Disassembly simulation of main pipe insulation layer of nuclear power plant pressure vessel based on DELMIA

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Abstract. In order to ensure that the temperature of the main feed water and the main steam pipe is at the design value, there is a thick insulation layer outside the main pipe line. According to the requirements of the specification, after a certain period of time, the insulation layer here needs to be replaced. However, due to the relatively high dose of radioactivity here, maintenance personnel are subject to a certain dose of radiation. We use 3D ergonomics simulation method to establish a 3D model of the scene here, simulate the correct disassembly and installation process of the operator, make the maintenance personnel familiar with the environment and operation process, reduce errors, shorten the operation time, and finally shorten the inspection cycle. This achieves increased safety and reduced overhaul time at low cost.

1. Introduction
Nuclear power plant maintenance can basically be divided into the following three categories: (1) Preventive maintenance----It is the maintenance that is carried out according to a predetermined plan to reduce the probability of equipment failure or functional decline; (2) Corrective maintenance----It is a corrective repair that is performed after a device failure; (3) Equipment improvement----It is a device update or technical transformation of a nuclear power plant based on empirical feedback.

Preventive maintenance can be divided into two categories: (1) Time-based scheduled maintenance----It is implemented according to a pre-established schedule (according to the manufacturer's maintenance manual and related maintenance procedures), regardless of the state of the equipment, such as periodic replacement of lubricants, sealing materials, ball bearings, etc. (2) State-by-service repairs with a set of procedures to measure the deterioration of equipment performance----Preventive maintenance by status has three supervisory tasks, namely monitoring, testing and inspection. These supervisions are the key to mastering modern maintenance and the most effective way to reduce the probability of failure of important components.

Overhaul in the traditional concept of a nuclear power plant is also part of preventive maintenance because it is pre-arranged and planned, and not repaired due to failure. Overhaul is not just about unpacking the equipment to inspect and repair the defects that have been discovered, but also to restore the equipment to its original design state by replacing worn and worn parts.
The maintenance of the replacement main water supply and main steam pipeline (collectively main pipeline) insulation layer analyzed in this paper is also a preventive maintenance. The purpose is to replace the insulation layer before the insulation layer has been destroyed to ensure the temperature of the main water supply pipeline during normal operation of the reactor.

Ergonomics is currently being used in design, and the design of automobiles, airplanes, and even daily necessities is gradually beginning to consider the comfort requirements of users and the environment [1, 2]. In the field of industrial safety, there are few obstacles to the promotion of ergonomics. The author has used ergonomics to simulate and analyze the hoisting of large tower equipment and achieved very good results. There is no report on the application of ergonomics to nuclear power engineering and only one paper pointed out. In nuclear power plants, the human-machine system also includes people, machines and the environment, but there are no specific application examples [3].

The physical picture of the main pipe is shown in Figure 1, and the three-dimensional model of the design is shown in Figure 2.

![Figure 1. The actual physical scene of the main pipeline: (a) hot end overall; (b) the maintenance personnel enters the main pipeline location for operation and inspection.](image)

![Figure 2. 3D model of the profile of the main pipe and pressure vessel.](image)
2. Main pipeline replacement insulation maintenance status

The insulation of the main pipe needs to be replaced regularly, mainly to ensure the insulation effect to ensure the feed water temperature and steam temperature of the evaporator. The normal nozzle inspection cycle is 5 years, but sometimes the experience feedback or temporary work will also check the need to remove the insulation but there is speciality here. First, the pipeline is located at the bottom of the evaporator and is a region with a relatively high dose of radioactivity. When maintenance workers enter the area for repairs, they are exposed to a certain dose of radiation. This requires workers to save as much time as possible when replacing the insulation layer here to reduce the radiation they receive. At the same time, because there are many sensors installed in the area, workers need to be cautious. When disassembling and installing the insulation layer, they need to be unable to touch the installed sensors. In the actual operation process, because the workers are worried that they are subject to too high radiation dose, the psychological will be affected, which will affect the accuracy of their operation. In actual operation, the temperature sensor is encountered when the insulation cotton is removed several times.

The wall-passing main pipe simulation body plus the evaporator lower head and the evaporator hand-eye hole simulation body involve an amount of about 300,000 yuan. The purpose of establishing this kind of physical training is very clear and simple. In order to alleviate the impact of the loss of skilled insulation workers in the control area, in addition to reduce the insulation in the control area in the future, it is necessary to reduce the unnecessary radioactive dose caused by the insulation layer. The dose rate at this location is on the order of millisieverts (mSv). Figure 3 is a photo of the training of the main pipeline insulation cotton inspection and dismantling established at the Daya Bay Nuclear Power Plant Training Base.

![Figure 3](image1.png)  
![Figure 3](image2.png)  

**Figure 3.** Training materials established at the daya bay training base: (a) overall physical scene; (b) training the physical main pipe position local.

