NEEDS FOR MASSIVE MOCK UPS AND CHALLENGES IN MANUFACTURING OF THEM FOR QUALIFICATION PURPOSES

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ABSTRACT

Fortum operates two VVER-440 nuclear power plants units in Loviisa, Finland. The main focus of the in service inspections of the primary circulation components are in ensuring the reliable and safe operation of the both units. These components are reactor pressure vessel, pressurizer, and steam generators including piping, valves and pumps linked to them. The in-service inspections of components are closely following ASME Section XI requirements. Inspection objects of the components are qualified according to Finnish qualification rules, closely following ENIQ recommended practices. Over the years, Fortum has gathered experience on inspection qualifications and on fabrication of own mock ups and defects.

Primary components have significant safety importance. The importance of the integrity of the primary components is the main reason to invest in the development of qualification. This includes development of the manufacturing techniques, purchasing relevant material for the mock ups and finally improving the qualification of the inspection system. Also the fact that main components are effectively not replaceable has to be considered when evaluating the needs for massive mock ups.

Massive mock ups are needed for the above mentioned components. It has been said, that the qualification of the inspection system will be as good as the used test blocks. The goodness or effectiveness can be estimate with several parameters. Probable the most significant factor is the authenticity of the mock up and more precisely the geometry and the materials of the test block. As known the main goal in qualification is to perform the capability of the selected inspection system (includes used manipulator, probes, data etc.) and that the inspection system fulfills requirements set up for the inspection.

Main focus in this paper is in the challenges in manufacturing massive mock ups, both in general and with respect to two different cases with similar challenges. Also reasons for use of the mock ups have been discussed. To have more practical view of the challenges, these are presented via two on-going cases.

Challenges in manufacturing of the massive mock up consist mainly from the way to handle the test pieces; is the mock up transportable to work shop. Is it needed to move the flaw manufacturing systems to the mock up. Preparing defects to emergency cooling nozzle inner radius in full-scale reactor pressure vessel and bottom head of the pressurizer for qualification purposes will be presented as example cases.

INTRODUCTION

Fortum operates two VVER-440 nuclear power plants units in Loviisa, Finland. The main focus of the in service inspections of the primary circulation components are in ensuring the reliable and safe operation of the both units. These components are reactor pressure vessel, pressurizer, and steam generators including piping, valves and pumps linked to them. Also these primary components have significant safety importance. The in-service inspections of components are closely following ASME Section XI requirements. Inspection objects of the components are qualified according to Finnish qualification rules, closely following ENIQ recommended practices. Over the years, Fortum has gathered experience on inspection qualifications and on fabrication with subcontractors of own mock ups and defects. Tight cooperation with Finnish companies Mekelex (EDM machining) and Trueflaw Ltd (thermal fatigue cracks) has started already early in their starting history and the cooperation still continues and develops.

The importance of the integrity of the primary components is the main reason to invest in the development of qualification. This includes development of the manufacturing techniques, purchasing relevant material for the mock ups and finally improving the qualification of the inspection system. Also the fact that main components are effectively not replaceable has to be considered when evaluating the needs for massive mock ups.

The main goal in qualification process is to verify the capability of the selected inspection system (includes used manipulator, probes, data etc.) and personnel to do inspections with qualified inspection procedure. During the qualification process, the inspection vendor selects techniques for inspection and also justifies selections in technical justification. Selections shall fulfill the requirements presented in the input information. Functionality of the selected inspection system is performed in open trials and witnessed by the qualification body Capability of the Inspection personnel to do data analyzing is performed with blind trial. In Blind trials the data is collected with selected inspection system. Blind-trials are also witnessed by the qualification body.

WHY MASSIVE MOCK-UPS ARE NEEDED

In Loviisa power plant cases the principle to use as authentic and representative mock-ups as possible, has been followed as often as possible. The geometry, size and materials of the mock-up should be as close to real situation as possible. In minimum, in the open trials have used at least geometrically as representative mock-ups as possible. Massive mock-ups for qualification process are usually needed in the cases where inspection objects are in the massive components like pressurizer, reactor pressure vessel etc.

