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ARTICLE

ADEPT^{TM}: An innovative tool to reduce worker exposure using virtual job planning

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Advanced Dose Exposure Planning Tool (ADEPT^{TM}) is an innovative solution that assists nuclear station staff to effectively minimize the worker's radiation dose during the inspection and maintenance activities and to improve ALARA job planning. ADEPT^{TM} provides 3D virtual reality job simulations for radioactive environments around the reactor components. ADEPT^{TM} allows power plant workers to realistically guage the radiation dose without physically being exposed.

Keywords: radiation exposure; dose evaluation; ALARA; virtual simulation; shielding effect; radiation job planning; nuclear station; reactor outage

1. Introduction

Nuclear plant operators continue to strive for an individual and collective radiation dose reduction. It is important to understand radiation fields around the various reactor components in order to effectively manage dose reduction. Measurements of gamma radiation fields in the reactor vault and around various reactor components indicate significant complexity in the distribution of the fields. These distributions depend on the design of the reactor and the primary heat transport system, as well as distributions of deposited activities on various reactor components. The deposited activity in general is a combination of a fixed activity associated with oxide deposits within system components, as well as of localized spots, which may be attributed to relatively mobile particulate or debris. Hence, observed radiation fields reflect the design and different types of radioactivity distributions on various reactor components. Information on radiation fields and data for their interpretation are typically collected during Outage Activity Transport Monitoring (OATM) surveys. OATM data is based on the estimation of absolute specific activity of individual radionuclides on reactor components [1].

Kinectrics has been involved in performing Outage Activity Transport Monitoring surveys at nuclear stations for several years, generating a detailed understanding of the radiation field characteristics and providing specific activity estimates for key reactor components. This work has led to the development of the Advanced Dose Exposure Planning Tool or ADEPT^{TM} [2].

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2. ADEPT methodology

ADEPT^{TM} is built around the idea of combining visualization and simulation of the radioactive environment at nuclear stations. Virtual models of the main reactor components include the reactor face, as well as the vertical and horizontal feeder cabinets. The 3D radiation field in this virtual environment allows the simulation of a radiation job for a virtual worker. Each worker has dosimeters that register the intensity of the radiation field. ADEPT^{TM} interface allows users to walk through a virtual job plan and receive a live dose estimate for the planned work.

2.1. Virtual model of the reactor vault

The graphical core of ADEPT^{TM} consists of a 3D geometrical model of the main components in a CANDU®[a] reactor vault, namely a horizontal feeder cabinet, a vertical feeder cabinet and a reactor face. 3D CAD design SolidWorks software was used to develop a geometrical model of the reactor components of interest. The model also depends on the type of CANDU® reactor being chosen. It allows ADEPT^{TM} users to visualize work environments in detail. Users can virtually walk into the reactor vault and move from one floor level to another, such as the horizontal feeder cabinet, using stairs.

2.2. Simulation of the radiation field

The central idea behind the 3D simulation of radiation fields is based on 3D radiation models of the main sources of radiation in the reactor vault and the superposition of these radiation fields at any desirable

[a] CANDU® is a registered trade mark of Atomic Energy of Canada Limited.

location in the reactor vault. These models were developed using "Mercurad" software [3]. Three main sources of radiation were considered for the radiation field modelling:

- Reactor face assembly including end fittings and associated feeders;
- Vertical feeder cabinet assembly consisting of inlet and outlet feeders;
- Horizontal feeder cabinet assembly consisting of inlet and outlet feeders.

The model parameters were estimated with measurements at reference points located inside the horizontal feeder cabinet and in the middle of the reactor vault in horizontal and vertical directions. **Figure 1** shows a comparison between the measured and estimated dose rates inside the horizontal feeder cabinet. The average ratio between the calculated and measured dose rates was 1.1±0.2, which validates the model.

The obtained 3D radiation field model was validated with the measured dose rate data throughout the entire reactor vault, including fields in proximity to the reactor face and along the end fitting body i.e., inboard of the reactor face. **Figures 2** and **3** demonstrate the validation of the model. Error bars correspond to an instrumental error of ± 20% in the measured dose rates. As shown in Figures 2 and 3, fitted dose rate curves are consistent with measured data at all elevations.

