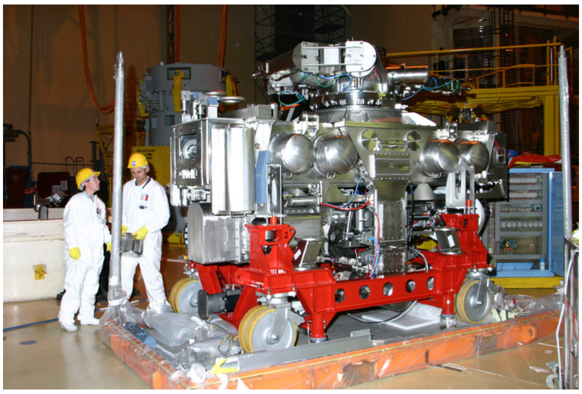

Figure 5 - MIS7 Multi-tool on its cart

Each inspection tool is dedicated to the examination of a specific part of the vessel: flange ligaments, shell welds, bottom welds and nozzle welds. Scanning speed is now as high as 300mm/s and parallel acquisitions are carried out. Because of its sturdy structure, accurate and repeatable scanning is guaranteed even when many years go by between inspections. A 200Ci Iridium 192 source with remote-controlled operation is embedded for gamma radiography of nozzle to safe-end dissimilar metal weld and safe-end to primary piping welds. Contingencies have been anticipated as auxiliary commands can be reached manually, using poles.

The MIS is remotely operated through a PC from outside the containment using numerous position feedback indicators, instrumentation and cameras, (Figure 6).

Figure 6 - MIS Remote operation control panel

The MIS axes are controlled by 10 embedded numerical servo-amplifiers together with 3 PLC (for miscellaneous digital and analog I/O) connected to a CanOpen field bus itself linked to an Ethernet network. Wide use of network links (even monitoring cameras use the network to broadcast their pictures) has lowered the number of cables and connections, improving reliability and minimizing cable management issues. It also eases communication between systems (I&C-Data acquisition system-Data storage system-Analysis system). Most of the cables now run inside the structure of the machine, thus avoiding contamination and keeping on with ALARA practice. For quick and easy set up, the link from the poolside control box to the remote control uses fiber optics in a small rugged sheath (150 meters or more if required). All these improvements make set up of the equipment significantly faster: it requires now less than 12 hours for assembling the MIS manipulator in the reactor building.

Room is left available on the machine to add other tools, either to address new safety requirements (capability to inspect nozzle welds in alloy 182 already exists, associating ET for detection and UT for characterization) or to provide RPV maintenance capability (grinding, EDM…).

6. The data acquisition system

The UT system used with the MIS machine is the Saphir^{PLUS} system (Figure 7) designed and manufactured by AREVA NP GmbH / IntelligeNDT. Many units of this well-established commercial UT system are operational worldwide. The Saphir^{PLUS} instrument and its acquisition software handle new generation activities of qualification and inspection both according to ASME new Appendix VIII PDI and RSEM using focused immersion transducers (ENIQ methodology).

Figure 7 - Saphir^{PLUS} phased array UT acquisition system

7. Analysis process and tools

Because vessel examination data is collected more rapidly, it has to be examined and cleared by the analysts as fast as possible. All analysis activities are carried out on screen, using high-end analysis software (Figure 8) developed by Intercontrôle with the CEA (Commissariat à l'Energie Atomique – the French Atomic Energy Commission).

- **CIVACUVE**: segmentation processing for a fast and reliable characterization and sizing of defects with partially automatic analysis process and data reporting
- **CIVAMIS**: on-line processing tools (modelling, crack tip diffraction analysis, phase analysis…) to support defect expert appraisal.

This package allows user friendly displaying of data and provides ability to:

- Generate standardized views to facilitate systematic analysis of search data
- Define volumes containing reportable indications by encompassing "boxes"
- Allow these volumes to be combined automatically across all the search beams
- Allow the data interpretation operator to define volumes surrounding any potential defects for viewing in three orthogonal directions
- Easily edit examination reports

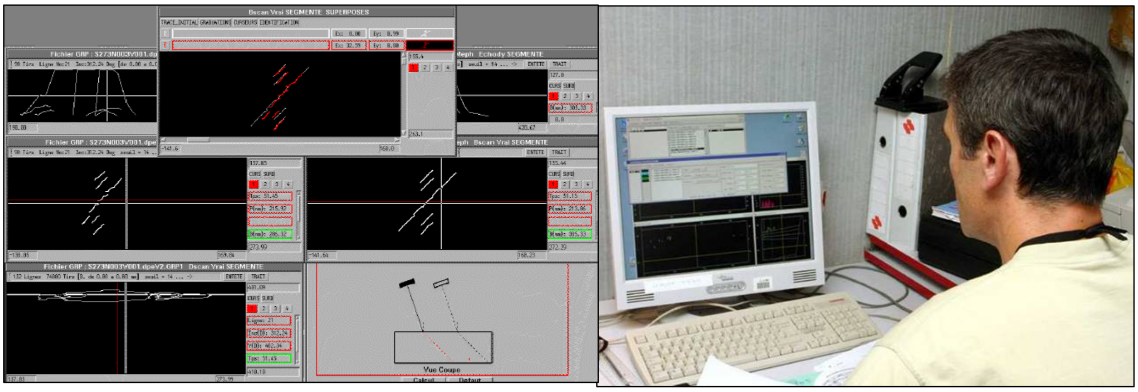

Figure 8 : UT data analysis & software display

8. Computer simulation

Advanced computer simulation (Figure 9) is extensively used for substantiation and improved analysis. As an example, it enables to take into account the effect of cladding to improve accuracy of sizing undercladding cracks.

