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Radiological environment within an NPP after a severe nuclear accident

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Abstract. The radiological environment following a severe nuclear accident can be visualised on building layouts. The direct radiation in an area (or room) can be visualized on the layout by a colouring scheme depending on the dose rate level (for example orange for high gamma dose rate level and purple for an intermediate gamma dose rate level). Following the Fukushima accident, a need for update of these layouts has been identified at the Swedish nuclear power plant of Forsmark. Shielding calculations for areas where access is desired for severe accident management have been performed. Many different sources of radiation together with different types of shielding material contribute to the dose that would be received by a person entering the area. External radiation from radioactivity within e.g. pipes and components is considered and also external radiation from radioactivity in the air (originating from diffuse leakage of the containment atmosphere). Results are presented as dose rates for relevant dose points together with a method for estimating the dose rate levels for each of the rooms of the reactor building.

1 Introduction

In case of emergency and during drills, layouts describing the radiological environment within the reactor building are used by the emergency preparedness organisation or the first responders team. A mapping of the radiological environment can also provide support when planning accident management. Existing layouts for the three boiling water reactors of the Swedish nuclear power plant Forsmark, need to be updated. New equipment is installed following Fukushima, updated accident management strategies need to be considered and results from recently updated calculations of core inventory release fractions need to be taken into account. A project aiming to provide dose estimations for relevant dose points has therefore been carried out by Vattenfall Engineering on behalf of Forsmark. The project is on-going and it will be finalized during the spring 2016.

2 Severe accident scenario

Released fractions of the core inventory is based on an extremely unlikely worst case scenario, when no safety systems are functioning during 24 hours. Since no core cooling is assumed to be functioning during the scenario, a complete core melt will occur. The containment pressure can be very high in these types of scenarios and all operating reactors in Sweden therefore have passive filtered venting systems. This system is designed to filter and retain the volatile fission products (e.g. I and Cs) during depressurization of the containment. Noble gases will be released unfiltered to the environment. The selected scenario has a highly conservative approach, however, the assumptions regarding shielding, source geometries, densities, etc. aims to be as realistic as possible.

3 Source term

In NUREG-1465 [1], typical accident source terms for light-water nuclear power plants are listed. However, release fractions are (slightly) lower than results from plant-specific simulations using the modular accident analysis program, MAAP. Temporal resolution is also much better in the MAAP results. Therefore, the source term in the containment was decided using the plant-specific core inventories together with plant specific calculations of the release fractions. Radioactive nuclides of the following elements were included in the source term: Xe, Kr, Cs, I, Te and Sb. The source term was determined for various times after the accident initiation, namely 3 h, 6 h, 8 h, 21 h, 24 h, 7 d and 30 d.

The amount of gas and water is also calculated by MAAP. The source term in the gas volume as well as the water volume within the containment was therefore specified in Bq/m^3 for each of the time steps.

4 Contaminated systems

During the scenario several systems outside the containment will be contaminated at certain times depending on the possibility to start a system (e.g. a cooling system). It will then contain contaminated media

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and the activity concentration is assumed to be the same as that of the activity concentration inside the containment at that time.

An example is the containment spray system, used for depressurization and washing out aerosols from the containment gas. Ideally, the system will receive water from an external uncontaminated water tank. However, there is also a possibility to take water from the contaminated water of the condensation pool within the containment. Dose rates from the system containing contaminated water were determined.

5 Shielding calculations

Shielding calculations has been performed using MERCURAD for different pipe dimensions, components (e.g. heat exchangers) and also for the containment itself. For complex geometries, an Ecxel-based tool was developed.

5.1 Containment

The containment has a height of about 40 m and a diameter of about 20 m. Initial water level is about 10 m above the containment bottom. Radiation dose rates outside the containment (within the reactor building) were calculated. Core melt on the containment floor and containment penetrations were given special consideration. The figure below illustrates a pipe penetration and its isolation valve.

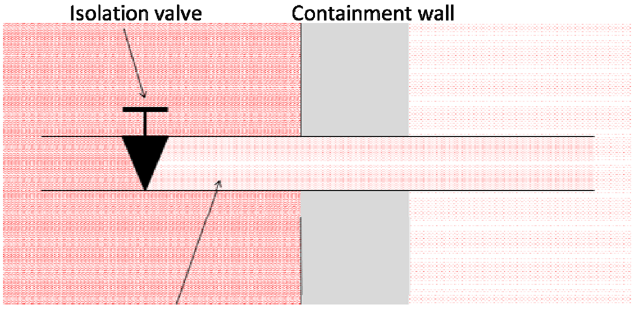

Figure 1. Pipe penetrating the containment

Other types of penetrations include personnel airlocks, electrical penetrations and equipment hatches. The shielding dimension and material varies depending on the type of containment penetration.

5.2 Pipes and components

Shielding calculations were done component wise for e.g. heat exchangers and pipes of different standardised geometries.

5.3 Complex geometries

Several rooms, interesting from accident management point of view, include several pipes of different dimensions and directions. In addition, the external radiation from the containment has to be considered (including the effect of relevant penetrations). There may also be radiation sources in adjacent rooms which has to be taken into consideration. An inventory of radiation sources for rooms of interest (using e.g. drawings and photographs) was made by engineers at Forsmark. Since there is a vast amount of complex geometries that needs to be modelled, the use of MERCURAD would be too time-consuming and a dedicated tool was therefore developed. A calculated unshielded flux was reduced using an Excel model that approximates attenuation and the build-up flux in different shielding materials and geometries.

6 Dose estimations

Resulting dose rates will be presented for each of the dose points that has been identified as relevant from an accident management perspective. This includes the access route to relevant areas,

In addition, a method will be developed for determining the dose in each room of the reactor building. There are about a hundred rooms in each of the three reactor buildings at Forsmark. The method for estimating the dose in all areas will be based on shielding calculations for single components and knowledge of attenuation for different thicknesses of shielding material (walls, doors, non-radioactive components, etc.)

In addition to the dose rate from external radiation from shielded radioactivity (within e.g. pipes and components), the dose rate from airborne radioactivity needs to be considered. Airborne radioactivity (dominated by the noble gases Xe and Kr) will leak via isolation valves, since the leakage rate is never zero, and into the reactor building. During a station blackout, the emergency ventilation system is unavailable and dose rates due to the diffuse leakage needs to be considered. However, if the power supply is working, the emergency ventilation system is used and the airborne radioactivity is then negligible.

7 Results

The project will be finalized during the spring 2016. Conclusion and results of the activity will be presented at the conference.

References

1. L. Soffer, S.B. Burson, C.M. Ferrell, R.Y. Lee and J. N. Ridgely NUREG-1465 (1995)