Preliminary ALARA Dose Assessment for Three APM DGR Concepts

NWMO TR-2014-18 November 2014

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ABSTRACT

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Report No.: **NWMO TR-2014-18**
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Abstract

The Nuclear Waste Management Organization (NWMO) is implementing Adaptive Phased Management (APM), which has as its endpoint the centralized containment and isolation of Canada's used nuclear fuel in a deep geologic repository (DGR). The NWMO is advancing three reference concepts for further investigation:

- The Mark I container concept in crystalline rock;
- The Mark I container concept in sedimentary rock; and
- The Mark II container concept in crystalline or sedimentary rock.

In relation to APM, operational safety aspects need to be considered as a part of design development. This report focusses on assessing the radiological consequences of normal operation for workers in the APM facilities. The aim of the preliminary ALARA (As Low As Reasonably Achievable) dose assessment is to guide design development. ALARA assessments are performed to ensure worker dose rates are within appropriate regulatory limits and to provide the necessary data that can be used to further optimize shielding, facility design and operational procedures.

The main components of the ALARA Assessment are the activity lists that identify the worker exposure situations during operation of the Used Fuel Packaging Plant (UFPP) and the DGR, and the calculated neutron and gamma dose rates for these expected exposure situations. These have been developed for the three APM concepts to obtain a preliminary estimation of the individual and collective doses. Potential changes to the design and operation of the facility that could reduce the occupational doses have also been identified.

The main conclusions of this preliminary assessment are that: (a) workers involved in the receipt of Used Fuel Transport Packages (UFTP) have the highest normal dose exposure; (b) dose exposures to workers in the rest of the UFPP and in the DGR are much lower; and (c) taking into account the results and recommendations of this assessment, the worker doses will be within applicable dose constraints. Important dose considerations are the volume of used fuel assumed to be received and processed at the UFPP (about 630 UFTPs received and max. 144,000 bundles processed), and the assumptions regarding the handling and temporary storage of UFTP at the facility.

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LIST OF ABBREVIATIONS

ALARA	As Low As Reasonably Achievable
APM	Adaptive Phased Management
CANDU	CANada Deuterium Uranium
CNSC	Canadian Nuclear Safety Commission
DGR	Deep Geologic Repository
NEW	Nuclear Energy Worker
NWMO	Nuclear Waste Management Organization
OPG	Ontario Power Generation
OTC	Overhead Transport Crane
SKB	Svensk Kärnbränslehantering AB (Sweden)
UFC	Used Fuel Container
UFPP	Used Fuel Packaging Plant
UFTP	Used Fuel Transport Package

1. INTRODUCTION

1.1 BACKGROUND

The NWMO is implementing Adaptive Phased Management (APM), which has as its endpoint the centralized containment and isolation of Canada's used nuclear fuel in a deep geologic repository (DGR). The NWMO is advancing three reference concepts (Figure 1) for further investigation:

- The Mark I container in crystalline rock (referred to as the Mark I (crystalline) concept herein);
- The Mark I container in sedimentary rock (referred to as the Mark I (sedimentary) concept herein); and
- The Mark II container in crystalline or sedimentary rock (referred to as the Mark II concept herein).

Operational safety aspects are being considered jointly with design development. ALARA dose assessments are performed to ensure that anticipated worker dose rates remain within acceptable limits and to provide feedback such that existing designs can be further optimized. At this very early stage, the facility design and related processes are still in the conceptual stage. As the facility design evolves, so will the ALARA assessment and additional feedback will be provided to further optimize the design.

1.2 CONCEPTUAL DESIGNS

All three APM concepts include a deep geologic repository in either crystalline or sedimentary host rock. Differences between these concepts arise because of differences in host rock environmental conditions and because of the two different Used Fuel Container (UFC) designs; namely, the Mark I and Mark II containers.

Each conceptual design consists of an underground repository constructed at a minimum depth of 500 m below surface in sparsely fractured crystalline rock or low permeability sedimentary rock. The repository contains a network of placement rooms, which will house the used fuel containers. The surface facilities include a Used Fuel Packaging Plant (UFPP), which receives Used Fuel Transport Packages (UFTPs) from interim storage locations and re-packages the used fuel into the used fuel containers (Mark I or II) for placement in the underground repository.

The Mark I container, which is similar to the SKB KBS-3 dual-shell vessel container, adopts the same copper outer shell but with an inner steel vessel designed to hold 288 used CANDU fuel bundles. The Mark II container is a smaller container with a thinner copper-coating that holds 48 used fuel bundles.

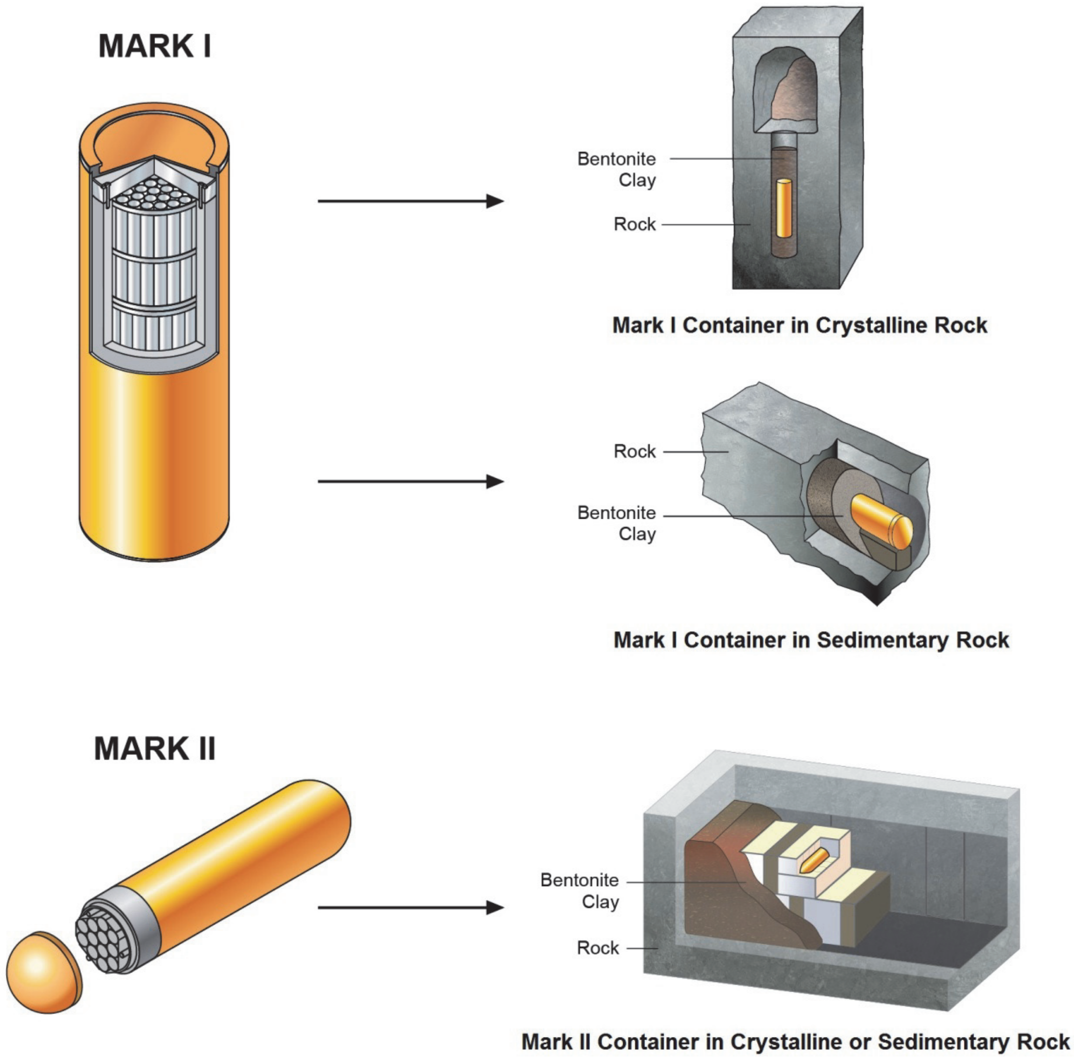


Figure 1: Schematic Illustrations of the Three APM Concepts

In Sections 3 and 4, the current design of the three APM concepts (Mark I (crystalline), Mark I (sedimentary) and Mark II) is described, with specific focus on the UFCs, UFPP, transfer systems, bentonite sealing systems and the underground layouts needed to achieve the required long-term containment and isolation. Because the design is currently at such an early stage, the design descriptions and exposures models are supplemented by information from international repository projects. Also, facility, equipment and waste handling logistics are described.

Section 3.3 discusses the characteristics of the waste.

1.3 OBJECTIVES

The assessment of the operational performance of each APM concept requires the estimation of doses to two types of workers, these being those that handle the used fuel and those that support operation of the facilities. This report focusses on assessing the dose consequences to both types of workers under *normal conditions of operation.* The dose estimates are preliminary in nature due to the very preliminary nature of the designs being assessed.

The CNSC Radiation Protection Regulations specify the dose limits required to protect the people and workers against unacceptable risks (see Section 2). Nonetheless, merely achieving doses below these limits is not considered sufficient under the principles of ALARA. Rather, optimization of the facility based on an ALARA assessment is seen as an essential part of design development to ensure a high level of operational safety.

The aims of the report are to:

1. Compile realistic Worker Exposure Models for each APM concept, taking into account the very preliminary nature of the current designs. The activities include:

   - UFPP activities;
   - Shaft operation activities;
   - Underground facilities activities; and
   - Facility support activities.

   The Worker Exposure Models describe:

   - Number of workers required to complete each task;
   - Type of worker assigned to each task
   - Distance to radiation source;
   - Estimated time of exposure; and
   - Frequency of each task.

2. Calculate the individual and collective dose rates for the workers, by using the Worker Exposure Models and dose rate calculations for each exposure situation.

3. Provide recommendations for further development and optimization of the facility designs to achieve doses that are ALARA. This is done by identifying reasonable opportunities to reduce occupational doses for each APM concept.

Results are then summarized for the three concepts. The results presented in this report are preliminary in nature and will be revised in the future when the design is further developed.

1.4 SCOPE

The scope of this work is limited to estimating the radiological impacts on workers in the DGR surface and underground facilities arising from normal conditions of operation. More specifically, the assessment will include all activities starting from receipt of the UFTPs at the UFPP to final placement in the repository.

Conventional safety, non-human biota impacts, and transportation of UFTPs from interim storage locations to the repository site are outside the scope of this work. Conventional safety refers to the safety from accidents that have no potential radiological impacts resulting from DGR activities, including the safety in relation to external human actions (such as accessibility and illegal actions). Risks from radionuclides occurring naturally in the host rock (i.e., radon) are also excluded. Also excluded are the doses accrued from potential retrieval of the used nuclear fuel.

1.5 CONCEPT SPECIFIC DEFINITIONS

This section describes a number of terms and concepts that are pre-requisites to understanding the ALARA assessment.

The **UFPP** building is a reinforced concrete structure with zoned areas for the radiological hazards. The detailed design differs between Mark I and Mark II. Plan view of the Mark I UFPP (transfer level, +0.00 m) is shown in Figure 2 and an illustration of the Mark II UFPP in Figure 3.

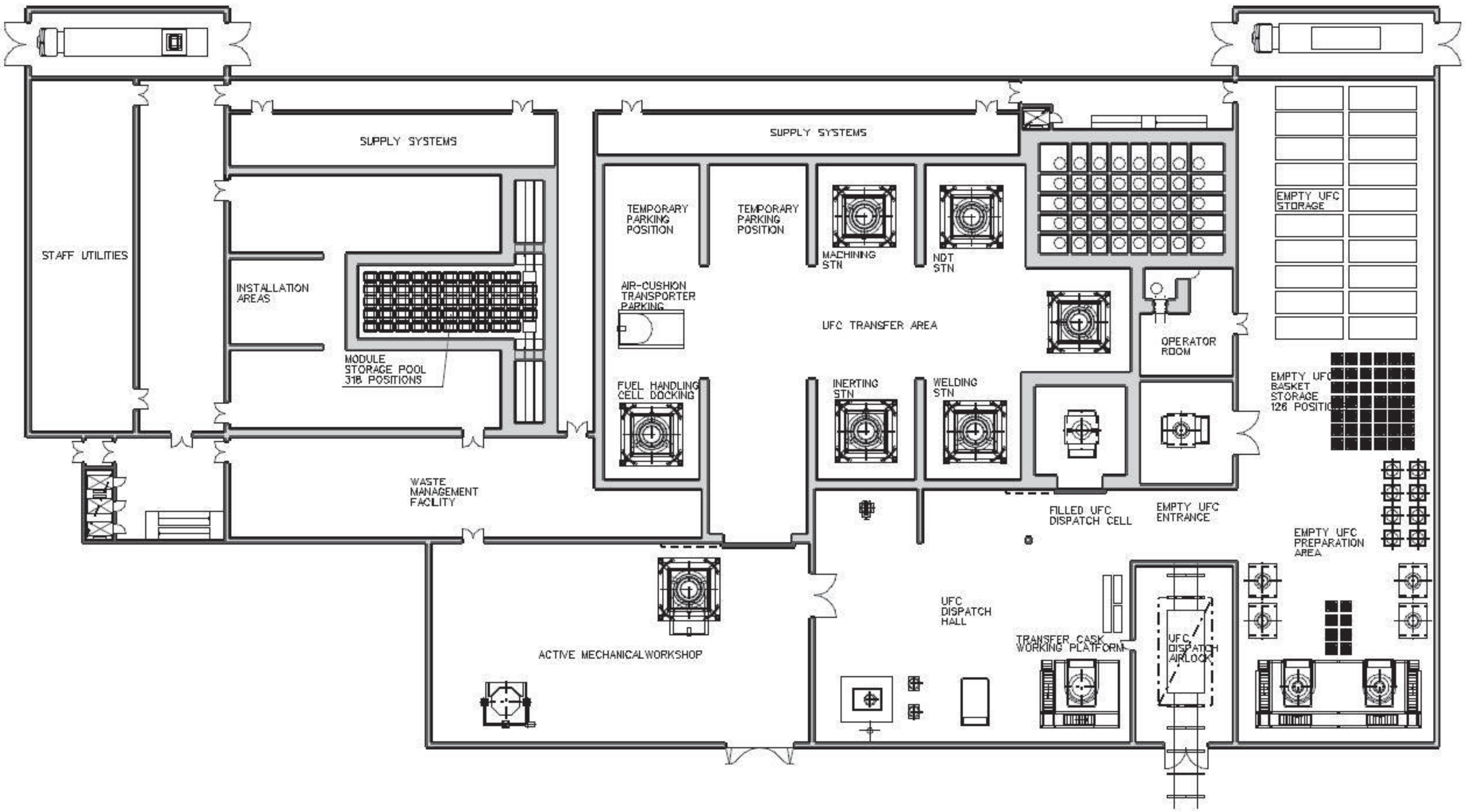


Figure 2: Mark I Concept UFPP, Transfer Level +0.00 m

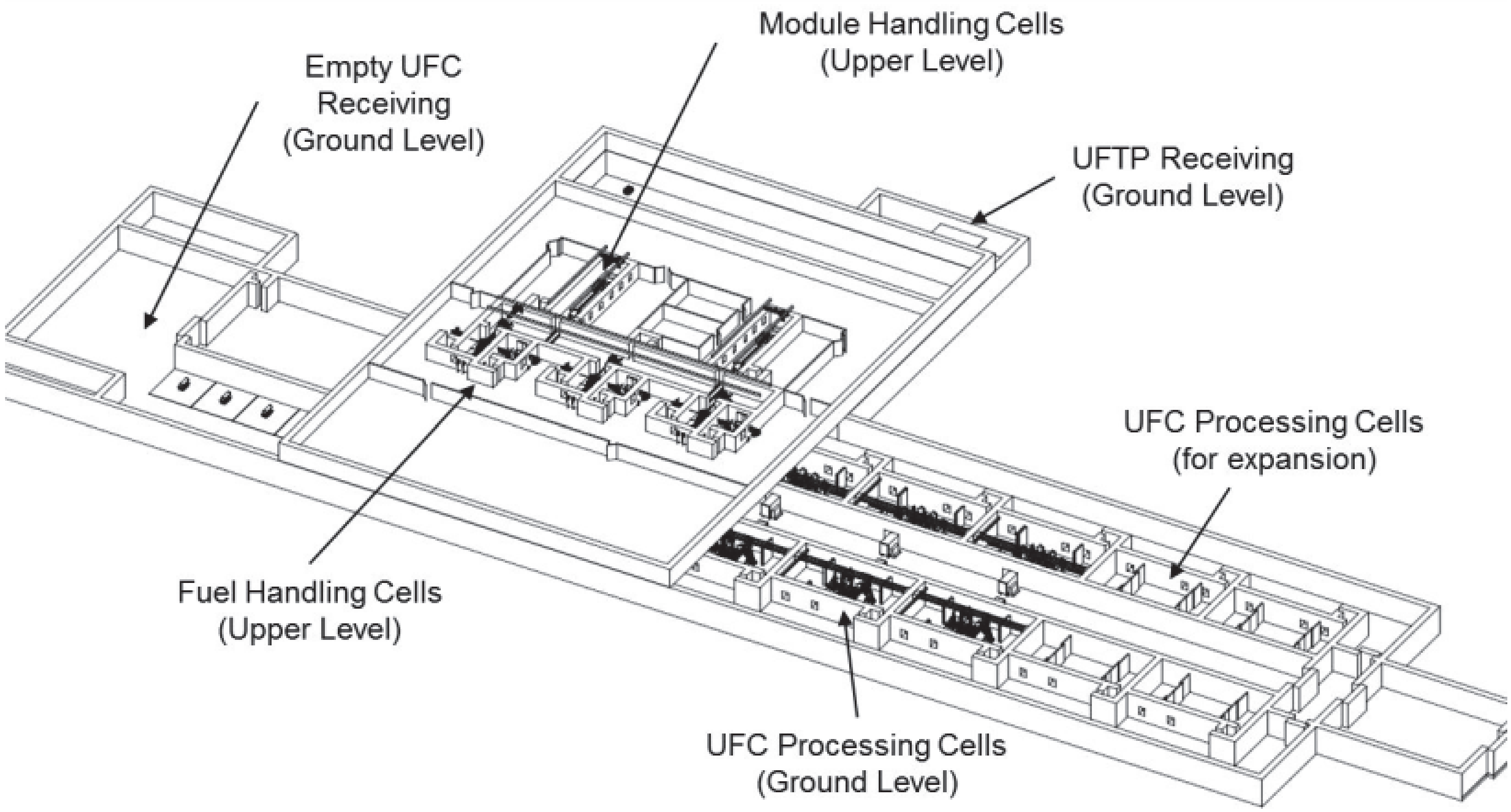


Figure 3: Mark II Concept UFPP Illustration

A **CANDU fuel bundle** consists of 28 or 37 fuel elements, depending on the type, with each containing a number of UO_2 fuel pellets. The elements are manufactured from Zircaloy 4, a zirconium metal alloy. Once filled with uranium pellets, they are sealed at both ends with zircaloy plugs and are welded together into a cylindrical matrix structure with plates at each end.

