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Exchange of Reactorwater Level Indicator Pipes in Lower Plenum In Reactor Pressure Vessel, Oskarshamn 1

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Oskarshamn 1 is a BWR with 1300 MW thermal power. The reactor was built by ASEA-ATOM and was connected to the grid for the first time in August 1972. The reactor has since 1993 undergone an extensive refitting which will be carried on further in the new millennium. During the years 1993 to 1995 one of the major works in the modernisation project was performed. That was the verification of a reactor with an operational history for power production of 20 years. As result from the verification extensive problems due to intergranular stress corrosion cracks (IGSCC) were found on reactor internals as well as the shroud support stand, all now being replaced. Also at time being considered minor problem was corrected. Among those was the measure pipes for reactor water level indication. For redundancy reasons the number of measure pipes was increased from two to four. The two previous installed pipe supports was given more mechanical strength at the point were they are fixed to the main recirculation baffle. This increased mechanical strength should in future show up as a construction error causing a shutdown of the reactor and leading to an extension of 25 days of outage period.

Topic: Health Physics management in a high doserate environment

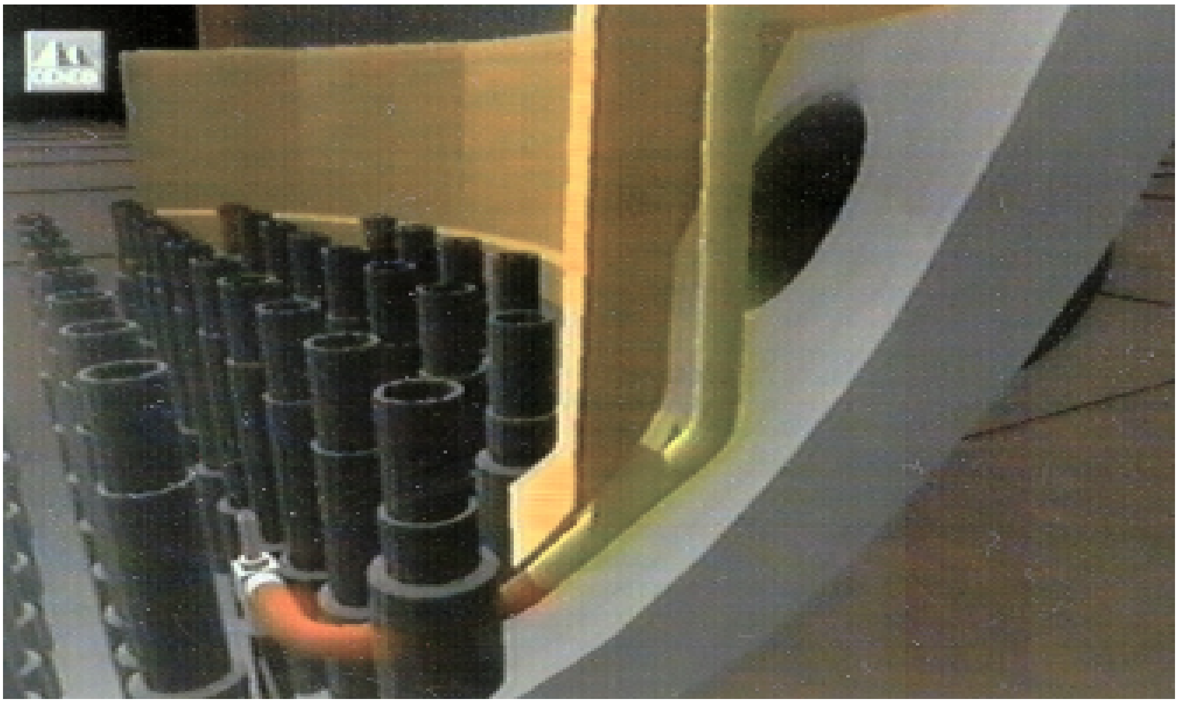

Figure 1, Location of the reactor water level indicator pipe at RPV lower plenum.

1 Introduction

In late February 1998 the reactor operators discovered a significant difference in one of the signals measuring the reactorwater level. The PowerStation was shutdown and a number of measures took place to determine the coarse. The measures showed clearly that one of the indicators was pressurised by the water in lower plenum instead of as normal, pressurised in the downcomer. The conclusion was that the measure pipe had to be broken.

The reactor pressure vessel was opened and inspection through TV-camera showed that the assumptions based on the pressure measurement was true. The measure pipe was totaly cut off at a level just above the support where the pipe is fixed to the main recirculation baffle. Even the support was partly demolished.

Four years earlier, during the FENIX project witch included a full system decontamination and verification of the Reactor Pressure Vessel the measure pipes for RPV water level was disassembled for the reason to make inspection of reactor lower plenum possible. At this point it was also discovered that both two pipes was lose at the support and that two out of four bolts was missing. This problem was fixed and at the same time two new, identical concerning construction, measure pipes was installed to cover each of the four 90 degree sectors (45, 135, 225 and 315 degree) of the reactor.

In May, year 1996 the reactor was restarted and power production retained until the day in late February 1998, the day when the mismatching reactor water level indication was discovered. This year, 1998, the outage period was scheduled to start early April. At this point giving a time respite of around 35 days to deal with this new unexpected highly qualified problem. A project team was immediately formed to handle the task.