Modeling is seen also as a potential option. The number of the flaws for qualification can be increased with modeling, but it does not replace the need to use mock-ups. The inspection performance especially in the open trials is needed to verify the inspection system in operation. Performing the actual sound paths is also one of the advantages while using the full scale massive mock-ups. Also, manipulator design results and further development needs can be discovered in testing due to the representative inspection conditions.

The goodness or effectiveness of the qualification process can be estimate with several parameters. Probably the most significant factor is the authenticity of the mock up and more precisely the geometry and the materials of the test block. The lack of representative materials is generally the reason that massive test blocks are not used. Years ago Fortum was able to purchase authentic full scale primary components which have been used for qualification purposes in resent year. These components include steam-generator, reactor pressure vessel, reactor pressure vessel head and all the internals.

The largest mock-up project up to date was the manufacturing of the collector nozzle to steam generator (dissimilar metal weld). Other large mock-ups were manufactured even before to main circulation pipe inspection qualification purposes. In these components more authentic materials were used . In contrast e.g. to the bottom head mock-up of pressurizer where western type of materials were used.

Fortum has been able to use authentic mock-ups for qualification in those cases. Materials and geometry could not be closer to real situation. After decision to use the massive mock-ups in qualification purposes manufacturing activities were started. For first massive mock up case was selected the qualification of the emergency cooling nozzle inner radius (TH-NIR). Before the manufacturing of the flaws to the reactor pressure vessel (RPV) TH-NIR, all manufacturing systems had to be redesigned to be movable.

In the first phase the manufacturing started with pressurizer bottom head which was assumed to be simpler than the full scale reactor pressure vessel. Bottom head of the pressurizer was seen as an excellent place for training and testing of the defect manufacturing systems. In addition, the development work of the defects manufacturing systems would not be needed during the defect manufacturing for TH nozzle inner radius. In that second phase the target was to use advanced manufacturing method without time consuming development work.

Needed practical training was one of the reasons to manufacture the full scale mock-up for qualification of the pressurizer bottom head inspections. In that case the manufacturing had to start by purchasing the bottom head of the pressurizer.

INSPECTION OBJECTS TO BE QUALIFIED

Example cases of this paper are related to the qualification of the inspection objects in pressurizer bottom head and emergency cooling nozzle in reactor pressure vessel. Both of these components inspection objects will be externally inspected with ultrasonic examination with long sound path.

In bottom head mock-up consists several inspection objects where to manufacture the defects. The most critical inspection object of the bottom head of the pressurizer is the inner radius of surge line nozzle, corrosion sleeve and its fixing weld in addition to dissimilar weld of nozzle. Also fixing welds of thermal sleeve holders that are located near the critical inner radius area are important.

In the rector pressure vessel there are four emergency cooling nozzles where to manufacture defects and one inspection object in each nozzle in proportion to the pressurizer inspection objects. Inspection objects are presented in Figure 1 through to Figure 3.

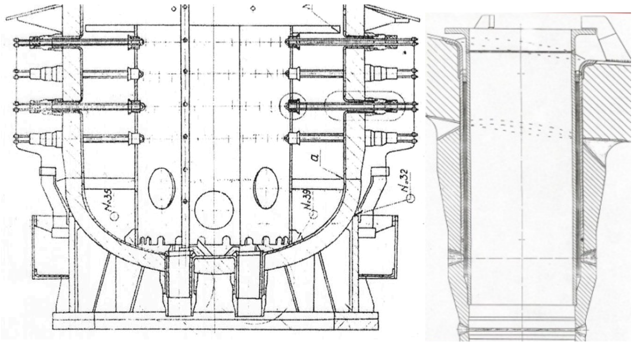

Figure 1. Bottom head of the pressurizer on left and example from the nozzles on right