A typical CANDU fuel bundle is shown in Figure 4. Each fuel bundle is approximately 500 mm long, 102 mm in diameter and weighs about 24 kg.

Figure 4: A CANDU Fuel Bundle

Modules are rectangular rack systems used to hold used nuclear fuel bundles at interim storage sites and during transport in a UFTP (Figure 5). A module contains 96 fuel bundles. The modules are identical in both the Mark I and Mark II concepts.

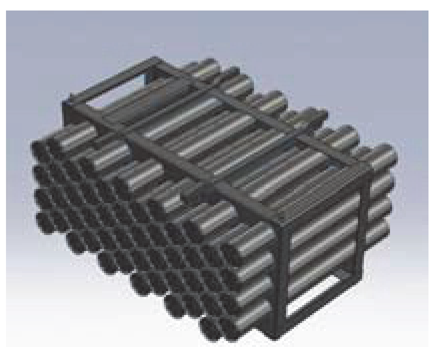


Figure 5: Module for 96 Fuel Bundles

Used Fuel Transport Packages (UFTPs) are the protective containers used to transport used nuclear fuel from the interim storage sites to the APM facility. The current package design is a solid stainless steel box with walls that are approximately 30 centimeters thick and a lid attached with 32 bolts. Each UFTP can house two modules. An impact limiter is attached to the top of the UFTP during transportation and during UFTP storage in the UFPP. The UFTP design is shown in Figure 6. Assumption for both Mark I and Mark II concepts is that 630 UFTPs are received per year.

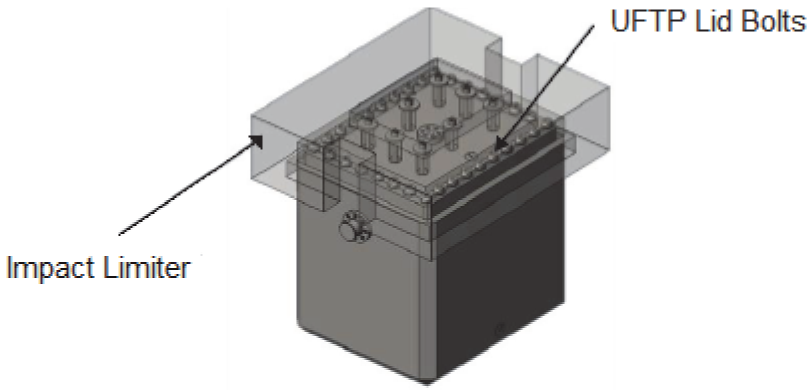


Figure 6: UFTP Shown with Impact Limiter

The **Used Fuel Containers (UFCs)** are containers used for the long-term underground placement of the used nuclear fuel. The Mark I UFC is similar for both the crystalline and sedimentary concepts, but the lid is different between the two as the equipment used to install them in the placement room is different (see concept descriptions in Section 1.2). The Mark II UFC is smaller and it has a thinner copper coating and two semi-hemispherical heads. The Mark I container holds 288 fuel bundles and the Mark II container holds 48 fuel bundles (Figure 7). The Mark II UFPP has a maximum throughput of 2 UFCs per day, which corresponds to 144,000 bundles per year. Though the rate of receipt of used fuel bundles in UFTPs is lower (120,000 bundles per year), the maximum throughput of 144,000 bundles per year has been adopted as a basis for the Mark I and Mark II UFPP processing rates. Thus, the Mark I UFPP produces 500 UFCs per year and the Mark II UFPP produces 3000 UFCs per year.

An **air-cushion transporter** is used in the Mark I concept to move the UFC through the transfer hall between stations (Figure 2). The design of the air-cushion transporter has been carried forward by SKB in Sweden, and can be adapted for use in the Mark I concept UFPP with minor modifications. While on the air-cushion transporter, the UFC is fitted into a **sleeve**, which is in a **shielded frame** that can be lifted and lowered between processing stations. An air-cushion transporter, with a lifted UFC visibly protruding from the shielded frame, as developed by SKB, is shown in Figure 7.

The **transfer cask** is a shielded container used to transfer the Mark I UFC from processing, through dispatch and down the shaft to underground facility. The transfer cask provides shielding for UFC during transfer operations. The UFC is placed in its transfer cask so that it can exit the filled UFC dispatch cell and is removed from the transfer cask in the reloading station (Mark I (crystalline) concept) or in the underground placement room (Mark I (sedimentary) concept).

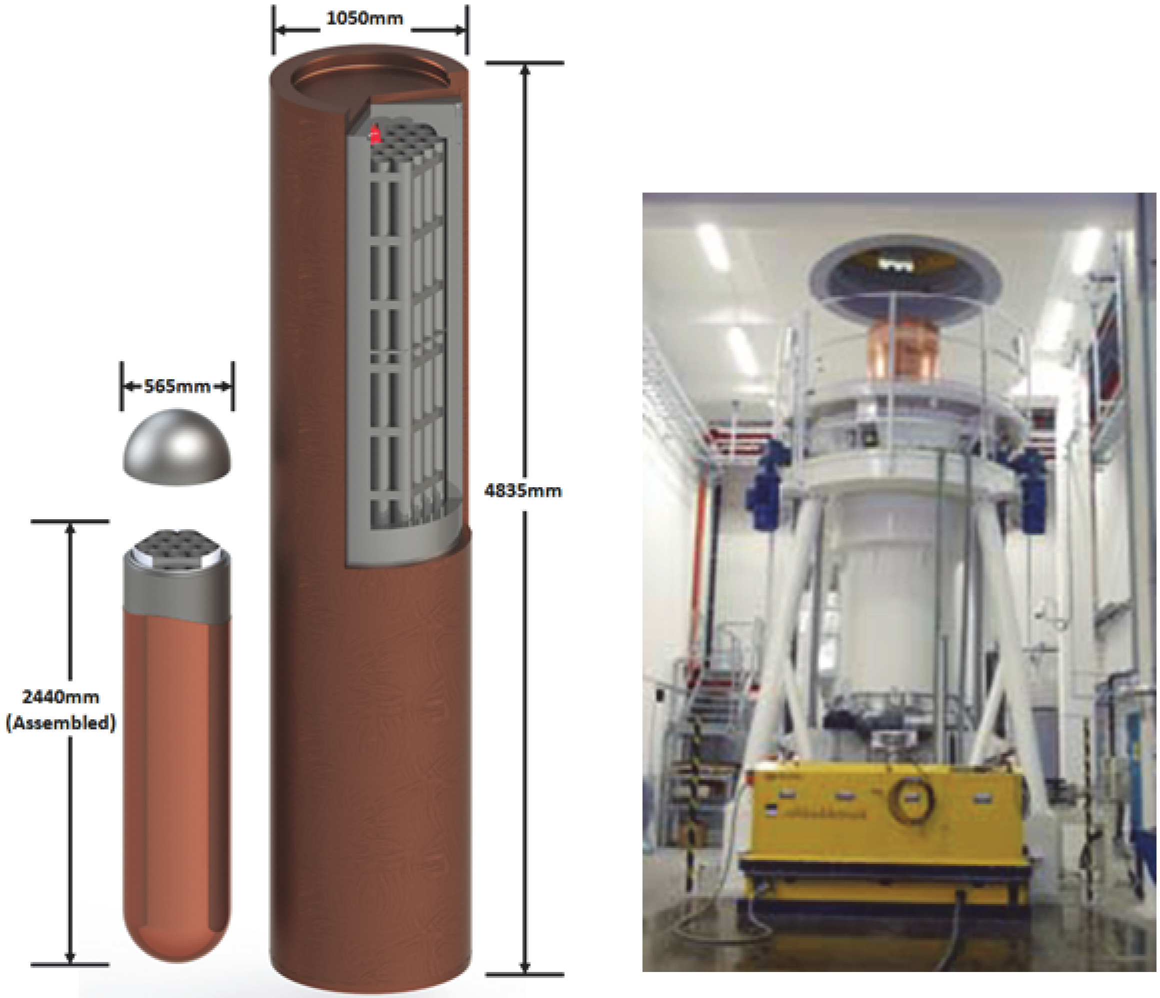


Figure 7: Mark I and Mark II Concept UFCs and Yellow Air-Cushion Transporter Moving Shielded Frame with UFC in Sleeve

The **deposition machine** is used in the Mark I (crystalline) concept to pick up the UFC from the reloading cell (and from within transfer cask), to move it into a placement room, and to lower it down into the deposition hole (Figure 8). It is a diesel fuelled vehicle, which is equipped with a radiation shield. It travels at very low speeds (approximately 5 km/h), and in its current design, is remote operated.

In the Mark I (sedimentary) concept, the UFC within a transfer cask is delivered directly from the shaft to the placement room on rails, using a locomotive. Once in the placement room, the **transfer cask** is connected to the radiation barrier and remotely installed on the **pedestal** using an electricity operated ram to push the UFC through the **shielding barrier** onto the **cart bed**. The cart bed then lowers the UFC onto its final position on the pedestal.

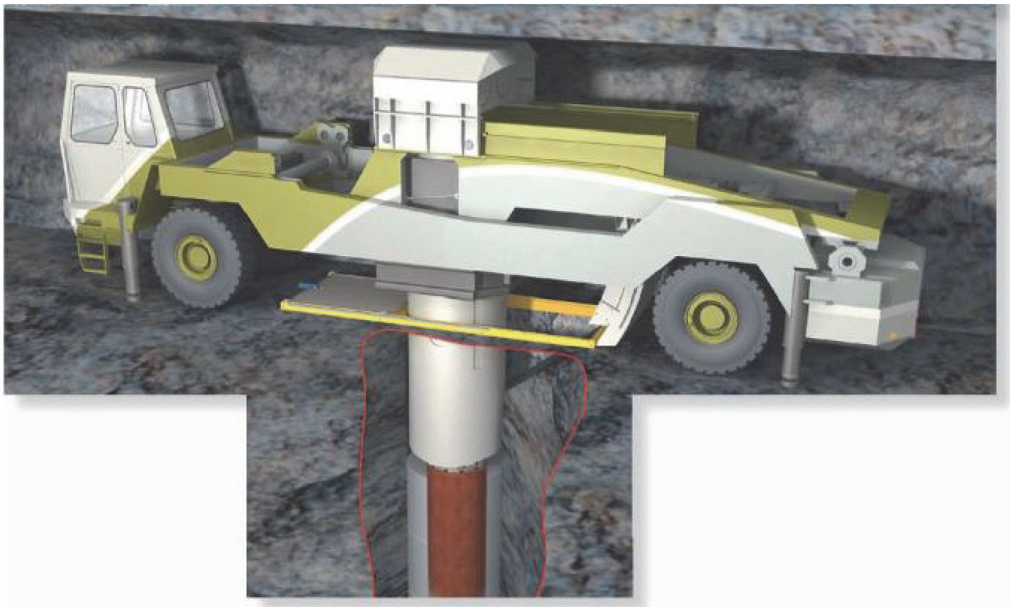


Figure 8: Mark I (Crystalline) Concept Deposition Machine

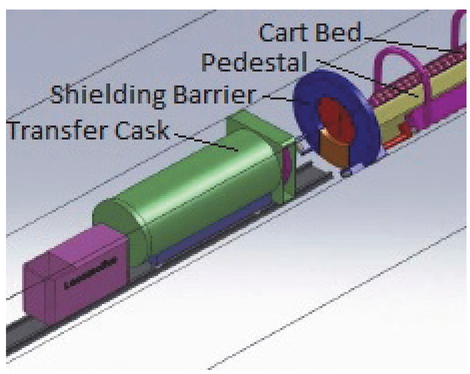


Figure 9: Mark I (Sedimentary) Concept Underground Placement Equipment

In the Mark II concept, the **transfer flask** is a shielded container used to move the UFC within the UFPP for processing (Figure 10). It is moved using a customised **automatic guided vehicle** (AGV) transportation system. Once the Mark II UFC is fully processed, blocks of highly compacted bentonite are placed around the UFC, and the assembly is encased in a thick steel shell. This forms the **bentonite buffer box**.

The **transport cask** is a shielded container that carries the bentonite buffer box from the UFPP to the placement room using tow vehicles (Figure 11). The buffer box is transferred from transport cask to a placement vehicle, though a **shielding canopy** at the entrance of the placement room. The shielding canopy serves to aid the transfer of the bentonite buffer box out of the transport cask onto the placement vehicle. A placement vehicle is used to remotely place the buffer box in its final location in the placement room (Figure 11).

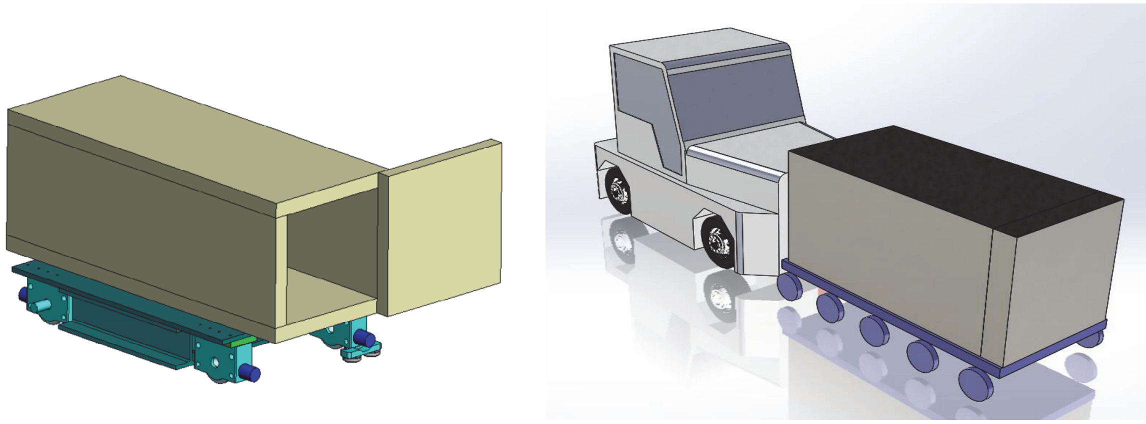


Figure 10: Transfer Flask Used in the UFPP for UFC Transfer (Left) and Transport Cask with Tow Vehicle Used to Transport Buffer Box with UFC to DGR (Right) (Mark II Concept)

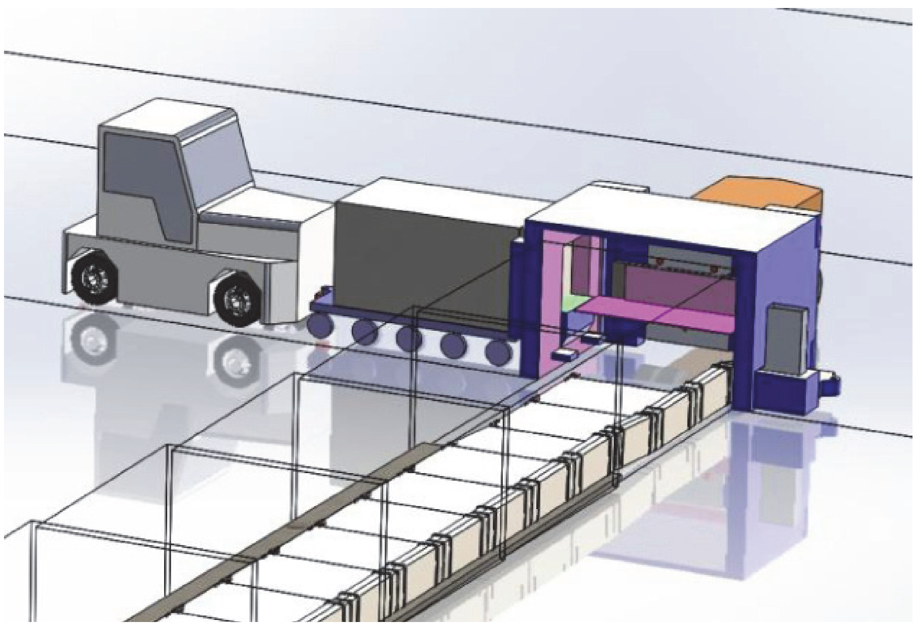


Figure 11: Tow Vehicle and Transport Cask at the Shielding Canopy Equipped with Placement Vehicle (Mark II Concept)

2. ASSESSMENT CONTEXT – REGULATORY REQUIREMENTS, GUIDELINES AND TARGETS

This report focusses on the **normal conditions of operation**. Canadian Nuclear Safety Commission (CNSC) Regulatory Guide G-129 (CNSC 2004) states that *"ALARA incorporates the notion that the magnitude of effort that should be applied to control doses depends on the magnitude of projected or historical doses"*. However, the CNSC underlines that in some cases, to avoid the commitment of resources that are likely to have a poor return in safety improvement, an ALARA assessment beyond initial analysis is not needed. This can be applied, when:

1. individual occupational doses are unlikely to exceed 1 mSv per year;
2. doses to individual members of the public are unlikely to exceed 50 μSv per year; and
3. the annual collective dose (both occupational and public) is unlikely to exceed 1 person-Sv (p-Sv).

The applicable Canadian *effective dose limits* are presented in the CNSC Radiation Protection Regulations (CNSC 2000, see Table 1). These limits are based on ICRP (1991).