2 Project task

Replacement of all four pipes for reactor water level indication considering the installation made in reactor lower plenum during the FENIX project ended 1995. The installation of the reactor water level measure pipes is shown on first page in figure 1. The mechanical implications of the installation may not be discovered directly from the figure. But bearing in mind that the distance between the pipe and the Reactor Pressure Vessel wall is only 45 millimetres some practical matters is to overcome.

The timeschedule: Start planning at late February and at the end of ordinary outage period scheduled to mid of June, start the replacement of the four pipes.

During this period of time, develop a method based on risk assessments from economical, health physics and the end product reliability stand point of view.

3 Methods considered

Several method options was considered based mainly on mechanical aspects but also health physics concerns included. The following three methods was considered,

- Decontamination of reactor lowers plenum. Install the telescope shielding for the reactor upper plenum and core region, earlier developed and used during the FENIX project. This to be able to do all manual work in a reasonable low dosrate environment and low risk for internal intake of radionuclides associated with the remaining contamination in reactor lower plenum.
- Do all disassemble and reassemble remotely with tools manipulated from the refuelling floor. Remote from a distance of 30 meters. Install the telescope shielding as mentioned above.
- Using a remote controlled robot installed on the bottom of reactor lower plenum. This includes the development of such a robot and it's programming.

The methods shortly described above, were the first outcome of discussions between the project team and the possible contractors. In parallel with this, another idea was formed. By splitting up the task into to the following three main parts,

- Disassemble the pipes, do the mechanical preparation and put the new pipes in place with fixture.
- Perform the welding and radiography for final approves.
- Clean up of working space in reactor lower plenum.

It was quite obvious that the first and third part had something in common. They could both be carried out underneath water. The second one, welding and to a certain degree also radiography differs on this point. Although it would be possible to qualify and perform the welding in wet condition, underneath water. But in this case considered a lot more time consuming than welding in dry condition.

Since the reactor at this point was back in operation the radiological situation at the working level at reactor lower plenum was not known. This information has to be based on calculations. From the knowledge of recontamination follow-up since reactor start up 1996, after the full system decontamination performed during the FENIX project, most needed information was possible to retain. The recontamination on the residual and heat removal system for reactor shutdown had been followed continuously on a point of a hot leg located a few seconds delayed from the reactor outlet. This measure is carried out with an advanced He-cooled high pure germanium detector for γ-spectroscopy. Data from this measuring point is reported in nuclide specific activity (Bq/m^2 and Mev/m^2, s). Feeding those data into the calculation model the results were computed for the situations in Reactor Pressure Vessel lower plenum filled with water (12m depth) and for dry condition. The calculations in both cases assume that the telescopic shielding was installed to cover reactor upper plenum and core region.

The calculated doserates for wet conditions showed that it would be possible to use divers to perform the first and third part of the task. And this within a reasonably low risk due to the radiation situation formed by the shielding effect from the water.

The second part of the task, welding and radiography was more difficult to accept from a risk assessment standpoint. For example, the average doserate at the working level, in the reactor radius centre, was calculated to 9,8 mSv/h. The surface doserate was calculated to be in the order of 25 mSv/h. It was obvious that this situation had to be improved before further decisions made.

The position of the pipes close to the RPV wall made together with the high dosrate a restriction. It was not possible to do the welding manually. An automatic welding machine definitely would be an improvement witch also gave an opening for a semi remote control, the worker could then be placed into a shielding cave in meanwhile.

From that a shielding cave was designed. The cave dimensions originally were based from a doserate reduction down to 0,1 mSv/h. But were furthermore optimised against the possibility to use the faster crane for transporting workers between the refuelling floor and the working platform at bottom of the RPV. The cave were equipped with, TV-camera, audible communication, doserate measure in-/outside the cave. For emergency escape two sets of mobile AGA-respirators were included in case of loss of breathing air from the airline or a major leakage occurring on the Muru V4 protective suit.

Based on the precautions discussed above the dosebudget now became within reasonable figure, at this point estimated to around 400 mmanSv. The radiological risk involved now became more reasonable not only for the first and third part of the practice but even for the second one, welding and radiography. The risk of exposure from intake of radionuclides judged low due to the fact that work in dry environment will be performed in air pressurised protective suite, the Muru V4. But still was there a clear risk left in case of injury in a high doserate field in combination with its, to a certain level inaccessible environment.

4 Decision on which method to use

The decision on which method to fall on must in all cases judge the matter of ALARA principles. At this point it was clear that only two methods had the ability to work within a frame set by factors as time, economically with inclusive of loss of power production and trustworthy in performing. The two methods were,

- Decontamination of reactor lower plenum, installed telescope shielding for the reactor upper plenum and core region. Man work in a reasonable low doserate environment and low risk for internal intake of radionuclides associated with the remaining contamination in reactor lower plenum.

- Work in a highly contaminated environment with both risks from high external irradiation as well as from exposure due to internal intake of radionuclides. A method based on the protective precautions adapted to the possible divide of the problem into a wet and a dry part.

The first method relies highly on the decontamination factor. That’s normally where main risk in judging the true result from this method on exposure is hidden. In this case we dealt with a part of the reactor where it’s easy to maintain a very god circulation through the main recirculation pumps. Probably a decontamination factor of at least 50 would be reached.