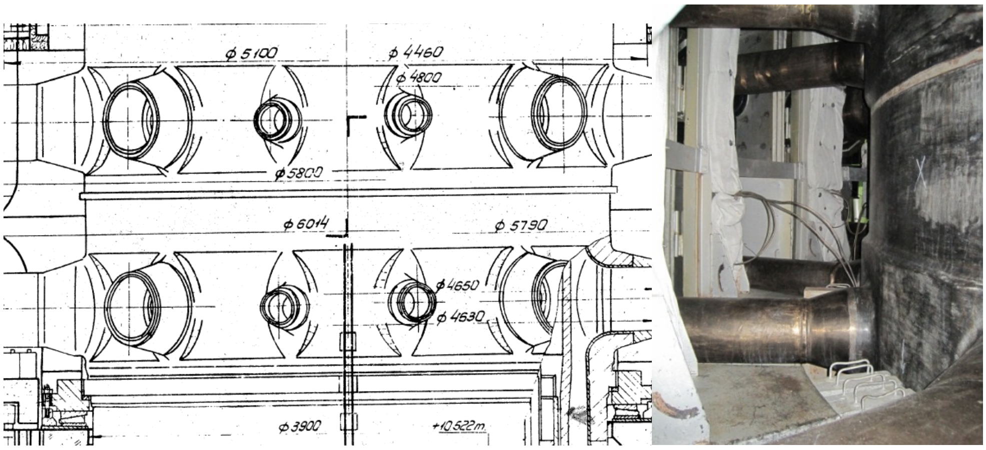

Figure 2. Front view from the reactor, TH-NIR in the middle on the left side and challenging inspection environment on right

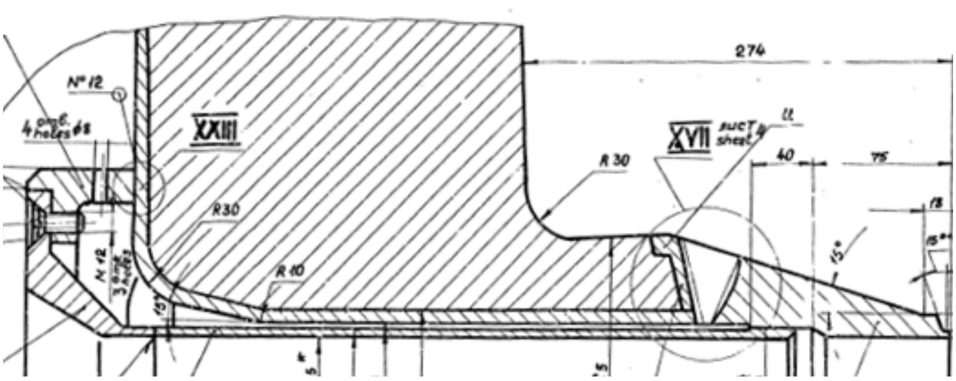

Figure 3. Crossection from the emergency cooling nozzle, inspection object is nozzle inner radius (TH-NIR)

REQUIREMENTS FOR THE MOCK-UPS

Any special requirements as compared to "smaller" mock ups were not placed. Test block design and selection of flaw types to be manufactured are performed by the utility based on the input data for qualification of the inspections. ASME XI principles have been applied in designing of the mock-ups. Same artificial defect types have been used to massive-mocks up as to other mock-ups. Detection targets and critical flaw sizes have also guided the selection of flaw fabrication methods. Used artificial defect types are thermal fatigue cracks, electro discharge machining EDM notches, solidification cracks and implantation defects. As the different types of defects have their advantages and disadvantages in detection and sizing, whole arsenal of manufacturing methods was desirable

The amount of the defects is mostly limited due ASME requirements of the grading unit, which should be at least 75mm. Current requirement has been followed in designing of the defect population. Also requirements presented in the input information for the qualification have been followed. These requirements are, among the other things, the detection target, specific and postulated defect types and assumed locations of them.