Table 1: CNSC Effective Dose Limits (CNSC 2000)

Person	Period	Effective Dose (mSv)
NEW, including pregnant NEW[a]	One-year dosimetry period	50
	Five-year dosimetry period	100
Pregnant NEW	Balance of pregnancy	4
A person who is not a NEW	One calendar year	1

a – Nuclear Energy Worker (NEW)

Occupational dose targets are also specified by the owners of nuclear facilities to ensure that the regulatory dose limits are not exceeded. These targets are more restrictive than the regulatory limits. Design specific dose rate limits can also be set. These are described as specific dose rate limits for areas of a facility or for working surfaces. For example, the dose targets for OPG's proposed deep geologic repository for low and intermediate level wastes (NWMO 2011) adhere to the OPG's Radiation Protection Requirements (OPG 2001a).

Radiation shielding system designs aim, at a minimum, to adhere to the limits shown in Table 1. However, to ensure that doses are maintained ALARA, the following additional constraints are imposed:

- the effective dose rate at the operational face of a UFC is less than 1 mSv/h near contact with the outer surface of the container;
- the effective dose rate on the accessible face of any shielded structure is less than 1 mSv/h near contact with the outer surface;
- the effective dose rate in normally occupied areas (at a distance of at least 1m from any wall or surface) is less than 10 μSv/h; and
- during normal operation, NEWs must not receive annual occupational radiation doses exceeding 10 mSv.

3. DESCRIPTION OF THE APM CONCEPTS AND OPERATIONS

3.1 MARK I (CRYSTALLINE) AND MARK I (SEDIMENTARY) CONCEPTS

3.1.1 Overview

The Worker Exposure Models for the Mark I (crystalline) and the Mark I (sedimentary) concepts are based on SNC-Lavalin (2011a and 2011b, respectively). These documents provided a basis for the overall operation of the UFPPs and DGR, but do not provide a detailed breakdown of the worker activities and activity durations. This information was estimated using available internal NWMO working documents, expert judgement and documented experience from similar facilities worldwide (for example, Rossi et al. 2009).

A general illustration of the Mark I (crystalline) concept repository is given in Figure 12, which is based on SKB's KBS-3V repository design. In this concept, copper UFCs are placed vertically in deposition holes and surrounded by a bentonite buffer. The deposition tunnel is then backfilled. The buffer that surrounds the UFC consists of:

- Highly Compacted Bentonite (HCB) (1.7 g/cm^3 dry density) rings and disks composed of 100% bentonite clay; and
- Gap Fill (GF) (1.4 g/cm^3 dry density) composed of 100% bentonite clay fabricated in the form of dense pellets.

The backfill material, which is used to seal the remainder of the placement rooms, access drifts, perimeter drifts and panel cross-cuts at the repository level, consists of:

- Dense Backfill (DBF) – a mixture of 70% crushed granite, 25% lake clay and 5% bentonite by mass;
- Light Backfill (LBF) – Pellets made from a mixture of 50% bentonite clay and 50% crushed host rock; and
- Gap Fill (GF) – composed of 100% bentonite clay fabricated in the form of dense pellets.

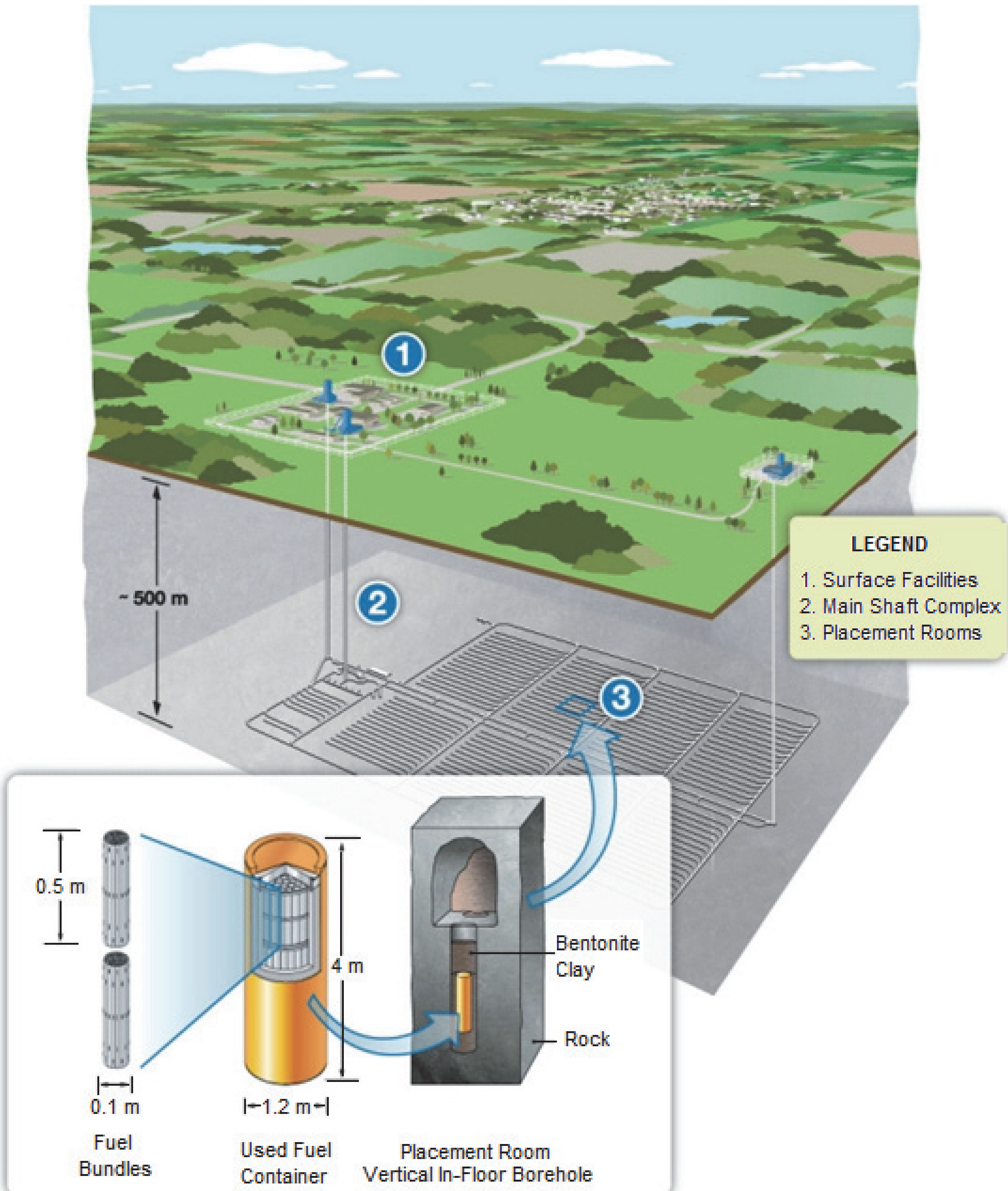


Figure 12: General Illustration of Mark I (Crystalline) Concept Repository

In the Mark I (sedimentary) concept repository, the UFCs are placed in horizontal TBM tunnels (TBM refers to tunnel boring machine). The UFCs are set on highly compacted bentonite pedestals and the remaining tunnel is backfilled with bentonite pellet gap fill (Figure 13).

The backfill material at the repository level consists of:

- Highly Compacted Bentonite (HCB) pedestal (1.6 g/cm^3 dry density) – 100% bentonite by mass; and
- Bentonite pellets, gap fill (1.4 g/cm^3 dry density) – 100% bentonite by mass.

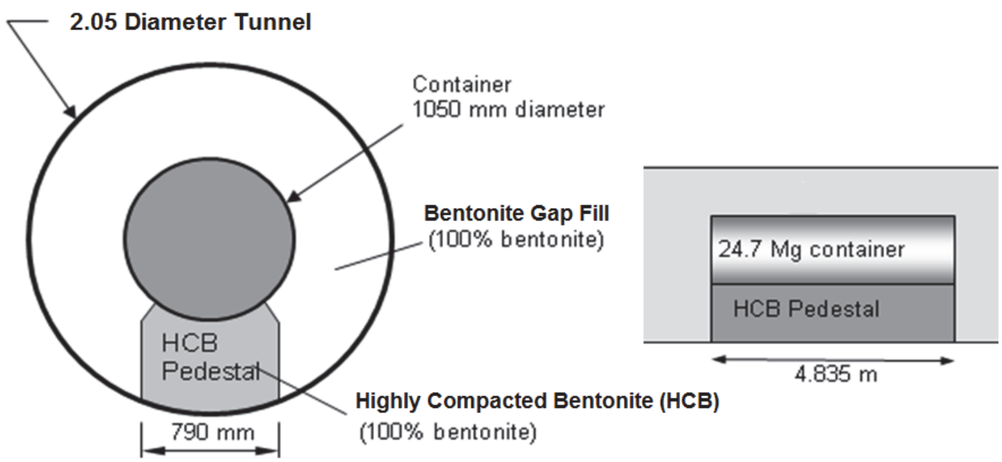


Figure 13: General Illustration of Mark I (Sedimentary) Concept Repository, UFC in Placement Room

The Mark-I UFC for both crystalline and sedimentary concepts has a large capacity (36 bundles/layer x 8 layers = 288 bundles) container based on the SKB KBS-3 dual–shell canister concept. It consists of a steel inner core (with a bolted upper lid and welded bottom lid) for structural strength and a 50 mm heavy wall wrought copper outer shell that is fully sealed by friction stir welding for corrosion resistance.

The following sections briefly describe the operations from the arrival of the used fuel at the UFPP to the final placement in the DGR. Activities are described to provide background for the development of the Worker Exposure Models (see Section 4). The UFPP activities are similar for both crystalline and sedimentary concepts. The only differences are in the lids of the UFC (due to differences in installing method) and in the transfer casks structure. These only affect the technical features of the components (not the flow of the process), and thus are not highlighted in the process description. The underground operations are described separately for both concepts (Sections 3.1.3 and 3.1.4), because there are significant differences.

3.1.2 UFPP Activities for Mark I Crystalline and Sedimentary Concepts

The main activities in the UFPP include the receipt of the used fuel in the UFTPs, removal of the used fuel from the UFTPs, insertion of the used fuel into the UFCs and final assembly / inspection of the UFCs. The UFPP building is a reinforced concrete structure with zoned areas for the radiological hazards. It measures 125 metres by 65 metres. A cut away view of the UFPP is shown in Figure 14.

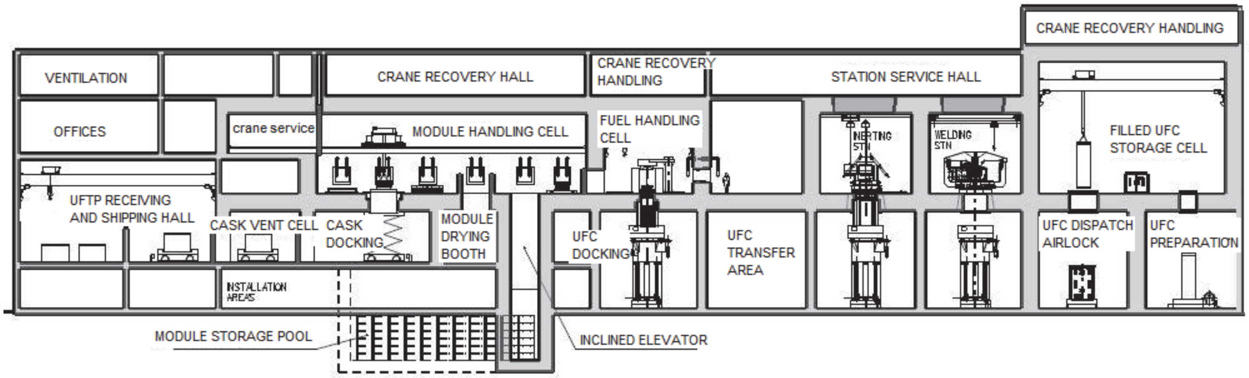


Figure 14: Illustration of the Mark I Concept UFPP

3.1.2.1 UFTP Activities

Upon arrival and parking of the UFTP transport vehicle in an airlock, the UFTP is transported into the UFPP through the UFTP receiving and shipping hall airlock port. The UFTP receiving and shipping area personnel open the weather cover, perform a smear test and a visual inspection of the UFTP and remove tie-downs. The roof of the airlock is then opened and the 40 tonne overhead transport crane (OTC) is lowered over the UFTP. The UFTP receiving and shipping area personnel attach the 40 tonne OTC onto the UFTP, which is then lifted from the airlock into the UFTP storage behind a shielding wall.

From the UFTP storage, the UFTP is lifted using the 40 tonne OTC onto a pallet at the entrance of a cell which transfers the UFTP to the module handling cell. While the UFTP is still on the pallet, personnel remove the impact limiter, which is lifted with the 40 tonne OTC to the impact limiter storage area. An alternative is to lift the UFTP directly from the airlock on the pallet for processing, but for completeness of the description of the facility process, rotation through the UFTP storage is included. It must be noted that adding this step practically doubles the number of UFTP-OTC connection and disconnection operations.

The UFTP is moved remotely, by pallet on rails, into the vent cell, where it is vented and its radiation levels are inspected. The bolts of the UFTP lid are opened and removed remotely in the vent cell. The UFTP is then moved forward, by pallet on rails, under the docking port of the module handling cell. It is lifted with the scissor lift that is integrated in the pallet, and sealed against the port to the module handling cell. The module handling cell gamma gate is opened and both the containment door and the UFTP lid are lifted into the module handling cell. The modules are then lifted (first the top module and then the bottom module) into the module handling cell.

The UFPP has two parallel lines for UFTP processing.

Once the modules have been removed, the UFTP lid is replaced, the containment door and the gamma gate is closed and the empty UFTP is lowered back down with the scissor lift of the pallet. The empty UFTP is moved by pallet on rails back into the vent cell, where it is inspected for contamination and, if required, decontaminated. The UFTP lid is bolted back onto the empty UFTP, which is then moved out of the vent cell back into the UFTP receiving and shipping area, where the impact limiter is re-installed. The empty UFTP is then returned to the UFTP trailer and returned for re-use.

3.1.2.2 Module Transfer Activities

The modules are lifted from the UFTP by module crane into the module storage area of the module handling cell. The modules are lifted one at a time and placed on one of four module storage sites. A module is lifted from the storage site with the module crane onto a module transfer cart and then transferred through a port that leads to the fuel handling cell.

There are two parallel module handling cells above the UFTP transfer corridors. Both module handling cells have ports to the same fuel handling cell. The module handling cells can be operated simultaneously and independently from each other.

From the module handling cell storage site, or directly from the UFTP through the module handling cell, it is also possible to transfer a module on an inclined elevator that leads to a surge storage pool for used fuel bundles (in modules). From the inclined elevator the module is transferred with an OTC to a storage pool site for longer storage time. The surge storage facilitates action of the UFPP in case of module delivery delay or interruption. The capacity of the storage pool is 318 modules, enough for three months of operation. When a module is removed from the surge storage it is lifted with the OTC back onto the inclined elevator, lifted into the module handling cell and straight into a drying booth. Once dried, the module is lifted with the module crane onto the transfer cart and transferred through a port into the fuel handling cell. There are inclined elevators and entrances to the same surge storage pool in both module handling cells.

3.1.2.3 Empty UFC Activities

Preassembled empty UFCs, which travel to the UFPP horizontally in transport frames, enter the UFPP through the UFC receiving airlock, from which they are lifted with a 30 tonne OTC into storage. The storage area has the capacity for 40 empty UFCs and 126 baskets, which are transported separately to the UFPP.

At the UFPP, only visual inspections of the empty UFC are performed; no dimension measurements are taken, since these have been done following a quality control procedure at the off-site manufacturing facility to ensure that only properly dimensioned UFCs are sent to the facility.

From the storage location, a transport frame with an empty UFC is tilted to the vertical position, transferred to a working platform in the empty UFC preparation area. The copper lid is then removed and transferred to the inerting station. The inner lid is opened and the inside of the UFC is inspected. The UFC is then inserted into a sleeve. The empty baskets that have been transported separately to the UFPP are then inserted into the empty UFC. The inner lid is replaced and bolts, though left loose, are fitted back onto the UFC. In its sleeve, the empty UFC is then transferred to an air-cushion transporter (see Figure 7), which travels to the empty UFC entrance position with the air-cushion transporter.

From the empty UFC entrance, the sleeve (with the empty UFC) is lifted with a 30 tonne OTC via the filled UFC storage cell and into the UFC entrance and exit station, where a shielded frame has been parked to receive it (Figure 15). After installation into the shielded frame, an air-cushion transporter is used to transfer the empty UFC to below the docking port of the fuel handling cell.

The empty UFC is lifted in the sleeve and sealed against the fuel handling cell port. The gamma gate is opened and the inner lid bolts are removed. The inner lid is off and the empty baskets are lifted with an in-cell crane onto the empty basket temporary storage positions in the fuel handling cell, before being moved to be filled with the used-fuel bundles.