This factor taken in count, a dose budget for the complete task would be within the scale of 10-20 mmanSv. The radiological environment at the workingplace would be of no considerable worry in practise. Probably in a doserate field of less then some 100 - 200 uSv/h. A remaining contamination on the surfaces of a few MBq/m^2 is also to expect. Which would not make a totally negligible risk for internal exposure but easy to overcome by keeping a high level of protection. In case of happening any way it would certainly not result in a dose equivalent of more than a few mSv.

The time spent to plan and perform the decontamination process as well as the overhead cost for chemicals and personnel resources is well known.

In summary of this method we can state the following,

- Low occupational exposure, in range of 10-20 mmanSv.
- Low risk of occupational exposure from intake of radionuclides due to easy adopt preventives.
- Requires long time to plan and perform.
- To some extent a risk for overoptimistic resulting decontamination effect.
- The use of decontamination chemicals produces a risk from RPV construction material concerns. Not easy to judge.
- High costs for performance, time and chemicals.

The second method, performed in the unchanged condition at the reactor lower plenum relies highly on the precautions made to reduce the radiological risk to an acceptable level with respect to the economical factor. This philosophy requires more efforts from the health physics management to determine the set of dose limitations and constraints. Then establish this through the precautions taken as well as the understanding from the different working teams.

In this working method the performance of the task is divided in mainly two parts, reactor pressure vessel filled with water (wet) or in totally drained (dry) condition.

The wet condition in average gives a reasonably good doserate environment but still the high contact doserate risk is obvious. It requires diver personnel to perform the task. The fact that the diver uses a dry-suite and breathing from airline out rules the risk from internal intake of radionuclides to a minimum. Risk from aeroembolism is reduced by restrict the water depth too 12 meters. In our case this water level just reaches the lower part of the telescope shield covering the reactor core region, leaves no part of the reactor surfaces uncovered. To reduce the risk from contact dose this has to be considered when developing the tools needed. The dose budget was at this moment estimated to 50 mmanSv. With eight divers to cover the shift an average individual exposure around 6 mSv is within reasonable.

The dry condition environment of the RPV is to be defined as the only remaining radiological high-risk part of the task. The environment at the working platform in the RPV can be described as follow:

- Average doserate at working platform ≥ 10 mSv/h.
- At 0,5-meter distance from all surfaces 19 mSv/h.
- Surface doserate of ≥ 25 mSv/h.
- High risk for airborne contamination.

To a certain extent overcome the high dose environment problem a shielding cave was designed. The shielding effect was optimised to reduce the environmental average doserate from 10 mSv/h down to a level around 0,2 mSv/h. Originally the reduced doserate level was set at 0,1 mSv/h. But this was modified to be able to use a faster crane for moving the cave up from the RPV lower plenum to the refuelling floor. This in case of the need to move an injured worker from the RPV bottom to refuelling floor.

The dry condition also produces a high risk for contamination from all surfaces that will be exposed directly to the air. Oxide layers that possibly could become mobile as aerosols would drift away with the ventilation air stream and course problems wherever. The risk of high exposure from internal intake of radionuclides is of no doubt to be taken care of. The ventilation of the RPV has to be constructed in such a way that it prevents contamination spread by using the correct flow direction. The high-risk from exposure due to internal intake is prevented by workers use of airline pressurised protective suite, like Muru V4.

To avoid spread of airborne contamination coming from the surfaces now being exposed directly to the ventilation air stream two connections was done to the RPV. The ventilation of the downcomer was connected trough the steam outlet. The second ventilation witch should take care of the main RPV volume and direct the air stream downwards was connected to one of the RPV bottom throughputs. Both ventilation lines then connects through separate filters before entering the ordinary main ventilation exhaust.

The last part to complete the task was best done by refilling the RPV with water and let the divers do the clean-up job.

This second method relies highly on the precautions discussed above and management of its performance. Most of the high doserate problems are manoeuvred to controllable levels. Left to be judged is the risk involved in the dry part of the method. Based on the estimated time-schedule made for each of the main three different parts of the task the dose budget now estimates to be in the range of 250 mmanSv.

In summary of this method we can state the following,

- Relatively to the environment the occupational exposure is manageable within 250 mmanSv.
- High doserate problems taken care of to a certain extent but still there is a not negligible risk.
- High risk of occupational exposure from intake of radionuclides taken care of.
- Requires development of special tools.
- Requires acceptance test and verification (FAT/SAT) of the applicability of the developed tools.
- Requires HP constraints and limitations to be predefined and respected.
- Requires more external dosimetry.
- Requires very specific training especially for the diver and welding teams but also the health physics involved in the performance.
- The absence of chemicals will produce no risk from RPV construction material concerns.
- Half the cost compared with the decontamination based method.

The final decision based from the arguments shown above fell on this method. In good competition with the first method discussed above but witch were considered much less economical and also more time consuming. The other two methods (ideas) were not really considered as realistic to carry out concerning time, performance and economics.

5 Training of the involved personnel

The method selected was an unproven card. It implied the divers to disassemble the old pipes. Also to do the mechanical preparatory work needed before fitting in the new pipes and lock their position with a fixture. In the next step the welding process needed use of an automatic welding machine developed specially for this task with its lack of space problem.

This all make a need for special tools to be developed, manufactured and tested under conditions that shows the strength both from mechanical, practical handle and radiological view. The radiological environment that the workers will perform the job in requires training. Things have to move smoothly without unnecessary re-works or time drops in high doserate fields due to lack of practical handle the tools developed for this particular task.