SPECIAL CHARACTERISTIC OF THE MANUFACTURING THE MASSIVE MOCK-UPS

The challenges in manufacturing massive mock ups can be discussed in general and with respect to two different cases with similar challenges. Also challenges can be described as expected and unexpected difficulties.

Expected challenges consist mostly from logistic and handling issues of the mock-up and manufacturing equipment. Difference between the cases consists from the situations where either the mock-up or equipment is moved. Other challenges consist from handling of the mock-ups. Smaller full size mock-ups can be moved and rotated to optimal position for manufacturing. Respectively transportable massive mock-ups e.g. bottom-head of the pressurizer can be moved to manufacturing system at workshop, but used manufacturing system shall be assembled to optimum position for manufacturing. Similar challenges consists in cases where manufacturing has done near mock-up e.g. full size reactor pressure vessel which is not transportable to the subcontractors due to the limitations of the workshops. Respectively field conditions set requirements for manufacturing systems. These are mainly consists from the limited yearly time window and also limited space around the reactor pressure vessel (RPV). RPV and other main components are stored to hall which used as a welding hall during the building time of the Loviisa power plant. Since then the hall has been modified to storage hall.

From the utility point of view, when deep surface or sub-surface cracks are needed to be fabricated into finished component surface, welding of solidification cracks is the easiest, cheapest and often representative enough as fatigue cracks, compared to other type of flaw options, to be used in ferrite and austenitic structures. Shallow solidification cracks are hard to produce as surface breaking. Logistic and handling issues, limited yearly time window among other challenges are presented in more detail via two similar cases. Challenges in flaw manufacturing are also presented.

MANUFACTURING OF THE PRESSURIZER BOTTOM HEAD MOCK-UP FOR INSPECTION QUALIFICATION

The simulation of the real inspection situation requires the same thickness as the bottom has. Also The frame structure around the bottom and the legs were designed at Loviisa NPP to simulate the inspection circumstances under the bottom. The solution was to order bottom from Germany with the same dimensions and shape as the pressurizer bottom. Welding of the cladding and manufacturing of the frame structure were done in Finland, Figure 4.

Figure 4. Half-finished bottom on the left and frame structure on the right.

Expected challenges were considered from the transportation and handling issues point of view in the workshops. Heavy lift transportation itself isn't a problem thus the pressurizer bottom head with the frames weight about 7 tons. Moving and handling the mock-up inside the workshop were assumed to be challenging, because a small fork lift would not be able to lift samples and bridge crane was not available. Moving of test block inside the workshop was settled by using U-profiles beams as a rails with roller set to roll along guides on the floor.

Expected challenges also observed to cause from undersized working facilities. Work shop facilities were updated to increase the work safety by improving ventilation and assembling curtains from floor to roof to limit grinding dust. Unexpected challenges caused from the repair and grinding of the cladding. The work took about four months of production time and caused extra costs. SAW welding of cladding layer on inner surface of bottom was a challenge for the welding company. Poor connection of parallel, adjacent strip welded passes and many welding defects in cladding caused long grinding job before the bonding of cladding could be inspected. Also due to the disturbing grinding work behind the curtains, other test blocks were not possible to be manufactured at the same time.

As mentioned, several types of artificial flaws have been manufactured. Used methods have been solidification cracks, aid-piece flaws, thermal flaws and EDM-notches. The deep cracks were produced by welding solidification cracks and shallow cracks with thermal fatigue by Trueflaw Ltd. Also narrow EDM notches with shape of crack front have been used.

Unexpected challenges did not occur during the flaw manufacturing by welding methods. Moisture were expected to occur during the flaw manufacturing and it removed with heating the mock-up. Remove of the hydrogen were daily time-consuming task. Anyhow work was necessary to do to avoid unexpected flaws.

Manufacturing of the EDM-notches did not cause either an unexpected challenges. Typical challenges which are expected also during normal EDM machining. This were e.g erosion of the electrode, re assembling of the electrode due to malfunction and impropriate parameters for current task. Usually parameters are needed to adjust during the manufacturing depending the material properties and size of the manufactured flaw size. To have acceptable process and tolerances to flaws in EDM machining, the head of the EDM machine shall be sturdy assembled. During the manufacturing process the head is not allowed to vibrate. Assembly system of the EDM machining is presented in the Figure 5.