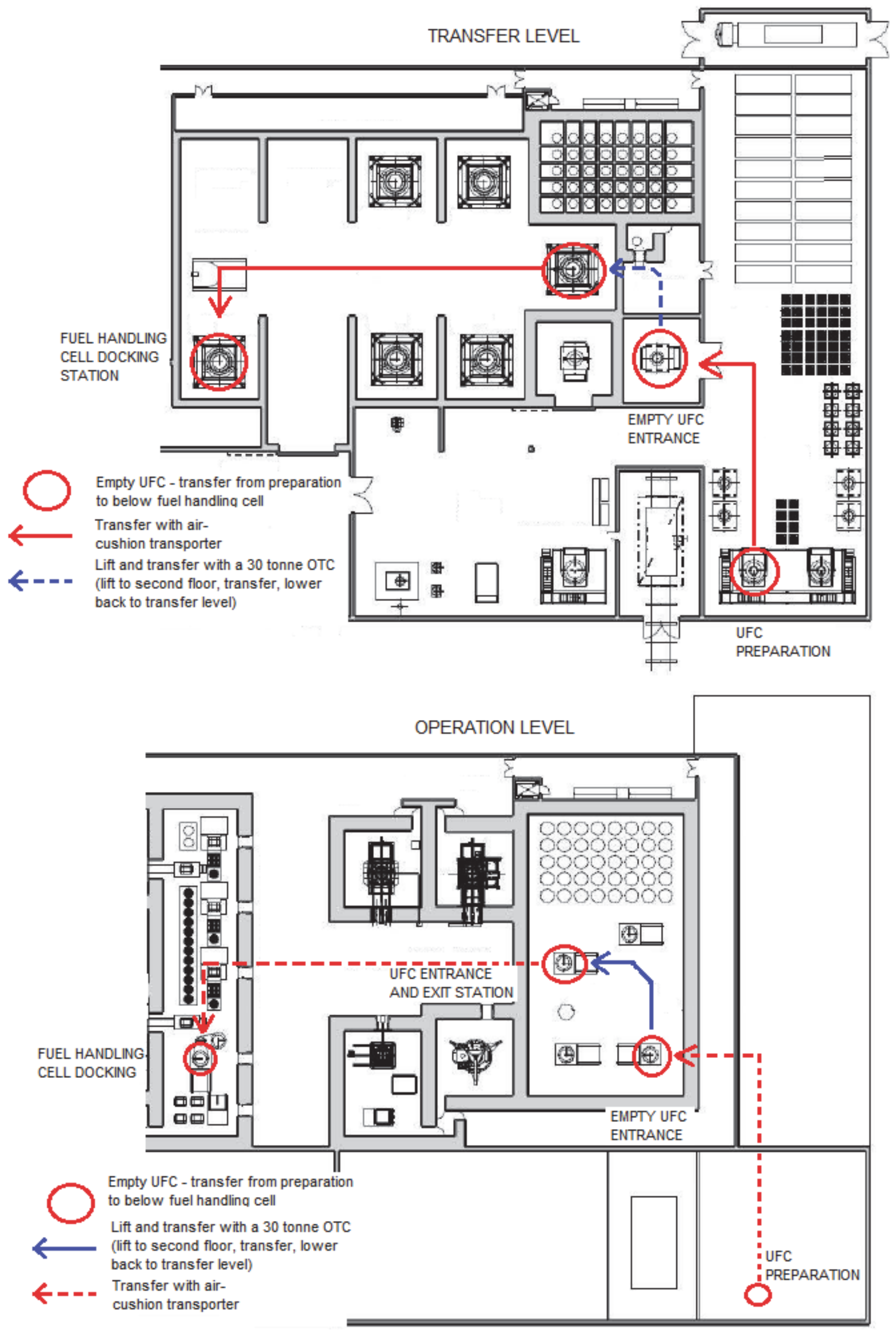


Figure 15: Mark I Transfer and Operation Level, Route of Empty UFC from Preparation to Fuel Handling Cell Docking

3.1.2.4 Fuel Bundle Transfer from Modules into Baskets

In the fuel handling cell, a module is transferred to one of the three fuel transfer machines using an in-cell crane. An empty basket is lifted using an in-cell crane to the same fuel transfer machine and positioned horizontally to receive fuel bundles. The fuel bundles are pushed two at a time out of the module and into the awaiting empty basket. This is repeated until the basket is full. Once full, the basket is tilted back to the vertical position, removed from the fuel handling machine and positioned in one of the 12 filled basket storage positions of the fuel handling cell. From its storage position, the filled basket is lifted with the in-cell crane back into an awaiting UFC. An alternative is to lift a full basket directly from the fuel handling machine to the awaiting UFC. Figure 16 presents an illustration of the fuel handling machine.

Note that it takes three modules to fill four baskets, because there are 96 bundles in each module and 72 bundles in each basket. A transfer operation for filling all baskets of one UFC includes the following steps:

- The first module and the first empty basket are transferred on the fuel handling machine.
- Fuel bundles are pushed into the first basket's tubes (two at a time, total 72 bundles).
- The first basket is removed from the fuel handling machine and replaced by the second basket.
- The remaining fuel bundles from the module are pushed into the second basket's tubes (two at a time, 24 bundles).
- Now empty, the first module is lifted out of the fuel handling machine and replaced with the second module.
- Fuel bundles are pushed into the remaining tubes of the second basket (two at a time, 48 bundles)
- The second basket is removed from the fuel handling machine and is replaced by the third.
- The remaining fuel bundles from the second module are pushed into the third basket's tubes (two at a time, 48 bundles).
- Now empty, the second module is lifted out of the fuel handling machine and replaced with the third module.
- Fuel bundles are pushed into the remaining tubes of the third basket (two at a time, 24 bundles).
- The third basket is removed from the fuel handling machine and is replaced with the fourth basket.
- The remaining fuel bundles from the third module are pushed into the fourth basket's tubes (two at a time, 72 bundles)
- Now filled, the fourth basket is removed from the fuel handling machine.
- Now empty, the third module is lifted out of the machine.

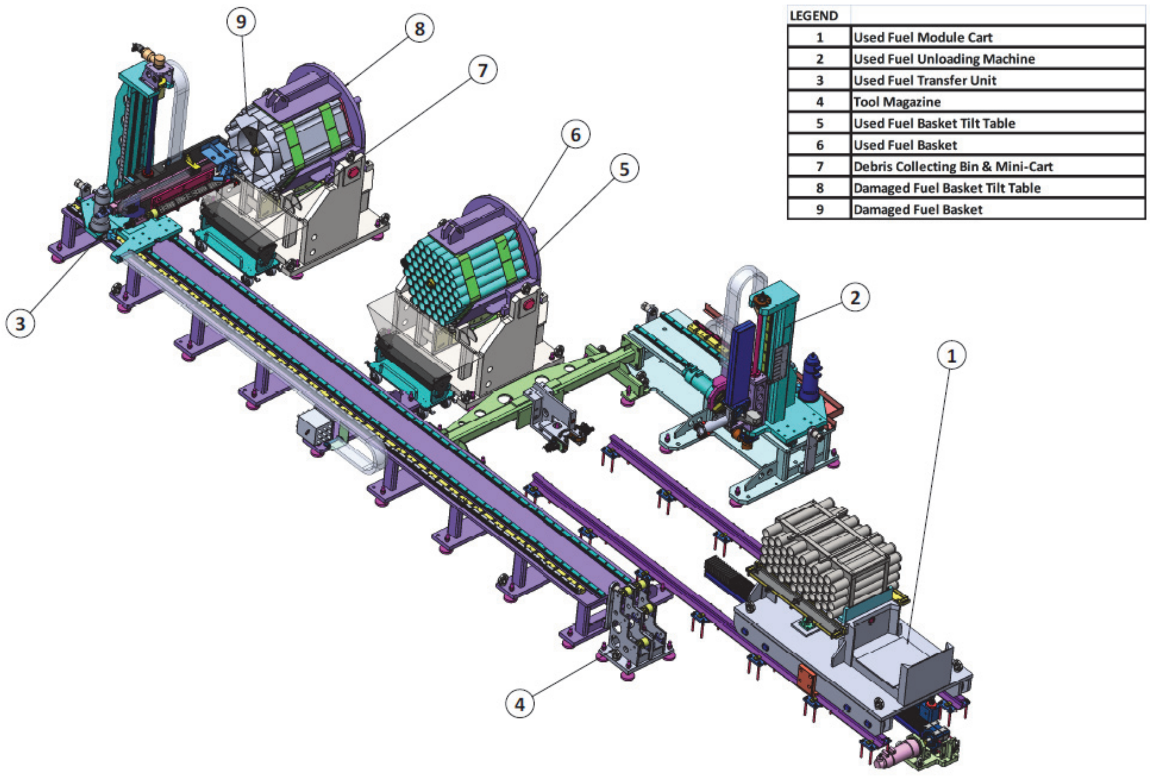


Figure 16: Fuel Handling Machine for Transferring Used Fuel Bundles from Modules in Baskets

Empty modules are removed from the fuel handling cell through a gamma gate and port to the waste management facility for inspection and decontamination. After decontamination the empty modules are transported from the UFPP to the off-site metal recycling facility.

3.1.2.5 Filling, Closing and Inspecting the UFC

Using the in-cell crane, the filled baskets are lowered into the UFC through the fuel handling cell docking station. Once the four baskets are loaded, the inner lid is replaced, the gamma gate of the docking station is closed and the filled UFC and sleeve are dispatched and lowered into the shielded frame. An air-cushion transporter is used to transfer UFC to the inerting station.

At the inerting station, the UFC is lifted in the shielded frame and docked. The inner lid is bolted back on and the lid valves are connected to the vacuum pump and inert gas supply. The UFC atmosphere is replaced. The procedure will be repeated until inspections confirm that the atmosphere exchange has been completed successfully. The valves are then disconnected, the top of the copper surface is cleaned, and the copper lid is placed on the UFC. The UFC is lowered with the shielded frame and transferred with the air-cushion transporter into the welding station.

At the welding station, the UFC is lifted in the shielded frame and docked, with only the top of the UFC in the station operating cell. Friction-stir welding is used to weld the copper lid onto the

UFC. After the welding, the UFC is lowered into the shielded frame and transferred to the machining station with the air-cushion transporter.

At the machining station, the UFC is lifted in the shielded frame and docked in the station, with only the top of the UFC in the station operating cell. The weld area is then machined smooth with the milling equipment of the machining station. After machining, the UFC is allowed to cool down and is then lowered in the shielded frame and back to the air-cushion transporter for transfer into the non-destructive testing (NDT) station.

At the NDT station the UFC is lifted in the shielded frame, such that top of the UFC is docked inside the station. The quality of the weld is inspected with ultrasonic equipment and, if needed, with radiographic equipment. After inspection of the weld, the UFC is undocked and lowered in the shielded frame and transferred with the air-cushion transporter to the entrance and exit station, below the port to the filled UFC storage.

At the entrance and exit station, the filled UFC is lifted out of the shielded frame and sleeve and transferred to the filled UFC storage with the 30 tonne OTC. The capacity of the filled UFC storage is 40 UFCs.

From the filled UFC storage, a filled UFC is transferred to the decontamination station using the 30 tonne OTC, where it is inspected for contamination and, if required, decontaminated. From the decontamination station, the UFC is lifted again with the 30 tonne OTC and transferred into the filled UFC dispatch cell, into an awaiting transfer cask.

3.1.2.6 Loading and Dispatching the UFC Transfer Cask

The transfer cask, which is used for most intra-site transfers of the filled UFC, is brought into UFPP through the UFC dispatch airlock on a trolley that moves on rails (trolley operated with locomotive). From the dispatch airlock, the transfer cask is transferred vertically using an 80 tonne OTC to the working platform in the dispatch hall where it is inspected and the lid bolts are removed. The transfer cask is then transferred into the filled UFC dispatch cell on a pallet using an air-cushion transporter. Here, the transfer cask is docked and the lid is removed using the 30 tonne OTC.

After placement of the filled UFC into the transfer cask, the lid is returned to the UFC using the 30 tonne OTC. The transfer cask is then transferred from the dispatch cell to the working platform using the air-cushion transporter. Here, the transfer cask lid is bolted back on and the transfer cask is inspected on all sides for contamination. After inspection, the 80 tonne OTC of the dispatch hall is used to lay the transfer cask horizontally onto the rail trolley, which is located in the dispatch airlock. The trolley is then dispatched to the main shaft, and lowered down to the DGR.

3.1.3 Underground Facility Activities for Mark I (Crystalline) Concept

3.1.3.1 Reloading Station Activities

The transfer cask is transferred via trolley and tow vehicle out of the main shaft into the reloading station. Here, the transfer cask is rotated to the vertical position and lifted with an OTC into one of the two reloading cell. There will be two reloading cells in the reloading station to facilitate operation, in case one of the reloading cells requires maintenance (Figure 17). The transfer cask's lid is removed, after which the placement vehicle, now parked above the reloading cell, uploads the UFC into its radiation shield. The shield and UFC are returned to the horizontal position for travel to the placement room.

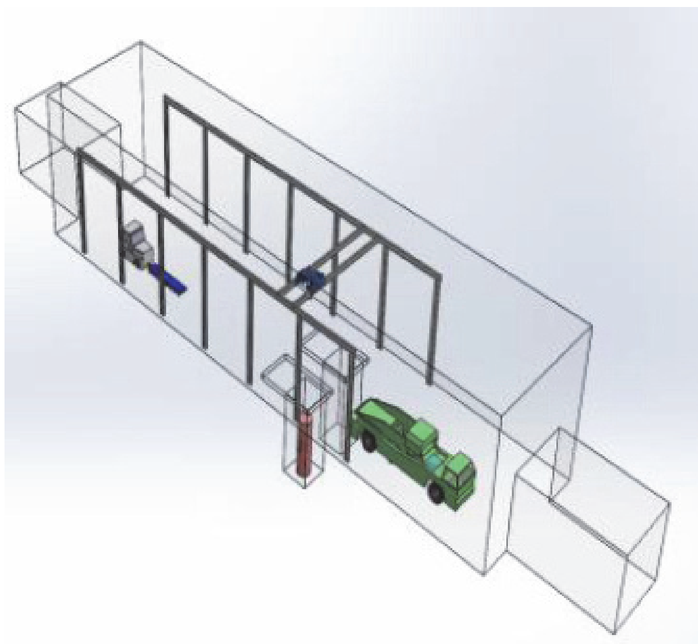


Figure 17: Illustration of the Reloading Station, UFC in Transfer Cask in the Reloading Cell

3.1.3.2 Placement Room Activities

Prior to the arrival of the UFC, a buffer disk is placed at the bottom of the placement borehole, and the borehole is lined with buffer rings. Upon arrival at the placement room, the placement vehicle is positioned above the placement borehole. The UFC, in its radiation shield, is turned back to the vertical position and lowered from the radiation shield into the borehole (in the buffer rings). Once the UFC is safely placed, the placement vehicle winch is detached and lifted. The radiation shield of the placement vehicle is turned back to the horizontal position and the vehicle is removed from the tunnel.

The bentonite pellet equipment is driven into the tunnel and positioned next to the deposition hole. Pellets are blown in to fill the annulus between the buffer ring and UFC as well as the annulus between the buffer rings and borehole wall. The pellet equipment is then removed to make space for the bentonite placement machine, which is positioned at the deposition hole. Three buffer discs and two dense backfill discs are brought in the tunnel by a forklift and are lowered on top of the UFC using the bentonite placement machine. After installation of discs, an extra piece of dense backfill, shaped to fit the chamber of the borehole, is installed. The forklift and bentonite placement machine are removed and pellet equipment are reintroduced to fill the annulus between the installed discs and placement borehole wall.

Once many UFCs have been placed, the placement room backfill is installed. To do this, the floor levelling material is installed, then the dense backfill blocks are positioned on top and finally the gap between backfill blocks and placement room walls is filled with sprayed bentonite pellets.

3.1.4 Underground Facility Activities for Mark I (Sedimentary) Concept

In the Mark I (sedimentary) concept, the transfer cask (with a UFC) is transferred on a trolley from the main shaft directly (or via a temporary underground storage area) to the placement room. In preparation for receipt of the UFC, a rail has been laid on the placement room floor, and a highly compacted bentonite pedestal, a UFC placement cart and a shielding barrier have been installed at the UFC placement location.

The transfer cask is coupled to the shielding barrier, the doors from the transfer cask and the shielding barrier are opened, and a hydraulic cylinder with a ram, which has now been placed behind the transfer cask, pushes the UFC over the pedestal (via the placement cart) (Figure 18). The shielding doors are closed and the empty transfer cask is removed from the placement tunnel.

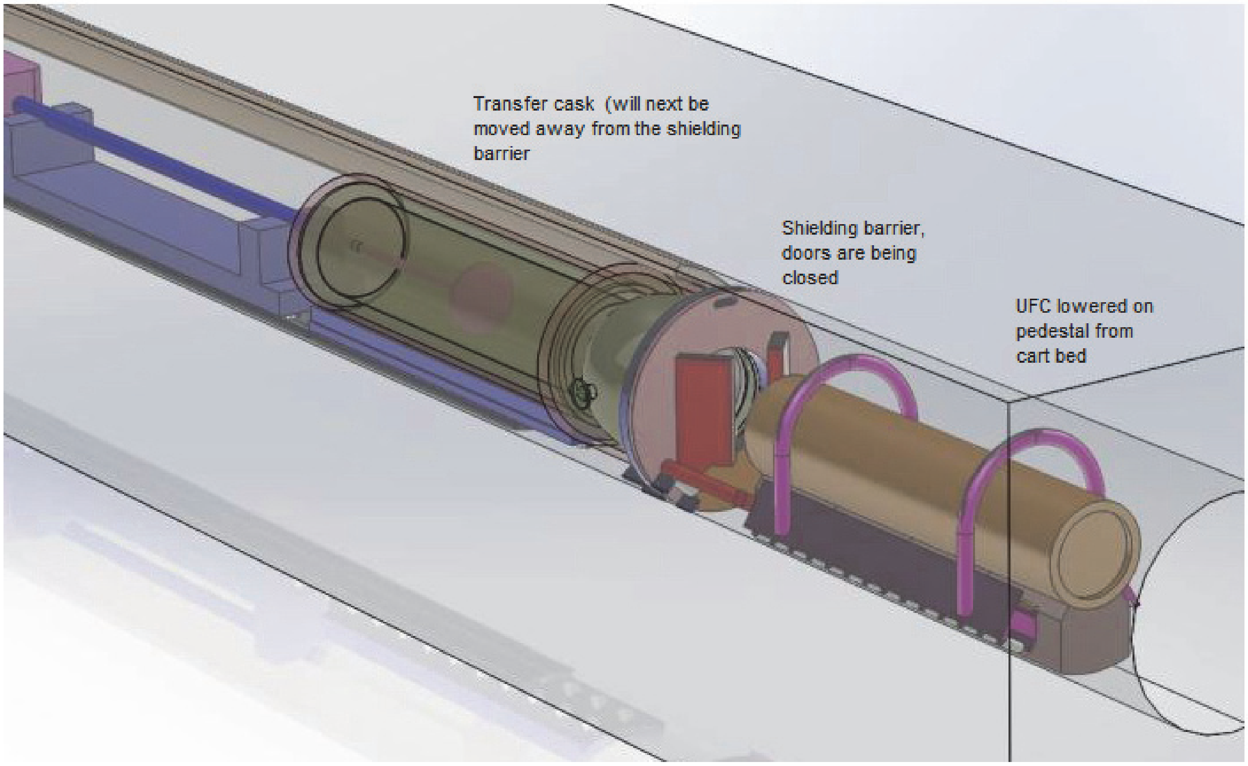


Figure 18: UFC Placed on Pedestal with Shielding Barrier Doors Closing

The floor segment with rails is then removed and the next pedestal is installed at a new UFC placement location. The bentonite blowing equipment is connected to the shielding barrier (over the newly installed pedestal), and bentonite pellets are blown in to fill the tunnel behind the shielding barrier. A locomotive is attached to both the shielding barrier and the placement cart and they are slowly pulled forward as the pellet blowing procedure progresses. Once at the next pedestal, a door is opened at the bottom of the shielding barrier to allow it to pass over the pedestal. When the placement cart is in the correct position over the pedestal, the bentonite blowing equipment is removed from the placement room so that the next UFC can be installed.