At the same time when the first special tools were manufactured the tools were sent to the training centre at ABB-atom in Västerås. The ABB facility LWR centre gave the divers an opportunity to carry out the training in a realistic environment. At the bottom of the LWR pool a mock-up in scale 1:1 was placed to simulate the exact area of lower plenum with the pipes to disassemble. During the training, a lot of changes to the tools were made to improve the reliability as well as easy handle. This lead to the final site acceptance test status go, in the last days of May - well in time.

For training of the welding team the same mock-up as used by the diver team were used, but now within the drained LWR pool. This work was to be done in dry conditions, radiation field free in air. It is a considerable doserate field outside the shielding cave. Therefore the time outside the shield is to be controlled and motivated as much as possible. This together with the reliability of the newly developed automatic welding machine was one of the most important things to study carefully. Therefore most of the training included a time study that should build the base for a very precise dose prognoses. This time study also become the base for the final approve on the site acceptance test, go no go. At end of May the status was go – also well in time. In total the two teams, divers and welders spent around 4 weeks with the mock-up training.

In mean while also the service personnel at the site was trained in handling the different type of equipment to be used. The training time needed for the service personnel was in the range of a working day.

6 Determination of the final dose prognoses

As mentioned above in chapter 5 the final site acceptance test (SAT) were in much built from what should become the realistic performance time for each of the different working sequences. The times and doses as outcome of the site acceptance tests are shown below.

Wet working environment

Disassembly of the old pipes

The time schedule for the disassemble of one old pipe and adaptation of a new pipe agreed on and verified at the site acceptance test was in total 9 hours. This should result in an estimated effective dose of 13-14 mSv per disassemble/assemble of one pipe. With four pipes to disassemble the total effective dose would become 55 mmanSv.

The removal of equipment and cleanup of RPV lower plenum after finish the complete task also requires the divers service the dose will be them contributed. A total collective effective dose estimates to 5 mmanSv.

Dry working environment

Welding of new pipes

The time schedule for the welding in of one pipe measured, verified and agreed on at the site acceptance test was 290 minutes. The division between time interval spent inside the shielding cave and outside was closely 1 to 8. From the two components,

- Effective dose while waiting inside shielding cave 1,2 mSv,
- Effective dose while working at welding position 13,8 mSv,

This results in a total effective dose of 15 mSv per weld. With four pipes and two welds each the total effective dose would become120 mmanSv.

Radiography of the welds

The time schedule for radiography of the two welds measured, verified and agreed on at the site acceptance test was 45 minutes. Division between time interval spent inside the shielding cave and outside was closely 1 to 16. From the two components,

- Effective dose while waiting inside the shielding cave 0,35 mSv,
- Effective dose while at the weld position 5,9 mSv,

This results in a total effective dose of 6,25 mSv per pipe. With four pipes the total effective dose would become 25 mmanSv.

Summary of dose prognoses

The final effective dose prognoses for the complete task was 245 mmanSv. This now included the establish/re-establish of the working place, health physics and common service dose, witch adds about 40 mmanSv more.

The prognoses collective effective dose distributed per occupational category was:

- Divers 60 mmanSv
- Welders 120 mmanSv
- Radiography 25 mmanSv
- Health physics and service personnel 40 mmanSv

Doses at this stage, now based on as realistic tests as possible can be done with respect to the exclusive of exact ambient environment, was not considerable high. The collective dose prognoses of 245 mmanSv was, compared to the budget figure of 250 mmanSv used at decision making stage was not considerable lowered.

7 Dosimetry

All personnel working in the project were on the upper torso wearing the standard TLD and electronic dosimeter (DRD) as required by normal routines at the plant.

The diver personnel while working in the RPV, were in addition wearing an electronic dosimetry system for extremity dose measure. This system was designed to stand a water depth down to 27 meters and in all consist of six individual detectors witch in this case all were placed underneath the “rubber skin” dry-suite. Detectors were located at foot, hands, upper torso and the head. Signals from the six detectors were multiplexed and sent through a single cable connected to a computer on the refuelling floor. The computer displayed real-time doserate and accumulated dose for each of the six locations on the divers body. All recorded doserate/dose information was stored with a frequency of every 4th seconds. This system together the view from a TV-camera following every movement of the diver was superintended by a health physicist. A combination that gave a lot of useful information on at what point to improve the shielding of the working place where ever was possible.

Divers wear on own request also a small version of an “old fashion” ratemeter with a loudspeaker echoing every event registered by the detector. This was placed inside the helmet and as told, gave them the possibility to better concentrate on the actual work while at same time “feel the distance” to the hazards.

Welders and radiography personnel wear in addition to the standard dosimetry, TLDs as extremity dosimeters. The extremity positions foot, hands and head was measured. For the reason to have the position to follow in real-time doserate and dose accumulation from the HP-quarter on the refuelling floor, a Tele-dosimeter was placed on the upper torso of the welding personnel.

The TL-dosimeters used for extremity dosimetry as well as the ordinary TLD was directly analysed after each working sequence has ended.

Control of intake of radionuclides was made on all involved personnel before the project performance started. All personnel working in the RPV was measured for internal intake after each sequence ended and then finally after finishing the task before leaving the plant.

No personnel were allowed to continue working in the RPV before each individual dosimetric result was reviewed and approved by the health physics management.