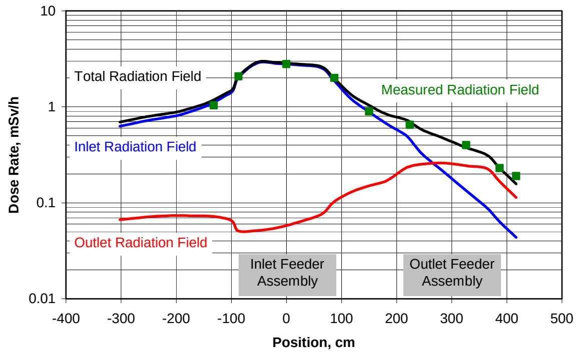

Figure 1. Variation of radiation fields in horizontal feeder cabinet.

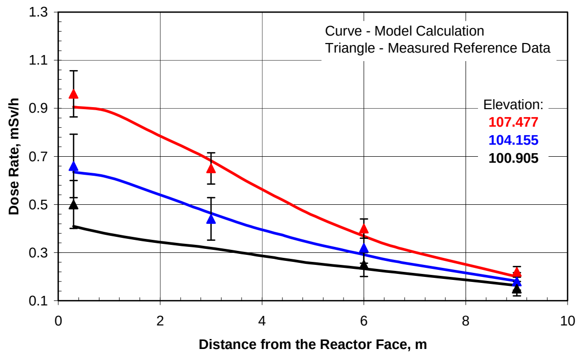

Figure 2. Variation of radiation fields with distance from the middle of the reactor face.

3. Features of ADEPT

ADEPT™ provides a fully customizable real time 3D virtual reality job simulation in a CANDU® reactor environment. Currently, areas of interest are focused on the reactor vault and the horizontal feeder cabinet. A general view of these areas is shown on **Figure 4**.

The radiation field in the reactor vault was simulated with the actual data collected during Outage Activity Transport Monitoring (OATM) surveys. As a result, the simulated radiation fields reflect the actual radiation environment in the unit of interest during the outage. A number of shielding options are available with the associated radiation fields. The shielding options for the reactor face are based on predetermined configurations and are stored in the configuration database.

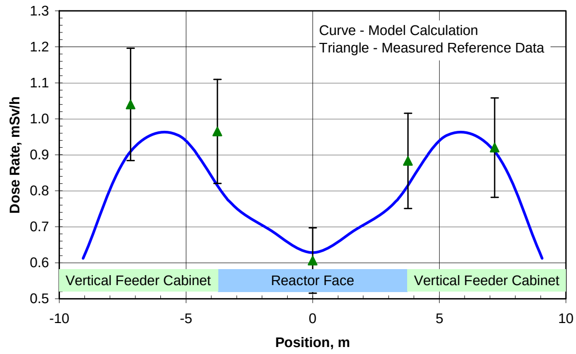

Figure 3. Variation of radiation fields at a distance of 0.3 m from the reactor face across the width of reactor vault.

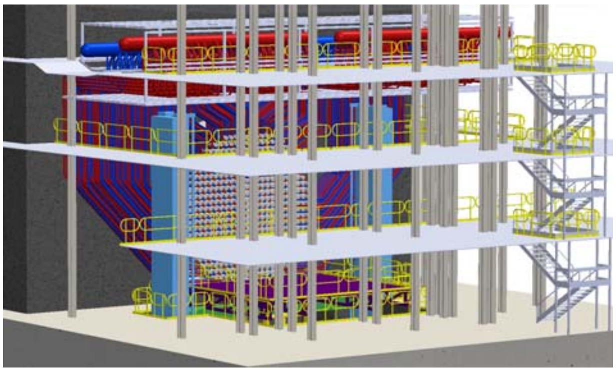

Figure 4. Reactor vault virtual model.

Figure 5 illustrates ADEPT™ windows for job simulations on the platform in front of the reactor face. These windows include the following:

- Job simulation scene with workers;
- Live display of individual dose rates and the total dose for workers (blue window);
- Dose exposure graph for the whole body and extremities;
- Dose rate graph for the whole body and extremities.

As virtual workers carry out job activities, a live display with the dose rate (blue window in Figure 5) is continuously updated.

Job simulations and associated doses received by workers are recorded for future analysis in the database. In addition to a live simulation, an optional feature allows accelerating the simulation if the worker remains at a certain location or performs a task. In this case, the program will automatically calculate the radiation doses once the length of action in the particular location or an instruction for the repeated task is specified. This feature can conveniently accelerate the simulation process.