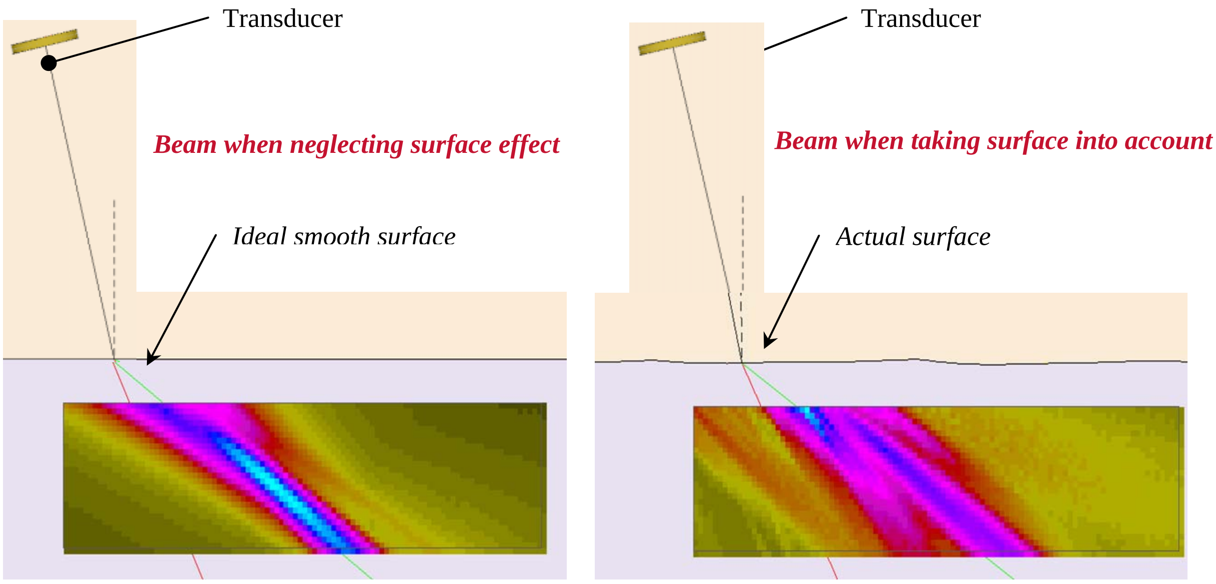

Figure 9 - Computerized UT simulation

9. UT Transducers

When no standard transducer is available to handle the task, Intercontrôle designs and builds tailored transducers (Figure 10 and 11) to meet customers' requirements.

Figure 10 - Transducers arrangement for vessel bottom inspection

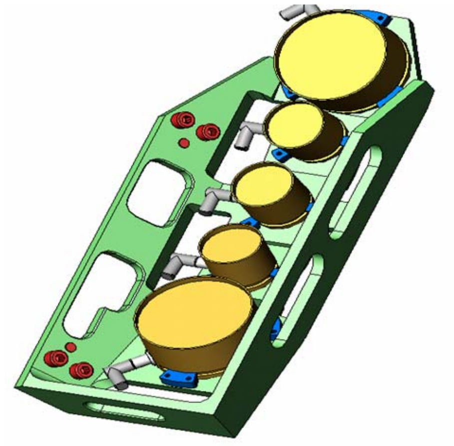

Figure 11 - CAD view of transducers arrangement for nozzle inspection

10. Conclusion

To date, Intercontrôle successfully performed four RPV full ten-year RSEM In-Service Inspections between May and September 2005 with its new MIS, (Figure 12). Each time the Vessel Occupation Time was lower than expected (from 10 to 20%). This proves the efficiency of the new concept (manipulator + Saphir^{PLUS} data acquisition system + Civacuve analysis software) as well as the strong commitment of the crews to provide the best services to our customer.

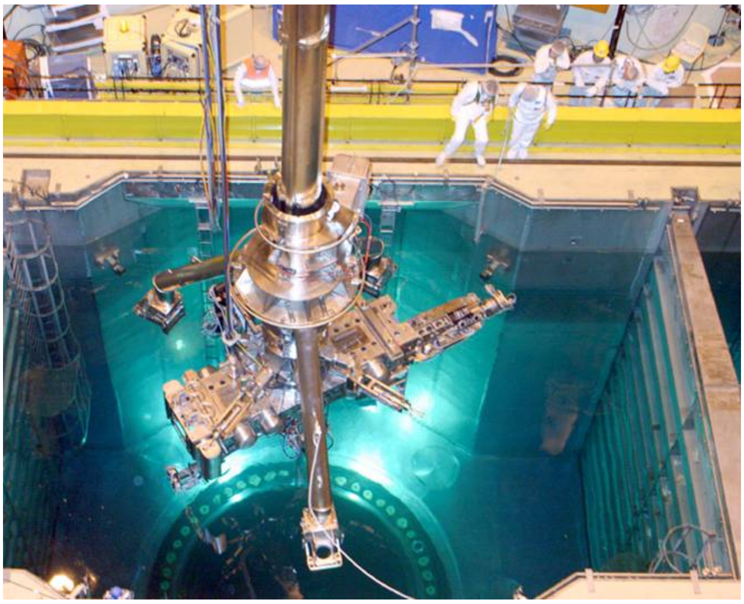

Figure 12 - Paluel 2 ISI, June 2005