Dose limits and constraints

The dose limits that restricted the work from authority demands on yearly basis are:

- Effective dose — 50 mSv
- Superficial equivalent dose — 500 mSv
- Extremity equivalent dose — 500 mSv
- Effective dose over a period of 5 years — 100 mSv

The effective dose E is the sum of all equivalent dose multiplied with its weighting factor for radiation and tissue/organ. To ensure not to exceed the maximum effective dose of 50 mSv, the sum of the superficial/extremity dose equivalent in practice could reach 140 mSv at the point when the measured whole body dose equivalent reaches 40 mSv. In this case the dose equivalent considers as penetrating gamma radiation, $H_P(10)$.

In practice the following dose limits was set up:

Individuals dose limits for the completeness of the entire project task:

- equivalent dose — 15 mSv
- extremity dose, hand, foot, head — 60 mSv
- commited equivalent dose from intake — < 1 mSv
- effective dose — < 20 mSv

Further more individuals dose limits were defined for a single sequence of the project task as:

- equivalent dose — 6 mSv
- extremity dose, hand, foot, head — 25 mSv
- equivalent dose from intake — < 0,25 mSv
- effective dose — < 8 mSv

In the purchasing agreement there were no penalty connected to either economic or time limiting of performing the task. In fact it was a purchase of a functionality to perform a given task. In this case such a penalty would have, not only by it self but through a connection to the agreements made during the site acceptance test and its approval, set up further valuable constraints.

8 Summary of other precautions taken

In addition to the restrictions based on the earlier discussion on how the selected method developed together with the dosimetric limits further more precaution were made to reduce the risk of injury and in case be able to be handled in a safe way. Worth mentioning was:

- Direct contact established with the hospital, helicopter transport and recompression facility at the marine centre.
- All time during divers activity in RPV, one diver was waiting on the refuelling floor fully equipped and ready to descent in case of help needs.
- For safety reason in case of an injury, every descent in RPV done by the welder’s follows one extra person who was waiting inside the shielding cave.
- Separately powered crane installed on the refuelling floor in case of a failure on the crane normally assigned for this job.
- Direct communication between the HP-quarter at refuelling floor and workers in RPV.
- Remote controlled TV-camera in RPV, viewed on video screen at HP-quarter at refuelling floor.
- Real-time dosimetry for the divers covering dose and doserate for whole body, feet, hands and head.
- Real-time dosimetry for the welder covering whole body dose and doserate.

9 Performance of the task

Divers operation in RPV

Establishment of the working place started with installation of the extension tank that connects to the RPV top and ends at refuelling floor level. Then, high pressure water spraying of all lateral and bottom surfaces in side RPV to get rid of easy mobile parts of the oxide layer (CRUD). This followed by installation of the telescopic shielding that covers the RPV upper plenum and reactor core region. Finally put the sectioned steel floor (50 mm) on top of the control rod pipes in RPV lower plenum and fill up of the RPV with water to a depth of 12 meters.

Divers first job in the RPV started with moving the sections of the steel floor that covered the lower part of each pipe to be disassembled at the working place. Then “spread” of the complementary lead shields to optimise the working space as much as possible around/over the removed steel floor section.

The real work with disassembly of the first pipes now started. All efforts to make the environment reasonable to work in seemed to be okay so far and the divers had a good awareness on how to improve for further dose savings. The structured way that the divers were used to work in made the whole operation, disassemble the old pipes and reassemble of the new pipes ready to be weld in, an easy and calm task.

The dose statistic's is displayed in figure 2 below, which can be summarised in the following:

Total collective effective dose	61,95	mmanSv
Highest individual effective dose	9,66	mSv
Average individual effective dose	7,74	mSv
Number of personnel involved	8	