3. DELMIA training simulation

For the physical model of the Daya Bay training base, we simplified the physical model appropriately and built a three-dimensional virtual model in the CATIA software, as shown in Figure 4. The pipe is a little less than the training scene, but the main pipe and the insulation cotton part are models that are completely in accordance with the size of the training object. Considering that the simulation is to simulate the process of replacing the insulation cotton, the other pipeline parts have been simplified. The purpose of the project is to illustrate that the three-dimensional model simulation can achieve the purpose of the main pipeline insulation cotton replacement training.
Within the DELMIA software, the process of worker overhaul and operation of replacing the insulation cotton was simulated [4-6]. Two operators are set up in the scene, and they need to cooperate with each other to complete the replacement and maintenance operations. An auxiliary tooling is also set in the scene [7] ----Auxiliary ladder. Workers are required to climb the ladder and do some work. The overall scene of the layout is shown in Figure 4.

The main simulated actions are: (1) The worker walks to the insulation cotton; (2) An operating worker holds the insulation cotton; (3) Another worker B takes out the hex socket wrench on the body and screws the nut on the outer layer of the insulation cotton; (4) Worker A continues to hold the insulation cotton, and Worker B removes the Hex socket wrench and put it back into the tooling worn by the body; (5) Worker A and Worker B move together to remove the first insulation cotton; (6) Worker A returns to the front of the main pipe and Worker B returns to the front of the ladder at the same time; (7) Worker B moves the ladder to the front of the main pipe, involving lateral movement and forward movement; (8) Worker B goes to the front of the ladder; (9) Worker B boards the ladder and turns to face the main pipe; (10) Worker B takes out the tooling tool hex socket wrench; (11) Worker B twists the nut on the insulation cotton, and worker A holds the insulation layer from the ground; (12) Worker A removes the disassembled insulation cotton; (13) Worker B continues to disassemble other insulation cotton; (14) Worker A goes to the other side and catches the insulation cotton; (15) Worker A transports the insulation cotton... some repeated steps are omitted in the middle; (16) The worker squats and removes the hexagonal socket wrench to screw the lower insulation cotton in the perforation of the concrete shield wall; (17) Worker B moves the ladder to the front of the shield wall and boards the ladder; (18) Worker B dismantles the insulation cotton on the ladder; (19) Worker B puts the insulation cotton on the ladder to the shoulder of the worker A; (20) Worker A puts the insulation cotton against the room.

According to the requirements put forward by the site, the system also adds the function of recording the doses received by the workers. According to the three-dimensional dose field obtained in the previous test, when the workers walk in different positions, they will bear different doses, and the system can automatically display the doses that are accepted by different disassembly methods.

**Figure 4.** Main equipment, auxiliary tooling and operators of the 3D simulation training scene.

In order to eliminate the fear of maintenance personnel on the nuclear reactor, and reduce the exposure time of nuclear power plant maintenance personnel to radioactivity, and improve their proficiency, we use the established 3D simulation scene to directly put the maintenance scene into the 3D projection system. Maintenance personnel can directly experience the three-dimensional maintenance environment and train their own operation actions by wearing 3D glasses. Figure 5 is a
schematic view of a three-dimensional projection system. After the person wears the sensing system, the operator's actions can be displayed in the system, and the devices in the display system can be directly operated to install and disassemble the devices in the three-dimensional system. Through repeated practice, the operator can familiarize with the scene and shorten the operation time.

Figure 5. 3D projection experience system.

4. Discussions and conclusions
After the simulation is completed, communication is conducted with the personnel who performed maintenance operations and training on site [8]. The feedback from the site is: Although the effect steps made are not correct, the insider can understand it. I read it to the insulation worker and recognized it. The correct steps and recommendations are as follows: (1) Safety helmets, gloves and protective clothing must be properly dressed; (2) Before the insulation is removed, it must be marked first, and there should be a marking action; (3) Remove the last piece of insulation on the first lap. No one can hold the insulation. In reality, it is easy to fall off; (4) This work is best based on a group of four people; (5) It is best to use a multi-purpose ladder to change to a one-meter-high scaffolding; (6) There is a handle on the outer surface of the nuclear island insulation. If you want to simulate the 3D simulation, you can add the handle; (7) Insulation connection does not require a hex wrench, it is recommended to change to a buckle connection more appropriate; (8) The red circle of insulation site is a soft connection of cotton bags, not a metal material, it is recommended to modify it; (9) On-site demolition and insulation is prohibited for shoulder blades, and should be changed to chest before delivery; (10) If three-dimensional can be realized, it is better to add an instrument analog probe on each side of the insulated wall. These good suggestions will be reflected in the new simulation. The simulation work also needs to work in more detail.

The simulation of the insulation cotton through the main pipe proves that the use of three-dimensional simulation software can fully play the role of simulation training. Under the condition of not having physical training, the three-dimensional simulation system can be used to train the workers to disassemble the insulation cotton. This saves the cost of building physical sites and allows for quick updates to the training based on site needs.

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