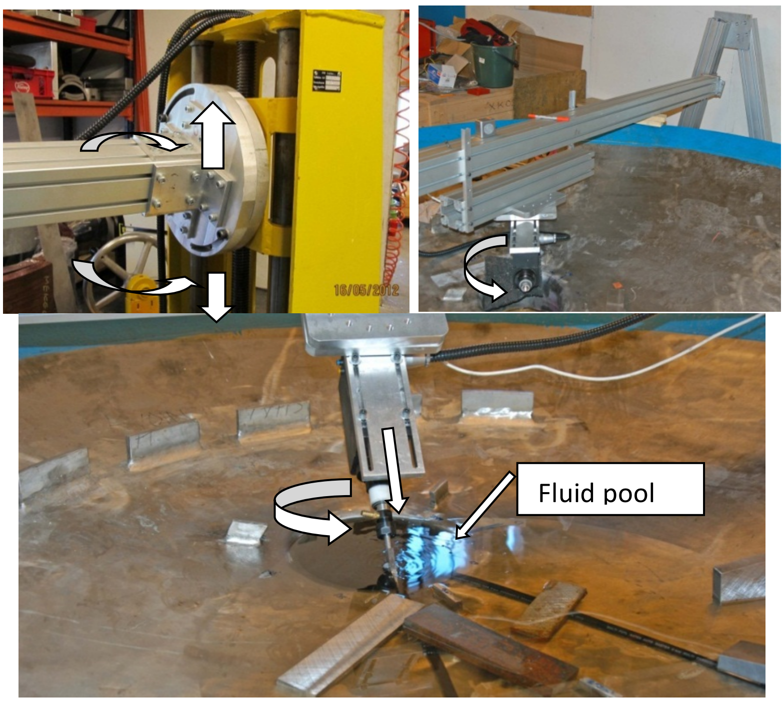

Figure 5. Assembly of the EDM machining system for YP-pressurizer bottom head flaw manufacturing. Adjustment movements are marked with arrows.

For Trueflaw, the pressurizer bottom was the largest mock-up to date. This caused some need for special arrangements. In particular, moving the heavy mock-up from transportation vehicle into suitable location at the shop floor and back to transportation vehicle required special attention (see Figure 6). The production location and transportation was well planned ahead and went accordingly. For flaw production, the mock-up size caused some additional challenges. The mock-up could not be rotated to optimal location for accessibility. Thus, the designated flaw locations were out of reach for normal flaw production tools. Special tooling with extended arm length was developed for this application. The extended arm also resulted in increased tool flexibility, which necessitated some additional fixtures to allow reliable flaw production. Although the need for further tooling was foreseen, it was also recognized that the specific needs may change due to changes in flaw location or sample orientation. Thus, the tooling was completed when the sample was already in place and tools could be adapted to the exact requirements of the situation. Overall, combination of good preparation and adaptability made producing cracks to massive mock-up successful without major extra effort.

Figure 6. The Massive mock-up rolled into Trueflaw facilities.

Modification of the assembly system during the manufacturing is also expected. Manufacturing process is also a learning process and observed limitations in the design are addressed. As mentioned the mock-up cannot move to optimum position, the manufacturing system shall be moved. In some cases the assembly is not flexible enough due to the temporary assembly of the machining head.

MANUFACTURING OF THE DEFECTS TO TH-NOZZLE INNER RADIUS INSPECTION QUALIFICATION

Based to experiences form the flaw manufacturing to the pressurizer bottom head mock-up and other mock-ups during the resent year, flaw manufacturing to authentic RPV was ready to begin. In this time the flaw manufacturing systems were moved away from workshop to the field conditions. Manufacturing was done in the storage hall at the Loviisa power plant area. In field conditions more detail design for manufacturing arrangements and flaw placement. Thus the mock-up is lying down, all manufacturing systems have their optimal grades which to use. Also the work safety issues, manufacturing of the defect or documentation procedure were observed more detail than in workshop manufacturing.