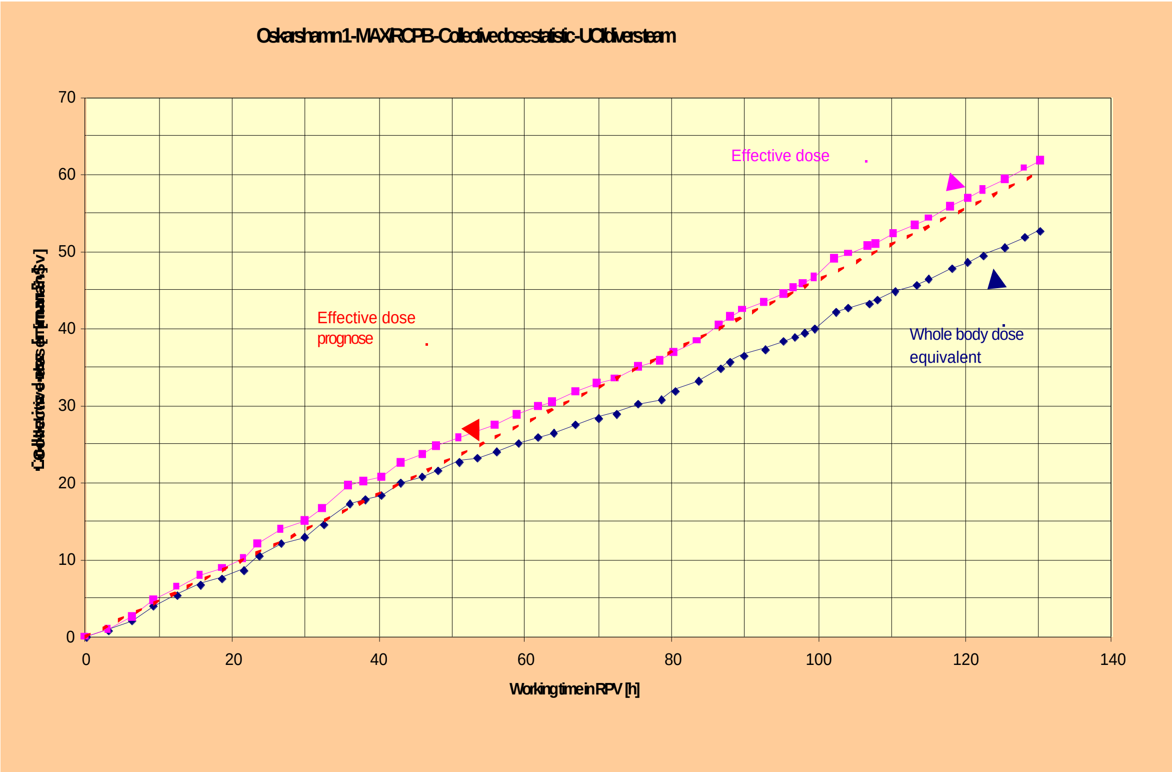

Figure 2, collective dose statistics for the divers work in Oskarshamn 1 – RPV.

The dose prognoses made during the site acceptance test did underestimate the whole body dose equivalent while the effective dose matched the prognoses in a reasonably good agreement.

Welders operation in RPV

This operation was for safety reasons planned to be carried out with two workers at every decent in the RPV. The safety assigned personnel was supposed to stay inside the shielding cave and only act in case of an injury occurred to his working mate who was assigned to perform the task sequence based on the schedule decided on before start of the decent action.

When the works really started things went reasonably okay but the time spent in the RPV seemed to increase more and more after each decent. The individuals dose developed significant faster than expected as determined from the site acceptance test. The dose statistics for the safety related personnel developed also witch was not to expect. Understanding things gave definitely a hint of that "those things downstairs" was not performing as was planned. At this state the time schedule was almost at the end point. The collective dose prognoses were significantly overridden and only about 40 % of the work done on the four pipes upper welds. Discussion with the welder's supervisory hierarchy pointed in two directions. The welders were very keen on the quality of the welds performed witch made them standing in the high doserate field most of the time. Being afraid that the automatic welding machine wouldn't do its job properly and in case leave them a rework to be done manually. To some extent this was understandable but not satisfying in any way remembering all time and efforts spent on both training and qualification at site acceptance test. A qualification that the risk assessment was partly built from. Secondly it also was to understand that the automatic machine did demand a lot more time of over viewing and adjustment now compared to during the qualification pass.

At this point the job was stopped and the troubling welding machine brought up to the workshop for service. The works in the RPV continued. All upper welds were finished and should start with the lower weld of each pipe.

The fixture that should keep the position of the pipes was not strong enough and had to be readjusted before the welding machine could be adapted to the first lower weld. This was not a really beneficial surprise to the dose development. Figure 3 below show the dose statistics for the welding task.

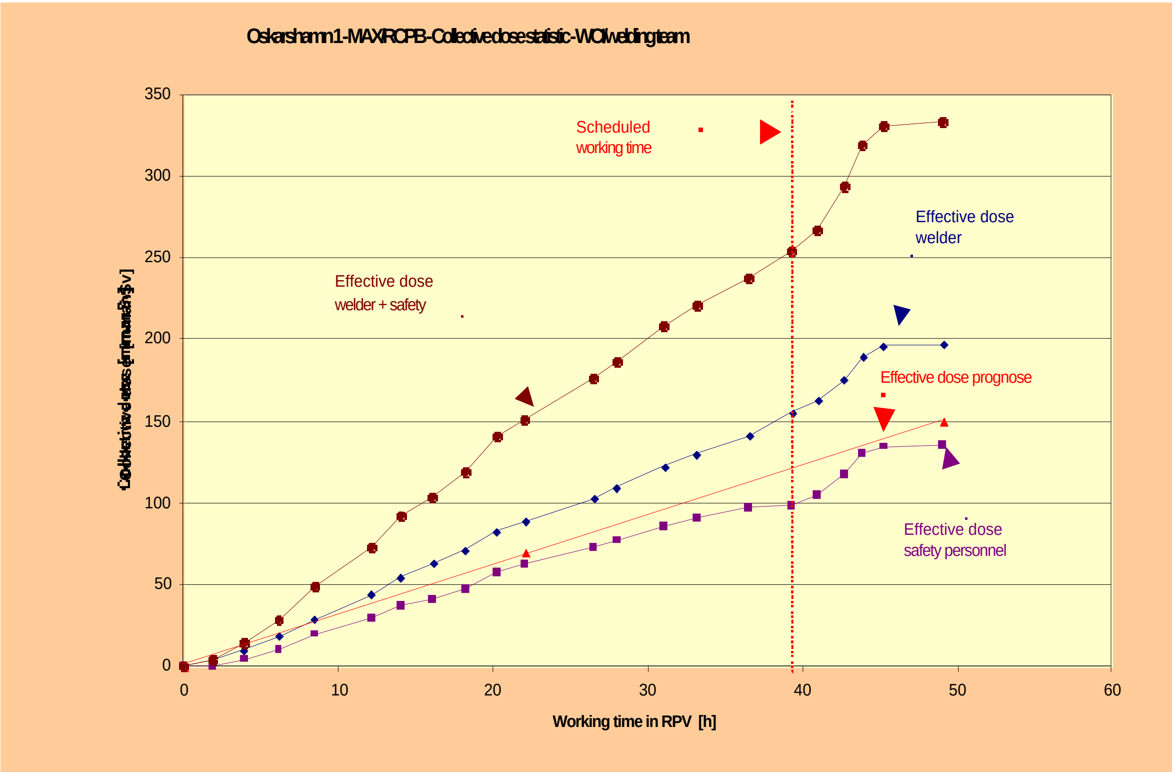

Figure 3, Effective dose statistics for the welding task.

