Implementation of a high-energy X-ray system for inspection of thick-walled copper welds

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SKB develop the KBS-3 method for final storage of the spent nuclear fuel. The method consists of three protective barriers, a canister, bentonite clay and the bedrock. The canisters in which the fuel is encapsulated have a diameter of 1 metre and a length of 5 metres. The canister consists of a cast iron insert surrounded by a 5 centimetre thick shell of copper, sealed by friction stir welding (FSW). The canisters are disposed in the bedrock at a depth of about 500 meters surrounded by bentonite clay. In order to assess the long-term safety, an extensive quality control programme is applied to the canisters before deposit, in which the use of non-destructive testing (NDT) is vital. One of the most crucial inspection objectives is to verify quality of the final sealing weld. SKB has since more than 15 years jointly developed the welding process and the associated NDT techniques in full scale at the Canister Laboratory in Oskarshamn. Due to the different characteristics for different types of defects (i.e. “volumetric” cavities and planar root defects), both phased array ultrasonic and high-energy digital X-ray techniques, has been selected as primary inspection methods. The high-energy X-ray system installed in 1998 was, at that time, considered to be on the technical forefront. The system included a 9 MeV linear accelerator together with a linear detector array. By inspection of about 100 full-scale lid welds followed by further analysis of defect indications, using metallography and computed tomography, knowledge of the characteristics of the cavities has been obtained. A preliminary POD study showed that the detection capability for cavities using high-energy X-ray is sufficient. However, due to the high demands for the final storage of the spent nuclear fuel extra margins are preferred. The desired extra margins and the fact that the original X-ray system became obsolete build the basis for the decision to procure a new and improved system. Initial tests using, for example, different energy levels and various detector types, showed that improved sensitivity could be achieved. The experiences from these trials were used as a basis for the specification of a new system in which several X-ray parameters, such as energy, dose rate and focal spot, could be varied. To enable a wider use of the system it was also supplied with a module for computed tomography (CT). After installation at the Canister Laboratory, various parameter trials have been conducted and the results show that clearly higher detection capability than with the original X-ray system could be achieved. The CT module has enabled more detailed characterisation of defects in test blocks both from copper friction stir welds and nodular cast iron inserts.