3.1.5 Facility Maintenance Activities

Operation of the UFPP and the DGR requires cleaning, maintenance and service activities. Four cleaning personnel are assumed to be in the UFPP each day (two per shift). The cleaning personnel circulate through the facility and enter most rooms, excluding the hot cells. Since the plans for maintenance and service activities are only preliminary in nature, an assumption has been made that these personnel circulate through different rooms of the UFPP (excluding the hot cells) at the same frequency and for the same duration as the cleaning staff. Additionally, an assumption has been made that all underground activities not directly related to the placement of UFCs (including cleaning) are performed by maintenance personnel.

3.2 MARK II CONCEPT

3.2.1 Overview

The Mark II concept is currently in an earlier stage of development than the other two concepts. As such, published documents that detail the concept are not available to support the Worker Exposure Model. However, there are a number of internal NWMO reports and working documents and these form the basis of the Worker Exposure Model. Gaps in the model were filled using expert judgement and similarities with the other two concepts

The Mark II UFC consists of several components. The basic terminology and relationship between these components are illustrated in Figure 19. Figure 20 shows an overview of the UFPP.

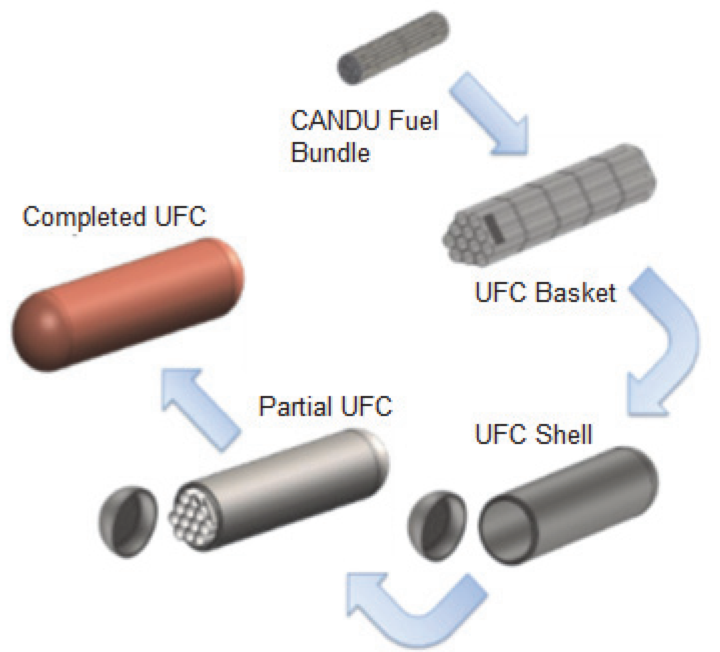


Figure 19: UFC Components and Terminology for Mark II Concept

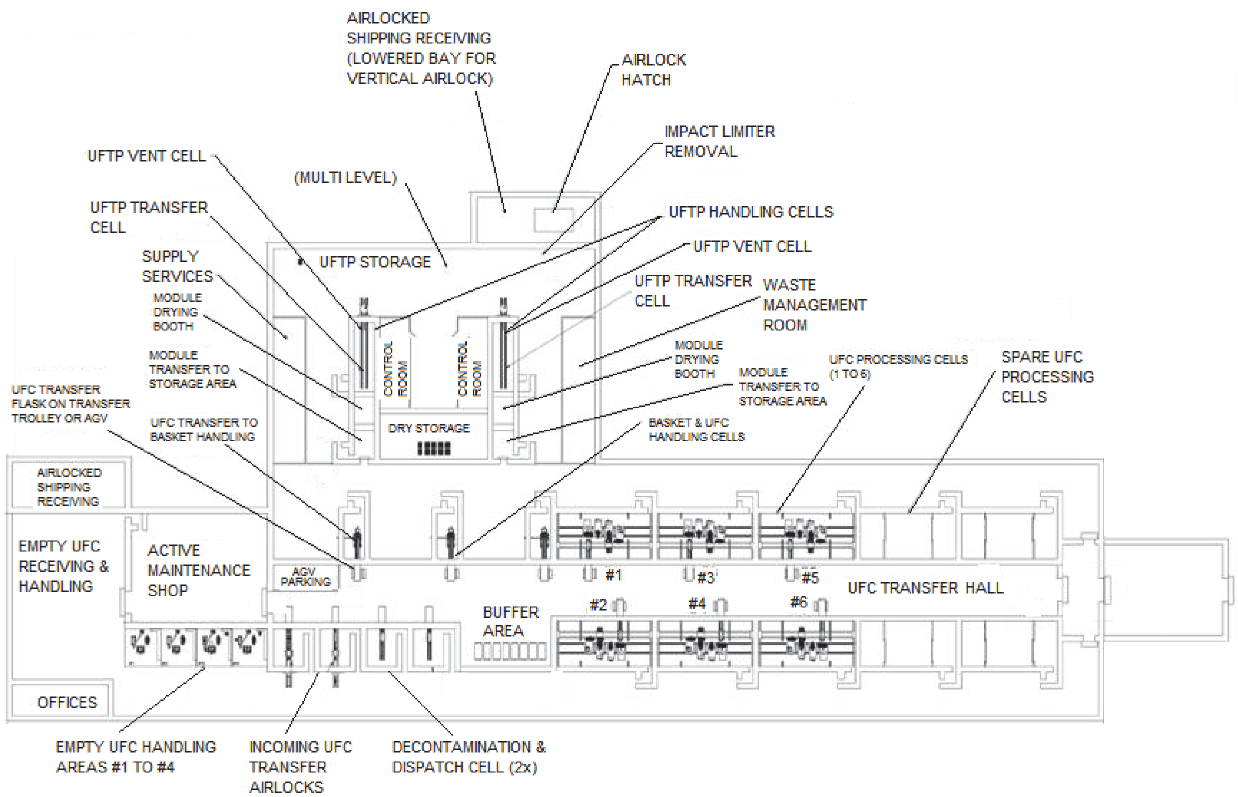


Figure 20: Overview of the Lower Level of the UFPP

3.2.2 UFPP Activities

In following sections, the processes within the UFPP are described. Only those steps that are relevant to the ALARA assessment are presented. The full list of process steps is given in Appendix A.2.

3.2.2.1 Used Fuel Module Receipt from Incoming UFTP

The following steps are similar to the Mark I concept UFTP processing procedure. The UFTP arrives at the UFPP from the interim storage locations via ground transportation and is transferred to the UFPP via airlock. The UFTPs are handled in the UFTP shipping and receiving hall, where they are moved to a dedicated storage space or directly to the UFTP handling cells (located on the ground level of the plant, Figure 21). Prior to being introduced to the handling cells, UFTP impact limiters are removed. The UFTP lid is removed in the UFTP handling cells, and the two fuel modules are transferred from the ground level to the module lay down area and further on to the module distribution hall and fuel handling cells on the upper level of the plant (Figure 22). There are two lines for UFTP processing and module handling and three fuel handling cells.

Each of the cells (UFTP, Module and Fuel Handling Cells) is equipped with airlocks, closed circuit television cameras for remote viewing and 100 cm-thick concrete shielding walls with lead glass windows. A Master Slave Manipulator (MSM) permits access to all areas within the cell for potential fault recovery and maintenance operations. Active ventilation is maintained in order to prevent contaminated airflow to connecting cells. There is also a dry storage at the ground level, where 20 modules can be stored during operation.

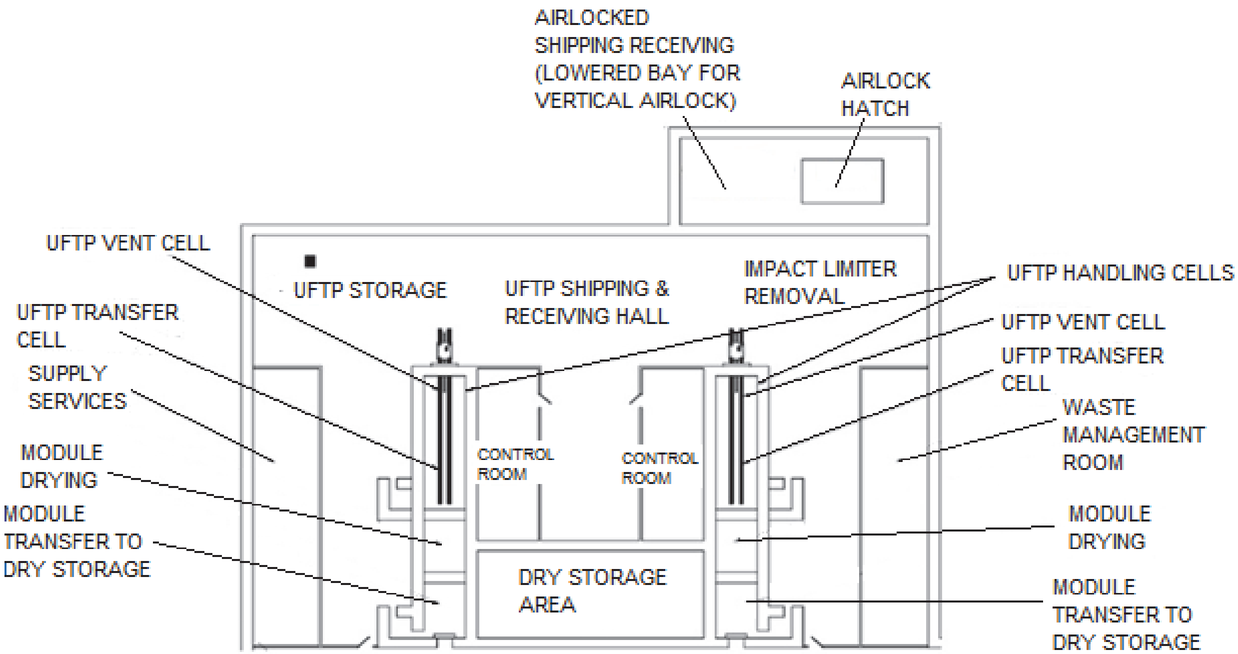
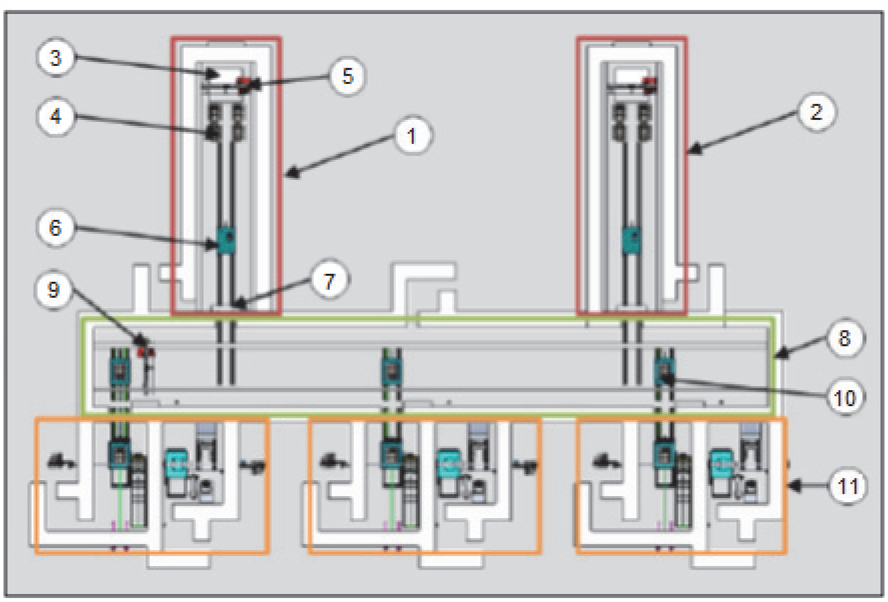


Figure 21: UFTP Receiving and Handling (Ground Level)



1. Module Handling Cell #1
2. Module Handling Cell #2
3. UFTP Access Airlock
4. Module Lay Down Area
5. Module Handling Cell OTC
6. Inter-Airlock Trolley
7. Airlock
8. Module Distribution Hall
9. Module Distribution Hall OTC
10. Inter-Airlock Trolley
11. Fuel Handling Cells (1, 2 & 3)

Figure 22: Module Handling and Fuel Handling Cells (Upper Level)

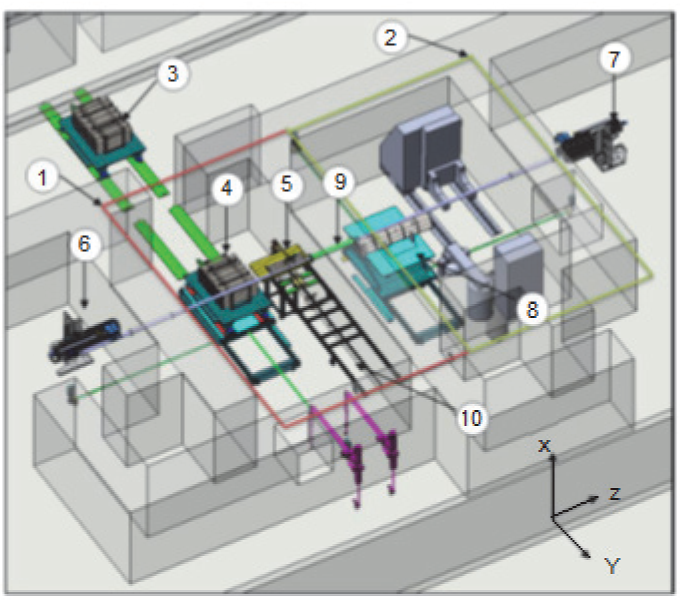
3.2.2.2 Empty UFC and Fuel Handling Cell Activities

From the ground floor, empty UFCs are inserted in the system via the UFC transfer cells, which are positioned directly beneath the fuel handling cells. UFCs are brought into the UFC transfer cells horizontally, but rotated vertically to be lifted to the fuel handling cells, where the hemispherical head is removed. The basket is then retracted from the container and positioned in the fuel handling system, where the used fuel is moved from the module to the basket (See Figure 23). Each module contains 96 fuel bundles and each basket contains 48 used fuel bundles. The basket has 12 tubes that each hosts 4 bundles. Therefore, two bundles at a time are inserted into the basket until the basket is filled.

It is assumed that some bundles are found to be defective upon inspection. These bundles are removed and placed in a defective fuel handling area. The assumption is that there is up to 10 defective bundles at a time in each fuel handling cell. Once the basket has been filled, it is returned to the UFC and the hemispherical head is re-installed. Then, the filled UFC is returned to UFC transfer cell (lower level of the facility), tilted to horizontal position and transferred to a shielded transfer flask, which is used in transfer hall to move the UFC.

To achieve the specified maximum daily throughput, a total of 12 UFC baskets must be loaded per day, which corresponds to 6 modules. To accomplish this, three parallel and independent processing lines will each process an average of two modules and four UFC baskets per day.

Fuel handling cells have 100-cm-thick concrete shielding walls and are equipped with lead glass windows and closed circuit television cameras for remote viewing. A Master Slave Manipulator (MSM) will permit access to all areas within the cell for potential fault recovery and maintenance operations. Active ventilation will be maintained within the fuel handling cells in order to prevent contaminated airflow to connecting cells.



1. Fuel Handling Cell
2. Basket Handling Cell
3. Inter-Airlock Trolley
4. Trolley Positioning Table
5. Bundle Inspection Table
6. Primary Fuel Push System
7. Secondary Fuel Push System
8. Basket Positioning Table
9. Transfer Port
10. Defect Bundle Handling Area

Figure 23: Fuel Handling System Components (Upper Level)

3.2.2.3 UFC Processing Cell Activities

Now in its transfer flask, the UFC is moved to the processing cell entrance, where it is inserted for processing (Figure 24). The current design of the facility has three welding cells and six copper application cells[1]. Each cell is equipped with airlocks, closed circuit television cameras for remote viewing and is shielded using 100 cm-thick concrete walls with lead glass windows. Each cell has a Master Slave Manipulator (MSM) that permits access to all areas of the cell for potential fault recovery and maintenance operations. Active ventilation is maintained within the UFC cells in order to prevent potential contaminated airflow to spread to connecting cells.

In the UFC processing cells, the UFC is first welded, inspected and machined. The copper is then applied to finalize the UFC concealment. After inspection, it is ready to be released from the cell and returned to the transfer flask.

3.2.2.4 UFC Decontamination and Buffer Box Assembly

After the UFCs have been completely processed, they are transferred to the decontamination cell using the transfer flask. The two decontamination cells in the UFPP provide the required capacity for the planned throughput (see Figure 20). The UFC is assumed to be inserted directly into the buffer box assembly after the final decontamination, which occurs in a dedicated hot cell[2] (see Figure 25). The final assembly is moved to the lower level of the facility using an OTC where it is either stored in a lay down area or placed directly onto the buffer box dispatch vehicle that is used to transfer the buffer box out of the facility.