The task, to weld in four new pipes exceeded the scheduled time with a factor of two concerning time outside the shielding cave, but the time spent in the RPV increased only with around 20 %. The collective effective dose was 333,02 mmanSv. This was out of range with a factor 2,5 times the prognosis. Individuals dose statistics were:

Total collective effective dose	332,02	mmanSv
Highest effective dose	36,84	mSv
Average effective dose	15,00	mSv
Number of personnel involved	22	

Radiography operation in the RPV

There’s not really much to comment on this operation. The personnel involved did the job as expected from them with skill. The effective dose prognosis and the real outcome were in quite good agreement as can be seen in figure 4, below.

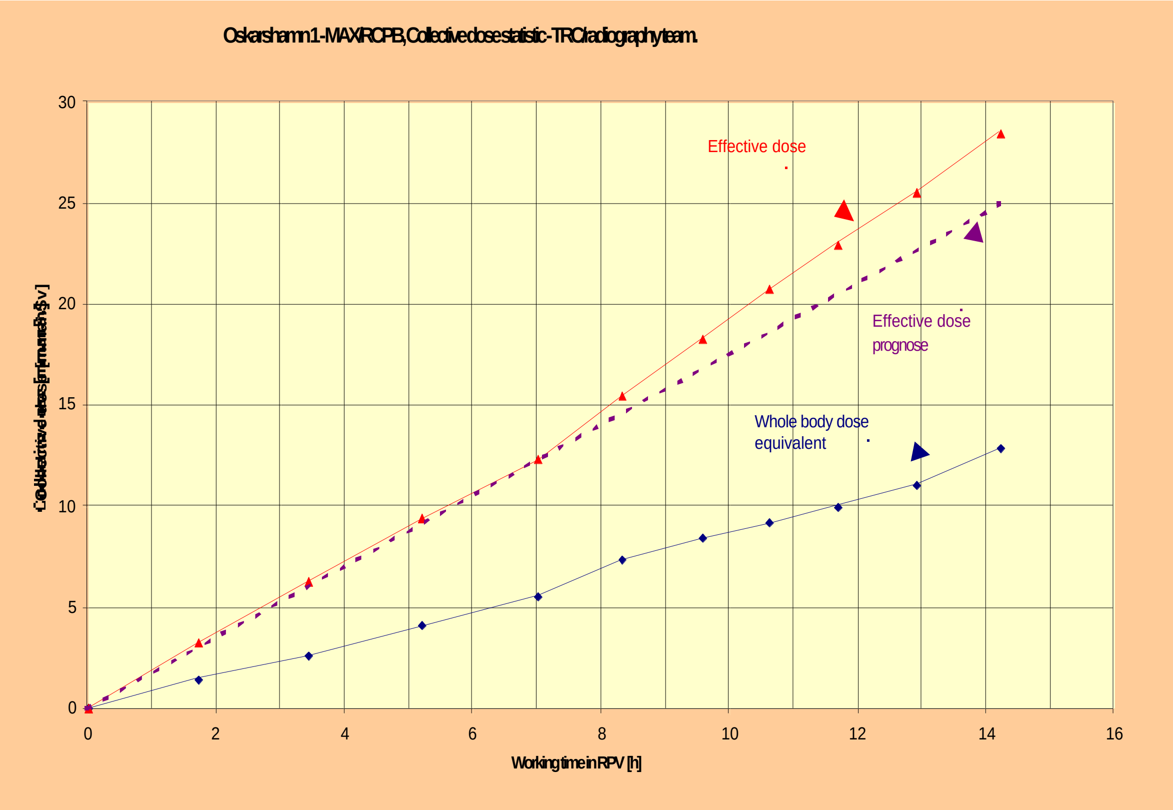

Figure 4, Effective dose statistics for the radiography personnel.

Radiography of the eight welds on the four new pipes did an exact match in time to the scheduled time. The collective effective dose was 28,51 mmanSv. This was only 3,5 mmanSv higher than the prognosis made from the site acceptance test.
Individuals dose statistics were:

Total collective effective dose	28,51	mmanSv
Highest effective dose	8,21	mSv
Average effective dose	7,12	mSv
Number of personnel involved	4	

10 Air contamination on refuelling floor

The air contamination was measured on the refuelling floor continually during the entire performens period. Figure 5 below show the results.