First preparation work was done already on the 2008. Then the thermal shields from the nozzles were removed. During that work the firs unexpected challenge occurred. Machining work were notable larger and took longer than expected due that the thermal shields were fully welded to RPV. Assumption was that there is only sealing weld and screw fixing. Work with RPV continued on 2012 after manufacturing of the pressurizer. Trueflaw started the flaw manufacturing work at the end of the summer 2012.

Unexpected challenges were observed and also solved during the manufacturing processes due to the environment. The weather conditions were expected to cause challenges during the manufacturing of the defects to reactor pressure vessel. One of the biggest challenges was that the manufacturing time window had to be scheduled to the summer / autumn time. Used storage hall for manufacturing is equipped only with the power supply and is without heating system.

In generally manufacturing systems worked as expected. Mostly challenges were related to the auxiliary systems which are usually permanently installed to function in work shop. Thermal fatigue flaws and EDM-notches are manufactured with remote control and surveillance system via mobile phone net. To ensure reliable connection to net took more time than expected. During the EDM manufacturing similar requirements were not needed than during the fully remote controlled thermal fatigue flaw manufacturing.

For Trueflaw, the most significant challenge was moving the production to remote location and inside the reactor pressure vessel. Although the flaw manufacturing machines ("flawmakers") were designed to be modular and transportable, this had never been tried before. Also, all the flawmakers are connected to central control computer and central database. This provided several possible configurations for remote operation and it was decided to use single central database for all machines while using separate control computers for both locations. This allowed remote monitoring and control of the units while still supporting continued operation in case of intermittent network errors. The flawmakers are also designed to monitor possible error conditions and stop in case of error. The remote machines were connected to central database and control computers through 3G mobile data network. The arrangement was "dry-tested" in the shop floor to make sure it operated as planned.

The dry-tested arrangement was then moved to production location. The arrangements at the site were good and thus getting the machines into location and re-connecting the machines went well. Figure 7 shows the production machines in the location, inside the reactor pressure vessel. After production started, network connectivity provided additional challenges. While the mobile network had worked well during testing, in actual location the link was more error prone and network hardware experienced intermittent crashes that required rebooting the devices. The remote location also increased the occurrences of some (rather harmless) error conditions. This combined with network problems caused excessive machine down time and slowed flaw production in the beginning. It took numerous trials until robust network configuration could be established and the final system included both better hardware as well as local link-status monitoring and automatic recovery. Furthermore, as the final locations of the flaws were decided, it became evident that some of the planned production optimizations could not be used.

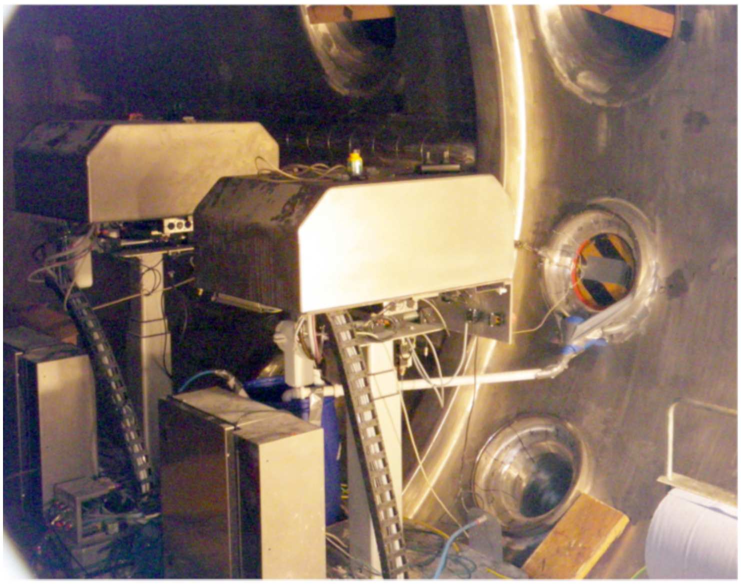

Figure 7. Flawmakers on location at Loviisa, inside reactor pressure vessel.

