ABSTRACT:
AREVA NDE-Solutions German division - intelligeNDT Systems & Services has performed numerous reactor vessel examinations of both pressurized and boiling water (PWR & BWR) nuclear power plants. In the late 1990s Swedish and Finnish utilities requested the nozzle portion of these examinations to be performed from the nozzle inside. This inspired the birth of AREVA’s underwater nozzle manipulator called Fozzie.

Fozzie was qualified to inspect all nozzle related welds including the safe-end to pipe, nozzle to safe-end, and the nozzle to shell welds plus the near-surface volume of the nozzle inner-radius with ultrasonic and eddy current sensors. The design was so flexible that it covered most BWR smaller diameter nozzles and extended to many of the larger diameter PWR vessel nozzles.

Today the need of a reactor vessel nozzle-only tool is increasing. Of course there are a wide range of full vessel systems, but the utilization of the full systems are not cost-effective compared to the simple nozzle-only inspection scope that may be covered by a simpler nozzle-only tool. The new Nozzle Pipe Manipulator NPM is an advancement of the older FOZZIE-Manipulator to address a wider range of nozzles and vessels plus incorporate advancements that allow shorter schedules, minimum polar crane support, and facilitate on-site personnel activities.

An important consideration for the new development was to limit use of polar cranes and other auxiliary handling devices. Furthermore it should be possible to perform all existing FOZZIE inspections with the new tool as well. Design features of the new tool include:
- Positioning the manipulator independently from the bridge or other auxiliary handling devices – (positioning in front of the nozzle by swimming as a submarine)
- Adjustment of the mechanics to cover all target P&BWR nozzle inspection areas for 2nd generation existing plants in the US, SA (Koeberg), and Germany plus 3rd generation new built plants (OL3, FA3).
- Optimized position of the cameras for (monitoring of the mounted probes, obstacle collision avoidance, manipulator positioning)
- Flexible cable management
- Reduction of the amount & dimension of cables as well as air tubes between control unit & manipulator

The NPM has been designed for inspections of the nozzle-to-shell weld (N2S), the nozzle inner radius (NIR) and the nozzle to pipe welds. The new version covers a wider range of inspection areas as outlined below:
- Nozzle inner diameter from 85mm to 800mm
- N2S-Weld up to a diameter of 1500mm
- NIR up to a diameter of 800mm
- Nozzle to pipe weld up to a depth of 1500mm

Benefits of the new NPM include faster and more economical nozzle-only inspection using a smaller inspection crew. If required, the vessel occupation time of a full vessel inspection may also be reduced by using the NPM working in the nozzles in parallel with a full RPV inspection system working on the shell welds. This new tool in AREVA’s Submarine family will help to reduce inspection time & cost, by integrating the latest technology and thereby broadening AREVA’s portfolio of highly reliable inspection tools.
INTRODUCTION
As a leading company in the field of building and servicing nuclear power plants, AREVA places a heavy focus on quality and safety in our day to day business. High performance pressure vessels for reactor coolant and steam supply systems require checks following the initial welds, following any repair, and periodically through the plant life to guarantee a high level of quality and to assure the overall integrity of the system. For components of the primary circuit, the requirements are well defined and are strongly checked by authorities and regulators. Non destructive testing (NDT) plays an essential part in the chain of quality checks which are performed in the plants. The US, French, and German NDE groups within AREVA each have a long history of NDE experience and a rich collection of tools and techniques to service the nuclear industry. To optimize this NDT workforce and to create more benefits for our global customers, the NDT-activities were bundled under one global management and named “AREVA NDE-Solutions” in 2010. Within this organization there are many engineers, scientists, and experts with more than 30 years of NDT experience in nuclear power plants built by various OEMs. AREVA’s goal is not only to satisfy their customers by delivering what is ordered, but also to find ways to exploit our global expertise and optimize the outage process for cost, schedule, dose and safety.

BACKGROUND:
In the past, RPV nozzles were inspected in the same cycle as the RPV because this capability was part of the full RPV inspection scope and was part of the full RPV inspection tool’s capability. The RPV inspection tools are quite heavy and need significant time to stage and install in the reactor and require a significant number of qualified operating staff (figure 1 & 2). As long as the outage reserves enough time for performing a full RPV exam including nozzle exams, this provides the most complete inspection alternative. In some cases however, a full vessel examination is not needed. In some cases the code has been relaxed to allow longer intervals between full vessel inspections even though nozzles must be inspected more frequently. In other cases, nozzle indications have been noted that must be regularly rescanned to confirm no growth or change in the indication. In such cases, the full-vessel inspection tool is an overly complex tool than may be more costly and more time consuming to deploy than a nozzle-only tool.

![Fig 1 CMM and for full vessel examination (left) and the nozzle attachment (right)](image-url)
In order to achieve the lower-cost, lower-schedule, and simplify operator demands, the nozzle-only tool must be able to reach the nozzles without the polar crane, it should be able to cover a large variance of nozzle dimensions, it should be easily handled by a small team, it should be easy to ship and easy to be decontaminated. It must also be as flexible as possible to cover all the requirements, inspection techniques required by the different codes and existing qualifications in various countries.