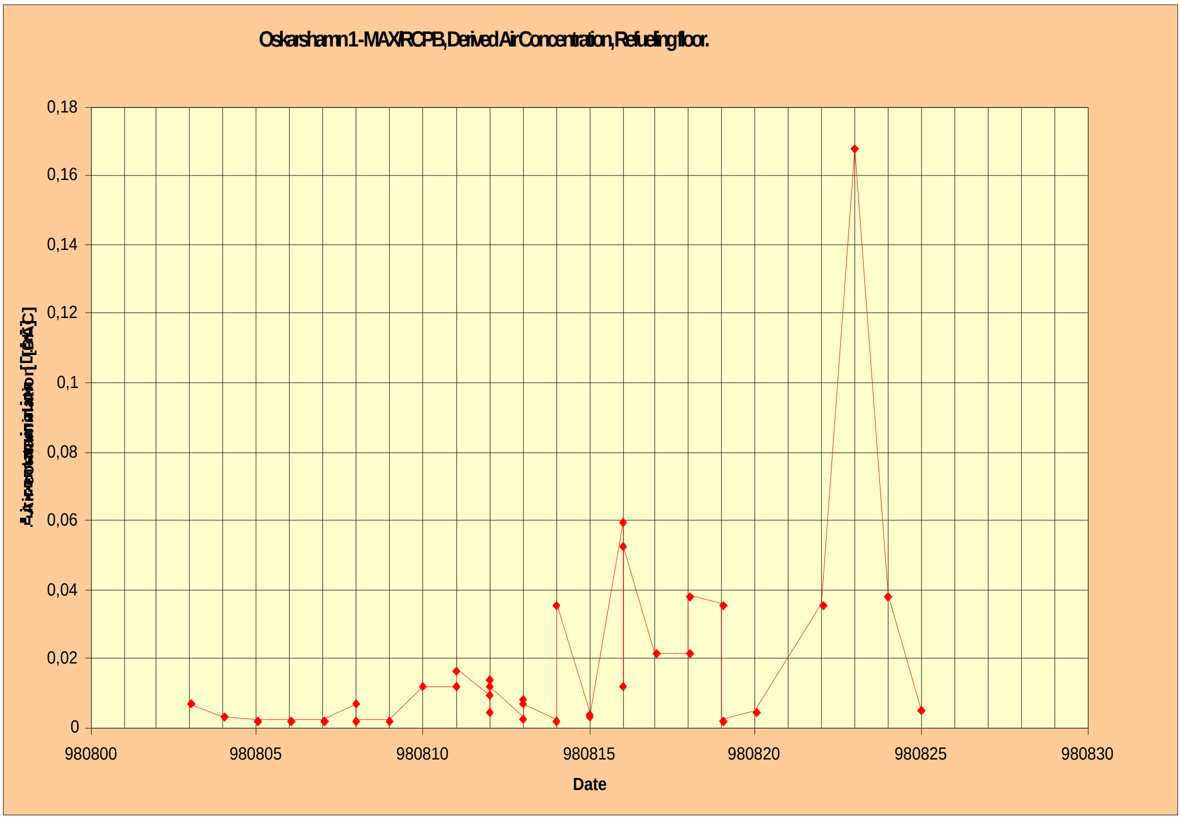

Figure 5, measured air contamination on refuelling floor.

During the performance of the task down the RPV no significant rise of air borne contamination at the level of refuelling floor could be seen as evidence of that the ventilation was wrongly built or malfunctioning. The periodically increase in air activity is related to moments in the “dry working” period when equipment was brought up from the RPV to refuelling floor level without enough care. Especially and to a certain extent understandable this is valid for the highest peak when the air concentration reaches a DAC value of 0,17. This DAC value corresponds to the re-establishment of the RPV at end of the project.

11 Internal intake of radionuclides

As mentioned earlier, all personnel involved in the work in RPV and on the refuelling floor were measured for intake of radionuclides. All were measured before establishing the working place and after re-establish of the entire project. The personnel that were working with the task in the RPV were measured after every single descent finished.

None of the measurement showed evidence of any increase of internal intake of radionuclides, all committed equivalent dose results were < 0,1 mSv.

12 Conclusion

Collective effective dose at end of the project was 423,48 mmanSv, corresponds to an underestimation in the prognoses of about 178 mmanSv. The main contributor to the unexpected increase in dose is directly related to the performance of the welding task. The following causes are defined:

- Safety assigned personnel did not respect the assignment. Instead acted with highly involvement in the actual work. Collective dose increase from estimated 11 mmanSv to 140 mmanSv.
- Welding personnel did not relay on the automatic of the welding machine. Must have been running on manual basis to be sure avoiding re-work.
- Readjustment of the pipes before performing lower welds was not counted for. Collective dose increase of 22 mmanSv.
- Supervising hierarchy of the welding team was out of reach from the project management.
- Radiological education of performance personnel is an essential resource to build a success in high doserate applications. This could really have been better in some cases as discussed earlier in this paper.

The divers showed professionalism in both performance of the task as well as in taking care of the radiological problems. The same judgement stands for the personnel performing the radiography.

The statistics of the effective dose caused by the project performance was:

Effective dose interval [mSv]	Welder	Diver	Radiography
E < 5		1	
≥ 5 E < 10	3	7	4
≥ 10 E < 15	8		
≥ 15 E < 20	7		
≥ 20 E < 25	3		
≥ 25 E < 30			
≥ 30 E < 35			
≥ 35 E < 40	1		

Highest recorded effective dose was 36,84 mSv and corresponds to the welding team's supervisor. Mainly dose corresponding to the readjustment of the pipes.

In four cases the limitation set on effective dose of 20 mSv were exceeded. All four cases corresponded to the welding team.

The project monetary budget was kept. And the savings counted for by the selection on the used working method was reached.