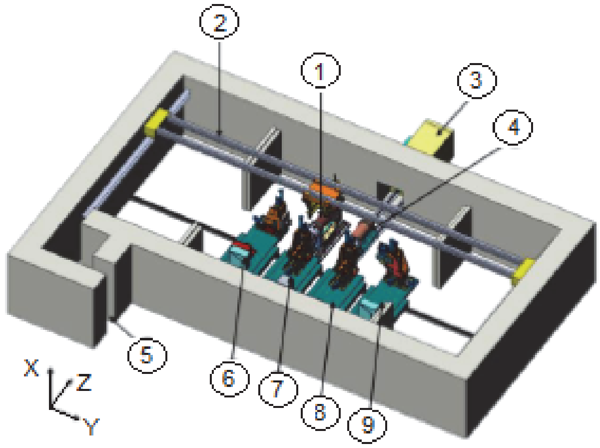
Each cell has 100 cm-thick concrete walls with lead glass windows and a Master Slave Manipulators (MSM) that permits access to all areas of the cell for potential fault recovery and maintenance operations. Active ventilation is maintained within the UFC cells in order to prevent potentially contaminated airflow from spreading to connecting cells.

The buffer box consists of prefabricated buffer blocks that are assembled in 4 stages (Figure 26):

1. The bottom blocks are installed on a platform within lower steel cover;
2. The UFC is placed over the bottom blocks;
3. Top blocks are installed; and
4. Top steel cover is installed.

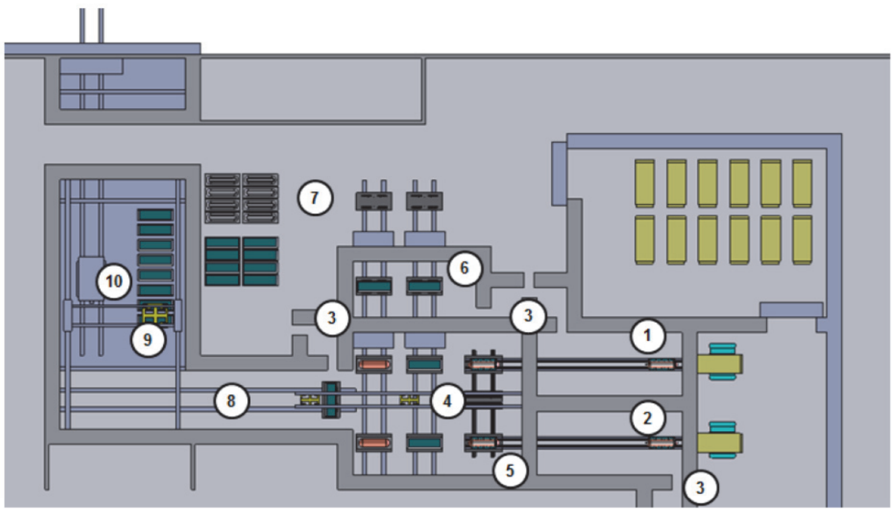
[1] Though the most current design of the facility has three welding cells and six copper application cells, the dose calculations were based on exposure situations for a previous facility design that had six processing cells that each performed all processing operations. To account for the current facility design with the available dose calculations, the number of personnel attending each cell and the number of transfers between cells has been increased. The values used are shown in Appendix A.2.

[2] The current design of the facility assumes that the transfer between the decontamination and buffer assembly cells does not require transfer of the UFC in the transfer flask (i.e. the cells are adjoining). However, the dose calculations are based on a previous facility design which assumes that the transfer between the decontamination and buffer assembly cells is done with a transfer flask. Therefore, this change has been accounted for by excluding the additional transfers of the UFC within the facility.



1. UFC Rotary Positioner
2. UFC Transfer Gantry
3. UFC Transfer Flask
4. Flask Trolley
5. Maintenance Entry/Exit Airlock
6. NDE Worktable
7. Copper Application Worktable
8. Welding Worktable
9. Machining Worktable

Figure 24: Original Design of UFC Processing Cell



1. Decontamination Cell #1
2. Decontamination Cell #2
3. Maintenance Access Airlocks
4. UFC Buffer Box Loading Area
5. UFC on Flask Trolley
6. Buffer Box Airlock
7. Buffer Box Pre-Assembly / Staging Area
8. Assembled Buffer Box Transfer Area
9. Assembled Buffer Box Laydown Area
10. Buffer Box Dispatch Vehicle

Figure 25: Decontamination and Dispatch and Buffer Box Assembly

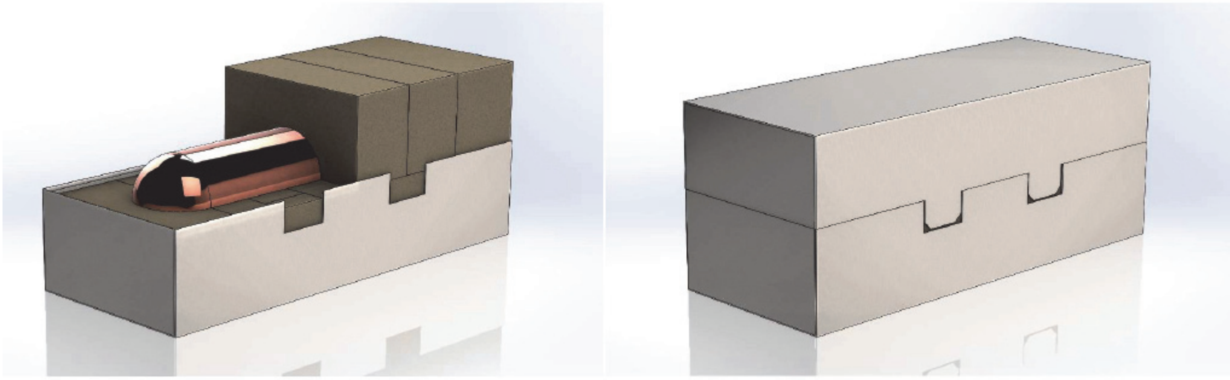


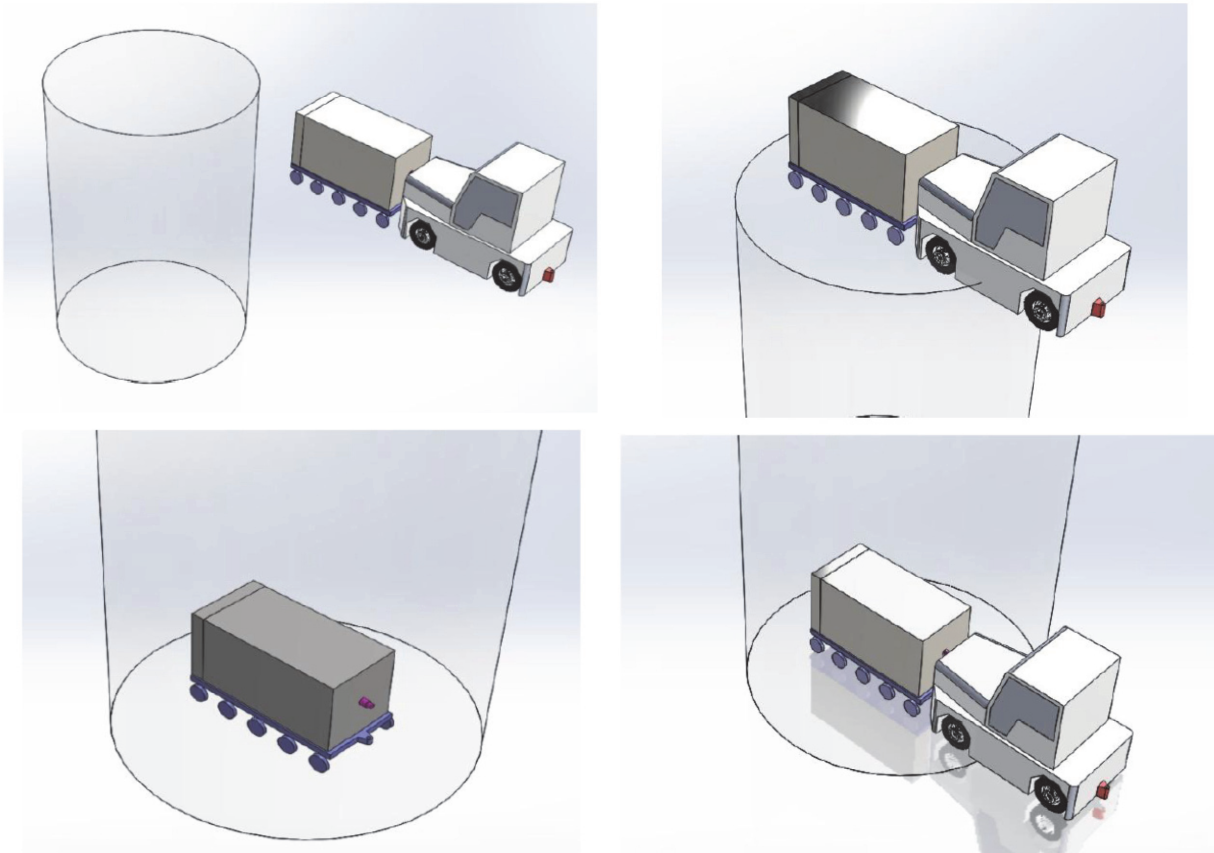
Figure 26: Buffer Box Assembly

3.2.2.5 Transferring UFC/Buffer Box in Shielded Cask from UFPP

The finalized buffer box assembly is then remotely placed in the shielded transfer cask for transfer to the shaft and final placement in the repository. The transfer cask is towed from the UFPP to the main shaft hoist area using a trolley and a tow vehicle (Figure 10 and Figure 27).

3.2.3 Shaft Operation Activities

The cask is driven to the main shaft hoist area, pushed into the shaft cage and secured. The hoist moves it to the underground repository where it is connected to another tow vehicle for transfer to the placement room. A generalized illustration of the shaft operation is given in Figure 27.



Note: Top Left: Trolley Moved with UFC Transfer Cask to Main Shaft Area; Top Right: Trolley Placed with UFC Transfer Cask into Shaft Hoist and Secured; Bottom Left: Trolley Lowered to DGR; Bottom Right: Trolley Unsecured and Dispatched

Figure 27: Schematic Presentation of Shaft Operations

3.2.4 Underground Facility Activities

The current design of the repository does not include plans to store filled transfer casks underground. However, it is anticipated that such a need may arise. Thus, although not implementing any process steps for use of the storage, storage for ten transfer casks in a single row (10) is accounted for as an ambient source of radiation for underground workers. A schematic illustration of the Mark II concept placement room is given in Figure 28.

Before any placement of the buffer boxes can begin, the placement rooms are prepared by installing a bentonite levelling layer on the floor and placing floor plates with ventilation ducts on the bentonite layer. Then, a shielding canopy is transferred to the entrance of the placement room. These steps do not pose any potential exposure and are thus not considered in the ALARA assessment.

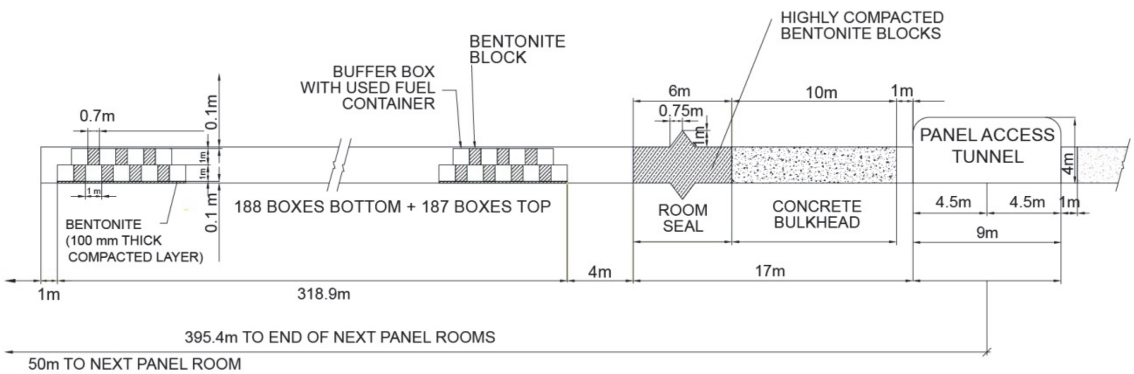


Figure 28: Mark II Concept Placement Room Layout

3.2.4.1 Shielding Canopy Reload Area and Placement Operation for Buffer Boxes

The transfer cask is driven to the active placement room, which is now equipped with an awaiting movable shielding canopy at the entrance and a remote forklift parked in the access tunnel across from it. The transfer cask connects with the canopy and the shielding door is opened (Figure 29). A hydraulic cylinder cart is used to push the buffer box out of the transfer cask, into the shielding canopy and onto a placement vehicle wedge tray. Once the shielding door of the shielding canopy is closed, the placement operations begin. The actual placement of the buffer box is performed with the remotely operated forklift (Figure 30 and Figure 31). There is a shielding wall on the front of the remote forklift to assist with potential recovery efforts if needed. However, it is assumed that the forklift would be winched out if it fails while in the room. Between each buffer box, a bentonite spacer block is installed (Figure 31).

3.2.4.2 Removing Floor Plates and Pellet Installation

After placement of the buffer boxes, the floor plates and ventilation ducts are remotely removed. Pellets are remotely blown in around the placed buffer boxes and the bentonite spacer blocks. Since all operations are remote, no exposure is anticipated from these operations.

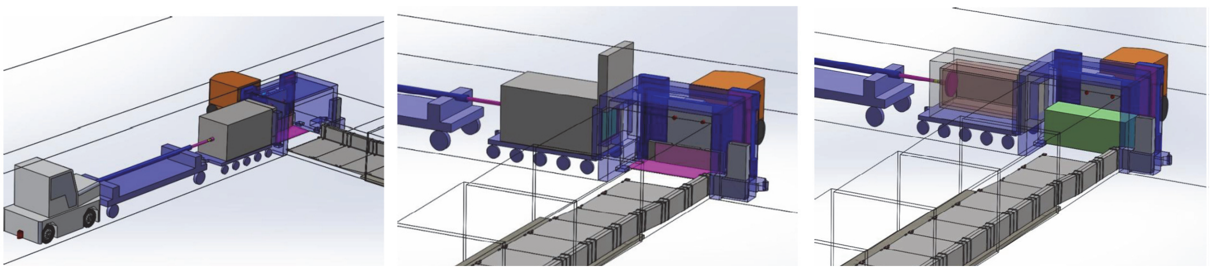


Figure 29: Transfer of the Buffer Box from Transfer Cask to Placement Forklift Using Hydraulic Cylinder Equipment

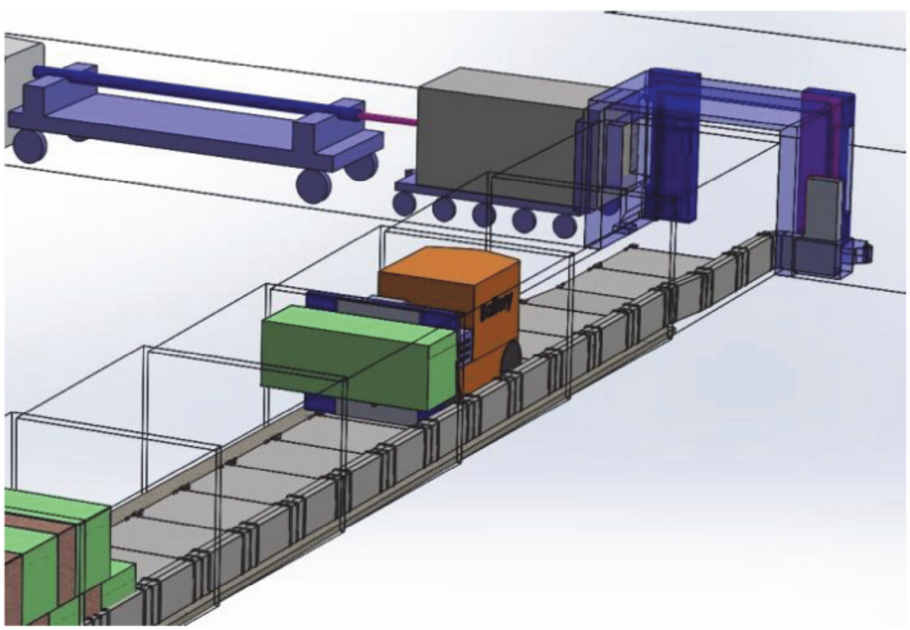


Figure 30: Transferring Buffer Box to Placement Room

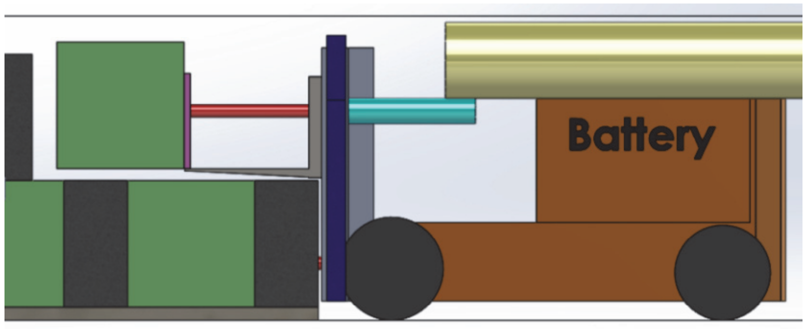


Figure 31: Buffer Box Placement (Green Boxes: Buffer Box; Grey Boxes: Bentonite Spacer Blocks)

3.2.5 Facility Support Activities for Dedicated NEWs

In addition to personnel involved directly in the facility operation process, this assessment accounts for doses to personnel having a supporting role in the facility. These include cleaning staff, service staff and other miscellaneous personnel assigned for work in the facility. These tasks are described in more detail in the Worker Exposure Models in Section 4 and Appendix A.2.

3.3 RADIATION SOURCES

3.3.1 Used Fuel

Bundle-discharge burnups for Pickering A, Pickering B, Bruce A, Bruce B, and Darlington stations have been examined (OPG 2001b and NWMO 2013). Both reports found that a burnup of 220 MWh/kgU represents the highest of the average burnups at these plants. A burnup of 280 MWh/kgU represents the 95th percentile of all discharged fuel bundles from Pickering A, Pickering B, and Bruce A stations; and the 99th percentile of all discharged bundles from Darlington and Bruce B stations.

A reference 37-element CANDU used fuel bundle with a 455 kW/bundle average power, a burnup of 220 MWh/kgU and 30 years of decay is adopted for the preliminary ALARA assessment (Figure 4). This is selected as a representative of an average fuel bundle, such that occupational dose is realistically estimated.