In the Comparison menu, recorded job simulations can be replayed and analyzed with different radiation field configurations in order to estimate the worker's dose. Comparison window is shown in **Figure 6.**

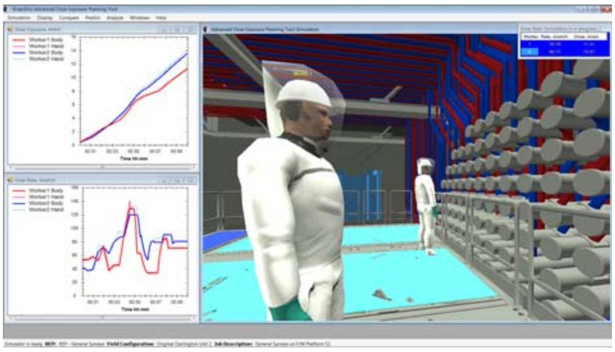

Figure 5. Typical windows for job simulations on the platform.

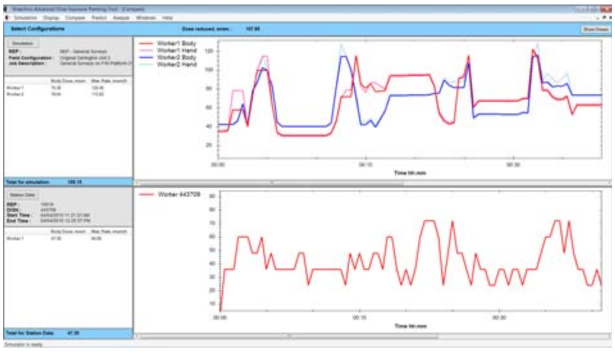

Figure 6. ADEPT comparison window.

A number of options exist for comparisons and analysis in ADEPT^{TM}. Comparisons can be made between simulations with different job descriptions or radiation field configurations. It is also possible to perform comparisons between different simulations, between a simulation and an actual station data, and between station data, when such station data is available. Furthermore, shielding option effects on the worker's dose that are based on the user-defined job descriptions can be estimated using this function. Comparisons are available between different job scenarios and may utilize real station data.

Another feature of ADEPT^{TM} is a multiple dosimeter option. A worker can wear multiple dosimeters for better evaluation of the effective dose in a high gradient radiation field, taking the accuracy of effective worker dose estimations to a new level.

4. Application of ADEPT

ADEPT^{TM} allows workers to virtually perform all activities associated with the inspection and maintenance jobs in the reactor vault, such as moving around in all directions, turning, standing and lifting hands. The following is a possible simulation scenario for workers who are performing a feeder inspection on the reactor face. The worker enters the reactor vault through an air lock. He is then positioned on the floor level of the reactor vault, awaiting orientation and preparations to enter the platform. A small staircase is used to enter the platform. The platform is operated and can be moved up or down to a certain position in order to allow convenient access to the feeder of interest. All required operations for the inspection of the feeder are then executed. The virtual worker can use his hands for the job actions, with dosimeters located on his hands. Upon completion of the procedure, the worker returns to the reactor vault floor and exits the vault. During this simulation, the worker's actions can be controlled with a joystick or a keyboard. Throughout the real time simulation, a live dose rate and the total dose are continuously provided. Once the simulation is completed, all information is stored in the database. ADEPT^{TM} allows the total dose to be recalculated for various radiation field configurations, while keeping the same job procedures.

Hence, in ADEPT^{TM}, a user can virtually walk around the vault and see the work environment from all perspectives. This feature can be used to train workers prior to commencement of their actual work, as well as to estimate their dose rates during the job and to minimize exposure to radiation. Actual workers can better understand the radiation field distribution for their planned job activities and become familiar with the anticipated dose rates on the platform. This should enable them to minimize their exposure to radiation by better choosing their work locations and performing planned tasks more efficiently. Workers will be completely familiar with the environment and the associated radiation field after the virtual model training. This acquired knowledge and skills will allow completion of the required job more effectively while reducing the dose.

It should be noted that with the implementation of ADEPT^{TM}, health physics personnel can now simplify the planning process and get a more accurate estimation of the radiation dose budget.

5. Conclusion

ADEPT^{TM} was developed to effectively assist nuclear utility staff in the estimation of the worker dose during the maintenance and inspection activities around the various reactor components and to improve ALARA job planning. It provides 3D virtual reality job simulations for radioactive environments around the reactor components. ADEPT^{TM} allows users to:

- ✓ Visualize work environments in a great detail;

- ✓ Provide planning options to reduce the worker's dose and save time on the critical path;
- ✓ Evaluate the impact of working in different configurations and scenarios;
- ✓ Assess the effect of shielding on the potential dose estimates for radiation work;
- ✓ Conduct pre-job reviews and post-job briefings of workers;
- ✓ Provide an important training tool for new staff and contractors.

References

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