After the initial problems, the production advanced smoothly. However, the combined effect of the early delays provided its own problems. Over time, the approaching winter caused outside temperature to drop (sometimes to -20°C or below). This caused the working conditions to deteriorate. Furthermore, the flawmakers started to experience cooling water freezing problems. These were remedied by local heating and addition of anti-freezing agent to the cooling water. Despite these final problems due to outside temperature, the flaw production was completed successfully and the production quality for the flaws is as good as it would have been in the shop.

Manufacturing activities continued again on the summer 2013 with solidification cracks. After that all EDM notches have been manufactured. Changes in material properties caused an unexpected challenges during the openings for welded flaws. Due to the hardness differences from expected the used manufacturing tools were needed to be changed. Local heating was also needed to avoid moisture based hydrogen problems. Similar challenges in assembly of the EDM machining occurred as during the machining of the pressurizer bottom head. Also expected normal machining challenges at the beginning of the machining had to be solved. After optimal parameters were reached the position of the EDM head has been the most challenging task to do. In this case the modification needs could not be excluded to predesigning. General view from the assembly of the EDM manufacturing system and assembly of the EDM machining head are presented in the Figure 8. Parts of the system is located to outside of the reactor pressure vessel, the air filter of the local ventilation and fluid collector (see the Figure 9). There can be seen the plugged nozzle which is also used as the pool for fluid.

Figure 8. General view from the assembly of the manufacturing system on left and assembly of the EDM machining head on the right

Figure 9. General view from the assembly of the manufacturing system outside of the reactor pressure vessel. In the front right is fluid collector and on the left side behind is the air filter of the local ventilation

CONCLUSION

Massive mock ups are needed to verify inspection procedures with qualification process to ensure integrity of the components. As mention the geometry and used material should be as authentic as possible for all inspection mock-ups. Especially authenticity is probably most effective factor in the open-trials where selected inspection technique is demonstrated to fulfill determined requirements. Under the circumstances the massive-mock ups are used and manufactured for qualification purposes of the primary components inspection objects. In addition to verified inspection procedure, the quality of inspection system and most of all the nuclear safety are increased

At the moment Fortum has under construction with the subcontractors the biggest mock-up than before manufactured –full scale Reactor Pressure Vessel. RPV mock-up will be used for emergency cooling nozzle inner radius inspections. Later plans for the RPV-mock up for qualification purposes have been also considered.

Many kind of artificial flaw types have been manufactured to the mock ups, more detail designing were done compared to the previous manufacturing projects. In both presented cases, the mock-up could not be moved to the optimum position for manufacturing. Also sector locations were chosen in design according to the limitations of the used manufacturing system.

Experience gathered in resent year from manufacturing methods were notable advantage for designing and manufacturing of the mock-ups. During the manufacturing processes both expected and unexpected challenges were met. Unexpected problems were caused mainly from auxiliary systems. Movable flaw manufacturing systems were developed without any massive extra effort. Afterward can be even said that it were easier than expected. Logistics and handling issues related to the moving of the component or the manufacturing systems were solved in both cases. Also challenges with the auxiliary systems were met. Other challenges in the field condition were mostly caused from the environment of the facilities due to the limited time window for all year defect manufacturing.

Although manufacturing were the first step in the process to have accepted mock-up for qualification. Finger print work will be also challenging, due the size of the mock-ups. There are only few companies which are able to give the feedback from the manufactured artificial flaws when scanning is performed externally. At the same time there are only few companies which can be qualified to do the actual inspection. This is one of the challenge which is still open. Qualification process continues and more detail results of the quality of the mock up will be received in near future after finger print and open trials. Fortum and subcontractors are more capably to carry out similar projects due to the gained experience from the presented cases.