To calculate an upper-end/bounding occupational dose estimate, an assessment sensitivity analysis has also been performed using fuel with a burnup of 280 MWh/kgU and 10 years of decay.

The inventories for the used fuel, which are based on Tait and Hanna (2001), are given in Table 2 and Table 3. The relative contribution of gammas and neutrons, as compared to used fuel with a burnup of 220 MWh/kgU and a decay time of 30 years, are shown in Table 4.

The bundle adopted for the preliminary ALARA assessment contains 37 fuel elements, each of which is 13.1 mm diameter and 486 mm long. This fuel bundle weighs 23.9 kg, of which 21.7 kg is UO_2 (19.25 kg U) and 2.2 kg is Zircaloy (Tait et al. 2000).

Table 2: Gamma Release Spectrum (Photon/Second per Fuel Bundle)

Mean energy (MeV)	220 MWh/kgU		280 MWh/kgU	
	10 Years of Decay	30 Years of Decay	10 Years of Decay	30 Years of Decay
0.01	9.725E+12	5.771E+12	1.176E+13	6.966E+12
0.03	4.419E+12	2.572E+12	5.424E+12	3.154E+12
0.055	2.130E+12	1.352E+12	2.590E+12	1.652E+12
0.085	1.107E+12	6.285E+11	1.335E+12	7.526E+11
0.12	8.590E+11	4.457E+11	1.070E+12	5.408E+11
0.17	7.067E+11	4.048E+11	8.473E+11	4.871E+11
0.3	7.323E+11	4.201E+11	8.792E+11	5.014E+11
0.65	1.663E+13	9.645E+12	2.137E+13	1.224E+13
1.12	1.036E+12	1.155E+11	1.344E+12	1.525E+11
1.58	2.470E+10	4.075E+09	3.605E+10	5.267E+09
2	1.113E+09	1.646E+08	1.332E+09	1.949E+08
2.4	2.099E+08	1.097E+05	2.753E+08	1.440E+05
2.8	4.614E+07	9.356E+06	6.277E+07	1.411E+07
3.25	5.956E+06	4.646E+03	7.854E+06	1.044E+04
3.75	6.834E+03	2.676E+03	1.432E+04	6.045E+03
4.25	2.445E+03	1.550E+03	6.314E+03	3.504E+03
4.75	1.411E+03	8.971E+02	3.658E+03	2.021E+03
5.5	1.274E+03	8.085E+02	3.311E+03	1.829E+03
TOTAL	**3.737E+13**	**2.136E+13**	**4.666E+13**	**2.645E+13**

Table 3: Neutron Release Spectrum (Neutron/Second per Fuel Bundle)

Energy interval (MeV)		220 MWh/kgU		280 MWh/kgU	
		10 Years of Decay	30 Years of Decay	10 Years of Decay	30 Years of Decay
0.041	0.067	0.000E+00	0.000E+00	0.000E+00	0.000E+00
0.067	0.111	1.001E+00	1.369E+00	1.373E+00	1.819E+00
0.111	0.183	6.507E+00	8.895E+00	8.919E+00	1.182E+01
0.183	0.297	1.029E+01	1.407E+01	1.411E+01	1.870E+01
0.297	0.369	2.801E+03	1.743E+03	7.388E+03	4.027E+03
0.369	0.498	5.392E+03	3.353E+03	1.422E+04	7.752E+03
0.498	0.608	4.672E+03	2.920E+03	1.230E+04	6.722E+03
0.608	0.743	5.844E+03	3.667E+03	1.536E+04	8.416E+03
0.743	0.821	3.294E+03	2.085E+03	8.628E+03	4.753E+03
0.821	1.00	6.959E+03	4.462E+03	1.813E+04	1.007E+04
1.00	1.35	1.408E+04	9.305E+03	3.621E+04	2.052E+04
1.35	1.65	1.104E+04	7.708E+03	2.770E+04	1.630E+04
1.65	1.92	8.969E+03	6.634E+03	2.187E+04	1.343E+04
1.92	2.23	9.752E+03	7.625E+03	2.308E+04	1.481E+04
2.23	2.35	3.357E+03	2.685E+03	7.841E+03	5.134E+03
2.35	2.37	5.763E+02	4.610E+02	1.346E+03	8.815E+02
2.37	2.47	2.897E+03	2.329E+03	6.745E+03	4.439E+03
2.47	2.73	6.888E+03	5.638E+03	1.586E+04	1.060E+04
2.73	3.01	6.216E+03	5.211E+03	1.410E+04	9.368E+03
3.01	3.68	1.083E+04	8.378E+03	2.576E+04	1.646E+04
3.68	4.97	9.735E+03	6.395E+03	2.510E+04	1.419E+04
4.97	6.07	3.540E+03	2.179E+03	9.379E+03	5.078E+03
6.07	7.41	1.774E+03	1.092E+03	4.699E+03	2.545E+03
7.41	8.61	5.869E+02	3.611E+02	1.555E+03	8.416E+02
8.61	10.0	1.849E+02	1.138E+02	4.897E+02	2.651E+02
10.0	12.2	1.198E+02	7.371E+01	3.172E+02	1.718E+02
12.2	14.2	1.372E+01	8.441E+00	3.634E+01	1.967E+01
14.2	17.3	0.000E+00	0.000E+00	0.000E+00	0.000E+00
TOTAL		**1.195E+05**	**8.445E+04**	**2.981E+05**	**1.768E+05**

Table 4: Relative Photon (photon/s) and Neutron (neutron/s) Sources in Different Fuels Compared with the Used Fuel with a Burnup of 220 MWh/kgU and 30 Years of Decay

Radiation	220 MWh/kgU		280 MWh/kgU	
	10 Years of Decay	30 Years of Decay	10 Years of Decay	30 Years of Decay
Gamma	1.750	1.000	2.184	1.238
Neutron	1.415	1.000	3.530	2.094

3.3.2 Definition of Radiation Sources

The sources that are common to both the Mark I and Mark II concepts are listed below, whereas the sources specific to Mark I are listed in Table 5 and those specific to Mark II are listed in Table 6:

- Module: 96 fuel bundles (see Figure 5)
- UFTP: UFTP contains 2 modules
- Empty Module: Contains no bundles. Based on internal documentation, the Co-60 concentration in the crud on the surface of CANDU used fuel at the discharge from the reactor is estimated to be in the range of 56 to 5600 MBq/m^2. This is in general agreement with the range for Co-60 surface contamination found on feeder pipes in Burrill (1998). It is assumed that 15% of the crud inventory on the bundles is released and deposited into the tubes of the empty module. For preliminary ALARA calculations, the upper limit of the surface contamination in the bundles at the discharge from the reactor (5600 MBq/m^2) was assumed. This means that for fuel that has decayed for 30 years, approximately 1100 MBq of Co-60 will remain in the module after the bundles have been removed and that for fuel that has decayed for 10 years, approximately 15 000 MBq of Co-60 will remain in the module after the fuel bundles have been removed.

Table 5: Mark I Concept Radiation Sources

Source	Definitions	Configuration
Mark I UFC	4 baskets (with a total of 288 bundles)	See Figure 7
Mark I UFC basket	72 bundles	See Figure 7
UFTP storage	12 full UFTPs	See Figure 34
Filled UFC storage	40 full UFCs	See Figure 35
Module handling cells	4 full modules	See Figure 35
Fuel handling cell	12 full baskets	See Figure 35
Vent cell	1 UFTP	See Figure 34
Defective bundles	10 bundles in fuel handling cell (not included in modelling)	See Figure 33

Table 6: Mark II Concept Radiation Sources

Source	Definitions	Configuration
UFTP storage	12 UFTPs (without shielding, no walls in the base case)	See Figure 20
Module handling cell	6 modules	See Figure 20
Vent cell	UFTP	See Figure 20
Dry storage	20 modules (full) maximum (10 modules located adjacent to each control room)	See Figure 43
Fuel handling cell	1 module + 10 defective fuel bundles and 1 full basket (conservatively assumed also full)	See Figure 44
UFC	48 bundles	See Figure 7
UFC in transfer flask	48 bundles	See Figure 10
Defective bundles in fuel handling cell	10 (located close to the wall)	See Figure 32
Buffer area in transfer hall	8 full UFCs in transfer flasks	See Figure 45
Decontamination cells	1 UFC	See Figure 45
Processing cells	1 UFC	See Figure 46
UFC in buffer box	48 bundles	See Figure 26
UFC in buffer box loading cell	1 UFC	See Figure 47
UFC buffer box in transfer cask	1 UFC	See Figure 26 and Figure 10
Underground storage	10 filled UFCs in transfer casks	No exact location defined
Storage area (transfer flasks with UFCs beside buffer box loading)	12 UFCs in transfer flasks	See Figure 47

The 10 damaged fuel bundles are included in the Mark II concept fuel handling cell model because they can have some effect on doses. The 10 damaged bundles are placed close to the wall nearest the dose points and represent a significant source when compared to the 96 bundles in the module (Figure 32). In the Mark I concept, the location of damaged bundles are farther from the dose calculation points than the fuel in the baskets (for ambient doses in Control Rooms A and B) and thus they have not been include in the modelling (Figure 33).

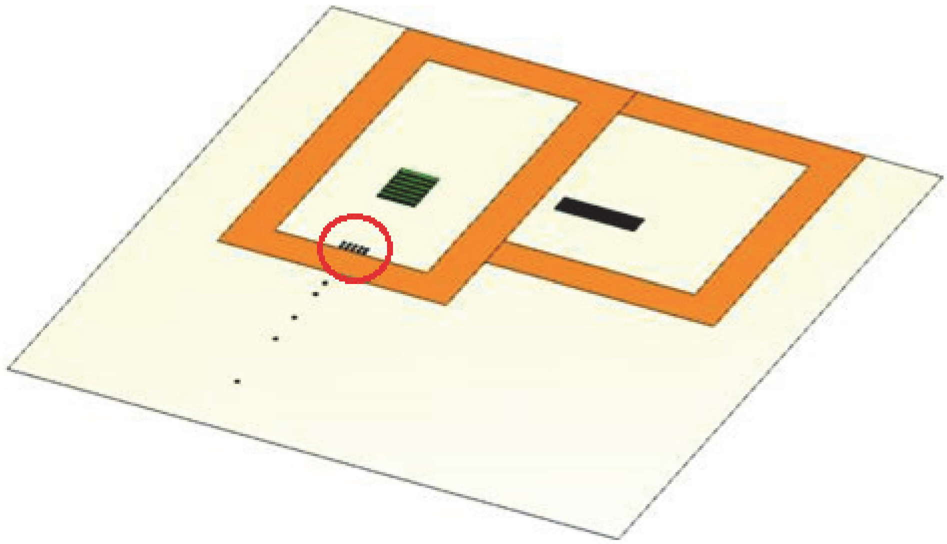


Figure 32: Mark II Fuel Handling Cell Showing the Location of the Defective Fuel Bundles (Red Circle)

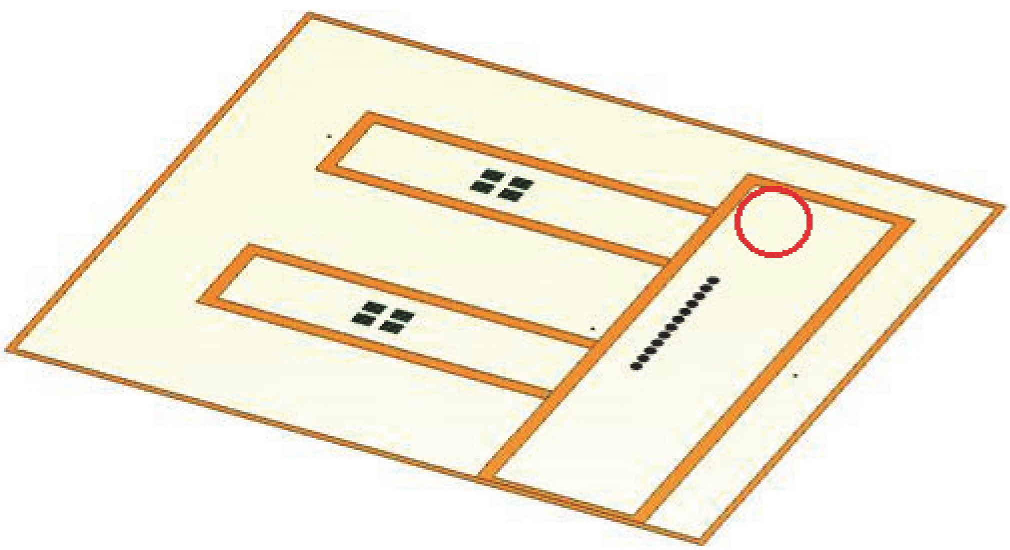


Figure 33: Mark I Module and Fuel Handling Cells Showing the Location of the Defective Fuel Bundles (Red Circle)

4. WORKER EXPOSURE MODELS

4.1 DEVELOPMENT OF WORKER EXPOSURE MODELS

The list of worker activities is based on the review of the three APM concepts as described in Sections 3.2 to 3.4, supplemented as required using professional judgement. In this section, details on the process steps included in the Worker Exposure Models are given and exposure maps showing personnel locations for dose calculations are presented. Worker Exposure Models are presented in Appendix A. The Worker Exposure Models specify the following:

- Activity description;
- Type of worker exposed (i.e., driver, technician, equipment operator etc.);
- Working group (i.e., UFTP receipt, fuel handling, underground operations etc.);
- Source (i.e., UFTP, module, basket, UFC, etc.);
- Distance to source;
- Exposure time;
- Annual rate per shift;
- Annual exposure time;
- Dose rate per activity; and
- Total annual dose per activity.

Appendix A presents all activities required for the operation of the facility that have the potential for worker exposure. Activities required for the operation of the facility that do not have an associated exposure are not included. Appendix A is divided in two: Appendix A.1 lists the Worker Exposure Models for Mark I (both crystalline and sedimentary) and Appendix A.2 lists the Worker Exposure Models for Mark II.

The general assumptions regarding the operation of the facility are:

- The facility operates for 250 working days per year in two shifts per day.
- An average rate of delivery is 120,000 bundles per year (SNC Lavalin 2011a and 2011b). This corresponds to approximately 630 UFTP shipments. However, the processing rate of the UFPPs has been conservatively assumed to be 144, 000 bundles per year, which is the maximum capacity throughput (see discussion in Section 1.5).
- There are ten defective fuel bundles temporarily stored in the fuel handling cells at any given time (In Mark I this does not cause additional exposure, but in Mark II it adds to some ambient radiation calculations).
- Personnel are not assumed to enter hot cells (all maintenance operations are performed remotely).

4.2 MARK I CONCEPT WORKER EXPOSURE MODEL

4.2.1 UFPP Activities

4.2.1.1 Main Assumptions

The maximum UFC output rate for the Mark I concept UFPP is two per day. The work is assumed to be divided evenly between two shifts. Personnel quantities and worker groups per shift are presented in Table 7.

Hot cell operations are remotely controlled by operators in one of the four UFPP operator rooms (Operator Rooms A – D). Throughout the facility, there are a number of temporary storage sites for various sources (UFTPs, modules, bundles, etc.). These storage sites are assumed to be occupied by radioactive sources at all times (for example, the UFTP storage is assumed to contain 12 full UFTPs at all times).

Only the NEWs whose job requirements are related to the processing of the used fuel and those whose activities require them to be in proximity of radioactive sources are considered in this assessment.

Note that the Mark I concept does not consider the dose from defective fuel bundles temporarily stored in the operator room. This is because the source would be too weak and too far from the dose points to contribute significantly to exposures.

Table 7: Mark I Concept Worker Groups and Quantity per Shift

Worker Group	Quantity of workers
UFPP	
Operation room A	3
Operation room B	6
Operation room C	3
Operation room D	3
UFC preparation	4
UFTP receiving and shipping	3
UFC transfer	2
UFC dispatch	4
Waste management facility	3
Shaft operations	1
Cleaning, UFPP	2
Maintenance, UFPP	4
Servicing, UFPP	2
Mark I (Crystalline) Concept	
Underground operations, remote controlled steps	3
Underground operations, pellet operations	4
Underground operations, backfill operations	4
Underground operations, buffer operations	4
Maintenance, DGR	2
Maintenance, Reloading Station	2
Mark I (Sedimentary) Concept	
Underground operations, remote operated steps	3
Underground operations, placement room operations	4
Underground operations, bentonite installation	4
Maintenance, DGR	2

Activity durations were estimated based on the processes described in SNC-Lavalin Nuclear Inc. (2011a and 2011b), on internal NWMO reports (cost analysis and throughput studies) and on expert judgement. Time estimates were often increased by 20% to 30% (depending on the confidence in the estimate) as a safety margin. Care was taken to ensure that the equivalent activities of each concept were equally quantified (same duration and staffing requirements).

Rather than being exposed for a specific duration for each activity, NEWs in operator rooms A, B and C are exposed to ambient radiation for the entirety of their work shift. These ambient exposures are described in Table 8. Locations of the operator rooms and the roles of each of the operators are described in Sections 4.2.1.3 - 4.2.1.5. All source terms (modules, baskets and UFCs) are conservatively assumed to be filled to capacity. Operator Room D personnel are not exposed to ambient radiation, and therefore, are not included in Table 8.