Many of the BWR nozzles can be inspected from the OD. This however carries significant dose penalties and sometimes due to obstructions, if difficult or impossible to do from the OD. In the late 1990s, Swedish and Finnish BWR nuclear plants requested to inspect nozzles in a BWR RPV from inside. The inspection was to be done under water with a simpler tool from the large full-vessel manipulator. The polar crane should also not be used continuously during the inspection to allow other outage tasks to continue in parallel. Together with our customers, the German branch of AREVA NDE-Solutions, IntelligeNDT System & Services GmbH designed a nozzle-only inspection tool named “FOZZIE A” (figure 4, 5 and 6). This manipulator was manufactured, and tested in the Erlangen laboratories. The “FOZZIE A”-tool was qualified according Swedish and Finnish code to perform all primary ID stand-alone ultrasonic and eddy current nozzle examinations including: safe-end to pipe, nozzle to safe-end weld, nozzle inner radius and the nozzle to shell weld. The design was so flexible that it covered most smaller diameters of BWR, and could be adjusted and extended to larger diameters of many PWR vessel nozzles. After successful performance in Sweden and Finland, lessons learned were incorporated into a second scanner that also had better coverage capability. This tool was designated “FOZZIE 2”.

Fig 2 CMM nozzle attachment with KTA acquisition probe arrangement
NPM DEVELOPMENT
In the last years, mostly driven by lifetime extension programs worldwide, stress modelling has been performed on the components of the primary circuit. These modelling results have shown that nozzles may have high stresses in their inner radius and safe-end welds that may be particularly susceptible to cracking. This result includes not only the smaller nozzles of typical German BWRs but also the larger PWR nozzles. Therefore more inspections on the nozzles are required. Competing with demands for more inspections are utility demands that the outage times must not expand, and the mandatory refueling activities in the pool must not be hindered. A big restriction for parallel activity is dependence on jibs and cranes. AREVA’s SUSI submarine has been quite successful performing various internals and vessel VT inspections completely independently of these containment resources (figure 7). This fostered the idea within AREVA to design a new swimming Nozzle Pipe Manipulator (NPM) combining the experience of FOZZIE with the submarine SUSI technology to achieve the target inspection performance while virtually eliminating dependence on crane or bridge support.
This new Nozzle Pipe Manipulator (NPM) has now been developed, successful qualified and deployed. The new manipulator is designated for the inspection of EPR, PWR and BWR nozzles. Inspection areas include; all inside surfaces and pipe welds plus the nozzle inner radius and the nozzle to shell welds. Some J-groove welds in the cylinder (without Bottom Mounted Instrumentation, BMI) plus ID shell inspections for small areas with an XY-tool are also optionally inspectable.

The design focuses on optimizing the outage activities. During the inspection neither the auxiliary bridge nor the refueling machine are needed as long as the water level is above the nozzle. The NPM can swim from nozzle to nozzle under remote control by a submarine pilot.

Design features of the NPM include the following:

- Cameras: Cameras for monitoring the mounted probes, watching for obstacles to avoid collisions, and for checking manipulator positioning are integral to the design. The cameras may be positioned above and below the tool and/or to either side of the central tool axis to avoid parallax error. Cameras are also included for monitoring the area around the manipulator to view the UT head from either side or from above and below.

- Flexible cable redirection: For maintenance, the preferred direction of the outgoing cable is towards the ground; for operation inside the RPV, the cable is most conveniently routed upwards. The direction of the cable is managed by the cable chain. (Figure 8.)

- Cable & Hose reduction: Reducing the amount and dimensions of cables and air tubes between the control unit and manipulator was essential to the design success. This is achieved using on-board electronic controllers and power-cube electronics resulting in improved cable management.

- Field bus cable management: Connecting all NPM sensors and motors inside the manipulator via field-bus devices improves the overall reliability and simplifies the cable management.

- On-Board Pneumatic control: Pneumatic valves are also managed via the field-bus. Having on-board valve packs minimizes air lines to the NPM.
• Pneumatic drives for centering control: Automatic centering of the manipulator within the nozzle uses 4 analog distance sensors arranged at 90° intervals around the tool. The system measures concentricity along the nozzle axis. The measured values are then used to calculate the best correction of horizontal and vertical pan and tilt to obtain best fit concentricity. The position correction is performed using the 4 tool pneumatic motors. (Figure 9)

• Low water inspection: Should it be necessary to inspect the nozzles with the water level below the nozzle level, AREVA has equipped the CMM head assembly with squirts to deliver water couplant between the transducers and the nozzle surface. The NPM was designed to support this kind of inspection if necessary.

• Neutro Buoyance and Swimming control: The NPM is able to float and swim like a submarine. In this case the crane or other lifting device is only used to bring the manipulator into the pool or to lift it out. This option is realized by modifying the existing SUSI control system so it is able to carry the Fozzie-like NPM to the nozzle area to be inspected. (see Fig. 10 and Fig. 11). The total weight of the manipulator with submarine is approx. 300 kg. Because of the swimming capability, the NPM is substantially independent of the jibs or cranes.
The first on-site applications was performed during the spring 2012 Koeberg Nuclear Power Plant in South Africa. An indication in the RPV nozzle-to-shell weld from a former inspections had to be reinspected. This is the ideal application for the new scanner. No regular RPV inspection was planned therefore no full-vessel inspection tool was required. A short inspection with minimal interference with other activities in the pool was requested. The required inspection areas are marked in Fig. 11 and 12.

Before deployment, the new NPM scanner was rigorously tested in Erlangen Germany. Tests included basic functionality, the setup procedure, all tool movements, positioning resolution and accuracy, the ability to swim and position from one nozzle to another, plus interactions with the UT...
system. Images from these tests are shown in figures 13 through 18. The test phase was also used to train and qualify the operator for using the new tool.

The inspection was performed as planned within the schedule time, with the required accuracy, and with the expected “no-growth” indication results compared with the former inspection data leading to complete customer satisfaction.
Figure 18: NPM ready to be installed into the pool