Table 8: Ambient Radiation in Operator Room A, B and C

<table>
<tr><th>Operator Room</th><th>Number of Workers</th><th>Specification of Personnel</th><th>Source Site in UFPP</th><th>Source</th><th>Distance from Wall (m)</th></tr>
<tr><td rowspan="9">Operator Room A (on operation level)</td><td rowspan="3">1</td><td rowspan="3">Module Handling Cell Operator, line 1</td><td>Module Handling Cell, Line 1</td><td>4 modules</td><td>1</td></tr>
<tr><td>Module Handling Cell, Line 2</td><td>4 modules</td><td>7</td></tr>
<tr><td>Fuel Handling Cell</td><td>12 baskets</td><td>1</td></tr>
<tr><td rowspan="3">1</td><td rowspan="3">Module Handling Cell Operator, line 2</td><td>Module Handling Cell, Line 1</td><td>4 modules</td><td>7</td></tr>
<tr><td>Module Handling Cell, Line 2</td><td>4 modules</td><td>1</td></tr>
<tr><td>Fuel Handling Cell</td><td>12 baskets</td><td>1</td></tr>
<tr><td rowspan="3">1</td><td rowspan="3">Operator, additional</td><td>Module Handling Cell, Line 1</td><td>4 modules</td><td>1</td></tr>
<tr><td>Module Handling Cell, Line 2</td><td>4 modules</td><td>7</td></tr>
<tr><td>Fuel Handling Cell</td><td>12 baskets</td><td>1</td></tr>
<tr><td rowspan="6">Operator Room B (on operation level)</td><td rowspan="2">2</td><td rowspan="2">Station Operator</td><td>Fuel Handling Cell</td><td>12 baskets</td><td>20</td></tr>
<tr><td>Filled UFC Storage</td><td>40 UFCs</td><td>1</td></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Station Operator, additional</td><td>Fuel Handling Cell</td><td>12 baskets</td><td>20</td></tr>
<tr><td>Filled UFC Storage</td><td>40 UFCs</td><td>1</td></tr>
<tr><td>2</td><td>Fuel Handling Cell Operator</td><td>Fuel Handling Cell</td><td>12 baskets</td><td>1</td></tr>
<tr><td>1</td><td>Fuel Handling Cell Operator, additional</td><td>Fuel Handling Cell</td><td>12 baskets</td><td>1</td></tr>
<tr><td rowspan="3">Operator Room C (on transfer level)</td><td>1</td><td>Storage and Decontamination Cell Operator</td><td>Filled UFC storage</td><td>40 UFCs</td><td>1</td></tr>
<tr><td>1</td><td>Dispatch Operator</td><td>Filled UFC storage</td><td>40 UFCs</td><td>1</td></tr>
<tr><td>1</td><td>Operator, additional</td><td>Filled UFC storage</td><td>40 UFCs</td><td>1</td></tr>
</table>

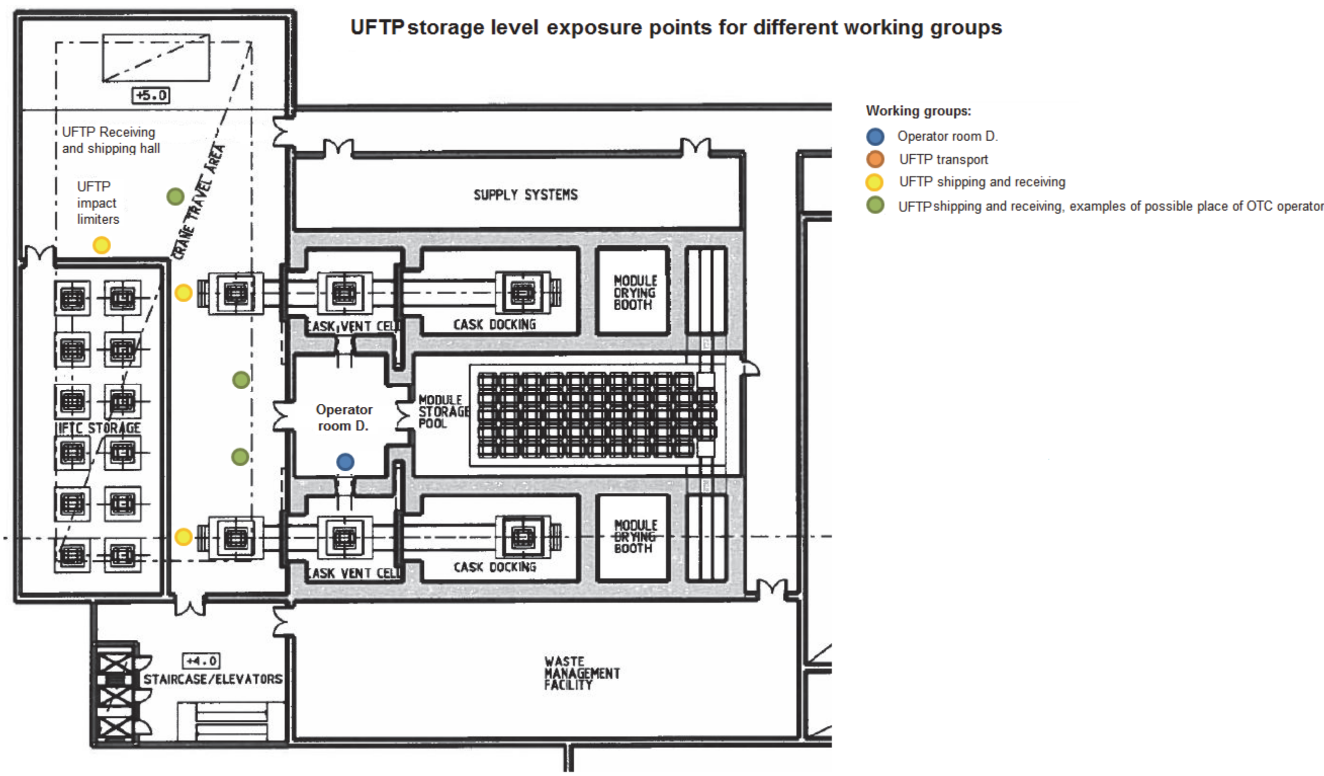
4.2.1.2 UFTP Activities

This assessment only includes workers of the UFPP and DGR facility; exposures to the UFTP transport trailer driver, co-driver and guard are not included.

Three NEWs are assumed to work in the UFTP shipping and receiving area: an OTC operator and two technicians. Their role is to operate the UFTP shipping and receiving area airlock and to coordinate activities in the shipping and receiving hall and at the entrance of the UFTP vent cell (Figure 34). They are exposed to radiation from UFTPs in various configurations (i.e., with and without impact limiters, in the airlock, lifted with OTC and on a pallet) and from the UFTP storage area (12 UFTPs with impact limiters on).

The NEWs in Operator Room D are exposed solely to the UFTP in the vent cell. Even though these operators are in the vicinity of the module storage pool, the dose contribution from the modules has been excluded from the assessment, since it is assumed that, with the water from the pool and the thick shielding walls, the dose contribution is negligible.

Appendix A.1 gives a detailed breakdown of all the activities related to handling full UFTPs and empty UFTPs.



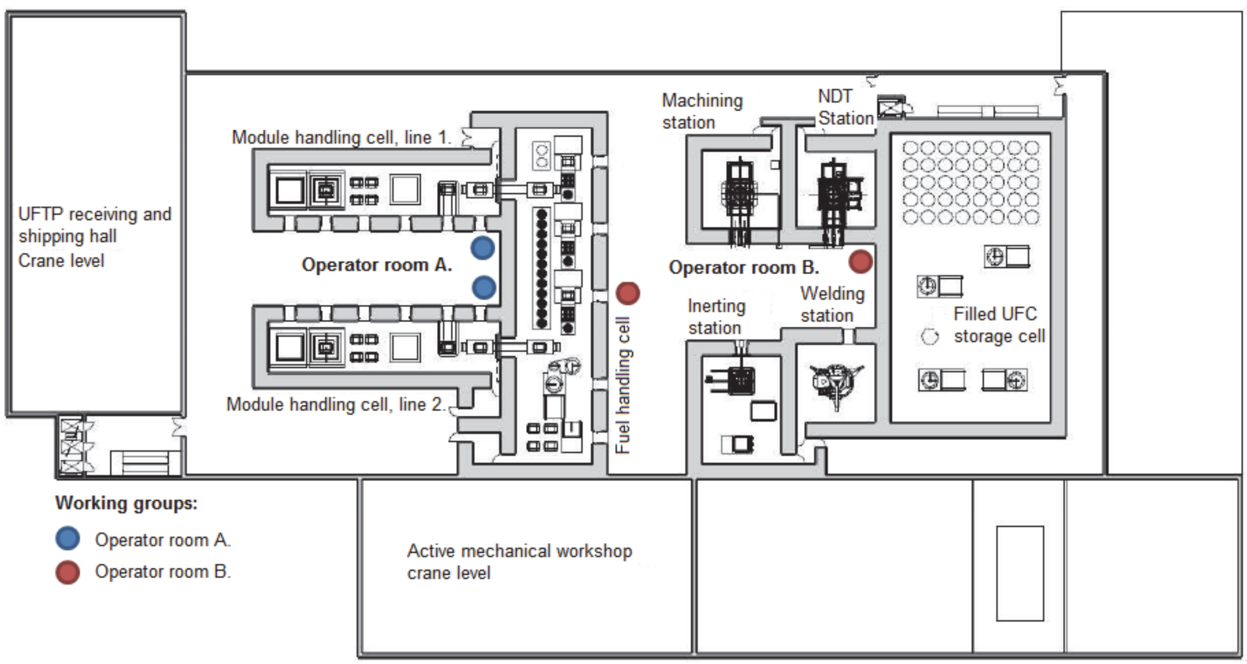
Note: The airlock is located in the top left corner of the image, but it is not visible because it is one level below the shipping and receiving area.

Figure 34: Exposure Points for Workers Involved with UFTP Processing

4.2.1.3 Module and Fuel Handling Activities

The module transfer activities are remotely controlled from Operator Room A by three operators: one for the operation of each of the two module handling cells and one for additional support. The fuel handling operations are controlled from Operator Room B. Exposure locations for Operator Rooms A and B are illustrated in Figure 35. The operation of the surge pool storage (located underneath the module handling cells) is not included in this assessment.

After the transferring the fuel bundles from modules into baskets, the empty modules are sent for decontaminations to the waste management facility. Activities related to handling the empty modules before decontamination are included in the assessment. The waste management facility location is shown in Figure 36.



Note: Module Handling Cell Operator in Operator Room A; fuel handling cell operators in Operator Room B next to Fuel handling cell; UFC station operators in Operator Room B near Filled UFC storage cell

Figure 35: Operator Rooms A and B Assumed Operator Locations

4.2.1.4 Empty UFC Activities

Empty UFC preparation activities are not assumed to result in any exposure. However, once the empty UFC enters areas that are controlled by the operators in Operator Room C, ambient exposure in Operator Room C are accounted for. The only activities with exposures to workers involved in empty UFC occur during dispatch of the UFC; these are described in Section 4.2.1.6. Figure 36 presents potential exposure locations of empty UFC preparation workers.

Four NEWs are assumed to work in the UFC preparation area. Two of these are responsible for transfer and lifting operations and the two others perform manual tasks next to the empty UFCs and baskets in the empty UFC preparation.

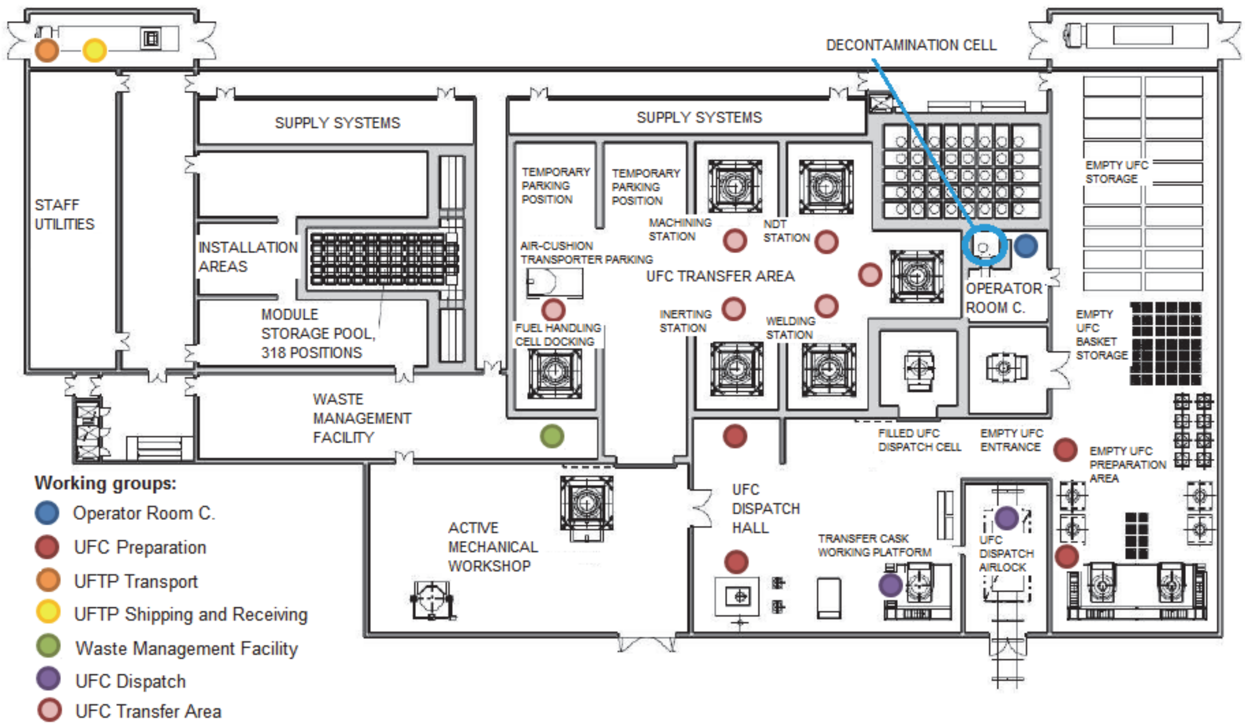


Figure 36: Worker Exposure Locations on Transfer Level

4.2.1.5 Filling, Closing and Inspecting the UFC

After baskets are loaded into the UFC and the lid is closed, the UFC, in its sleeve and shielded frame, is transferred within the UFC transfer area to various stations with an air-cushion transporter. Two workers per shift are assumed to work in the UFC transfer area. Every time a UFC is parked in a station (inerting, welding, machining and NDT), workers are assumed to leave the transfer area and thus are not exposed. The UFC stations are controlled from Operator Room B (Figure 35).

Transfer of the UFC into filled UFC storage, the decontamination cell and finally to the dispatch area is remotely controlled from Operator Room C (Figure 36). Three operators are assumed to manage operations from Operator Room C: one operator to control decontamination operations, one operator to control all OTC transfer operations and one operator for additional support. All UFCs are conservatively assumed to require decontamination. The exposure locations within Operator Room C are conservatively selected as the locations of highest exposure.

4.2.1.6 Loading and Dispatching the UFC Transfer Cask

The direct handling of empty transfer casks is not assumed to lead to exposure of NEWs. When the empty transfer casks are controlled from Operator Room C, exposure from surrounding sources is accounted for by the ambient radiation in Operator Room C, as listed in Appendix A.1.

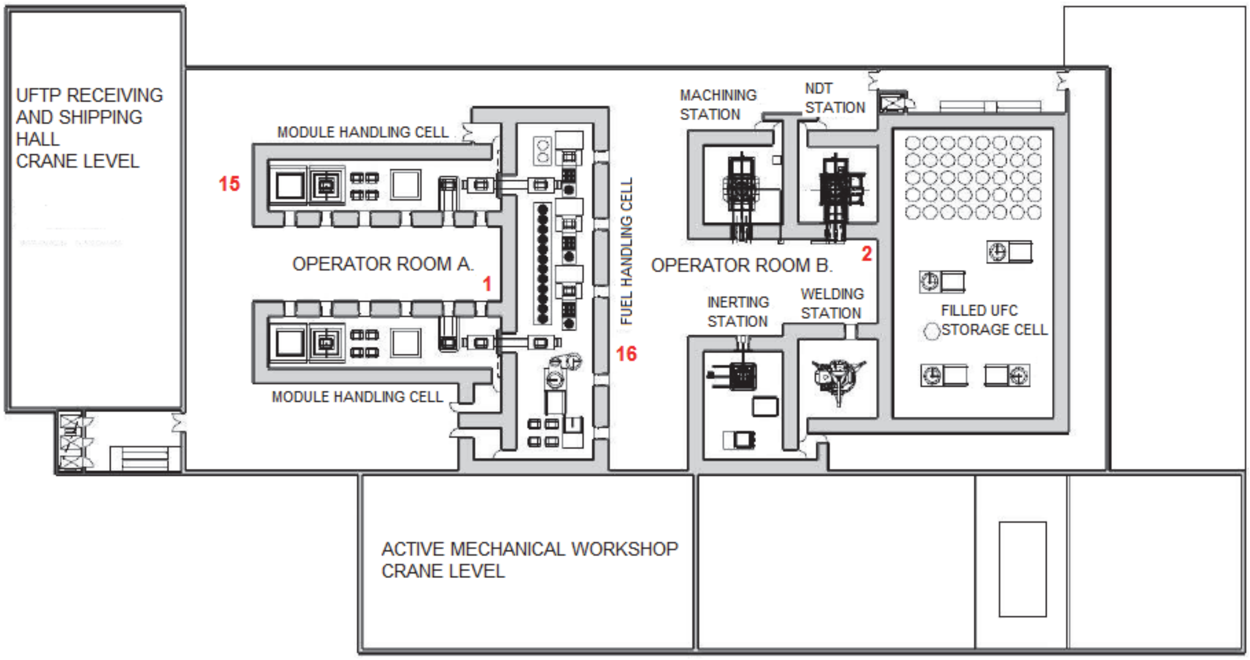
After the UFC has been loaded into the transfer cask, dispatch personnel take over operations. Inspectors are assumed to stand on the working platform at the side of the transfer cask and bolts are assumed to be attached remotely. Once the transfer cask is positioned horizontally during transfer, inspectors are assumed to stand at the sides and the ends and the tow vehicle driver is exposed to radiation from the end. The transfer cask is transferred from the UFPP to the shaft hoist with the tow vehicle. The tow vehicle driver and shaft hoist worker secure the transfer cask to the shaft cage so that it can be lowered (unaccompanied) into the DGR. A total of four NEWs are expected to work in this role.

4.2.2 Mark I Concept UFPP Cleaning, Maintenance and Servicing Operations

Facility cleaning, maintenance and servicing activities take place everywhere in the UFPP, except in the hot cells. Potential exposure may occur in the operator rooms (A-D), hallways, supply systems rooms, empty UFC preparation area, empty basket storage area, empty UFC storage, UFC dispatch hall, UFC dispatch airlock, waste management facility and UFTP shipping and receiving hall. These exposure locations are presented in Figure 37, Figure 38 and Figure 39.

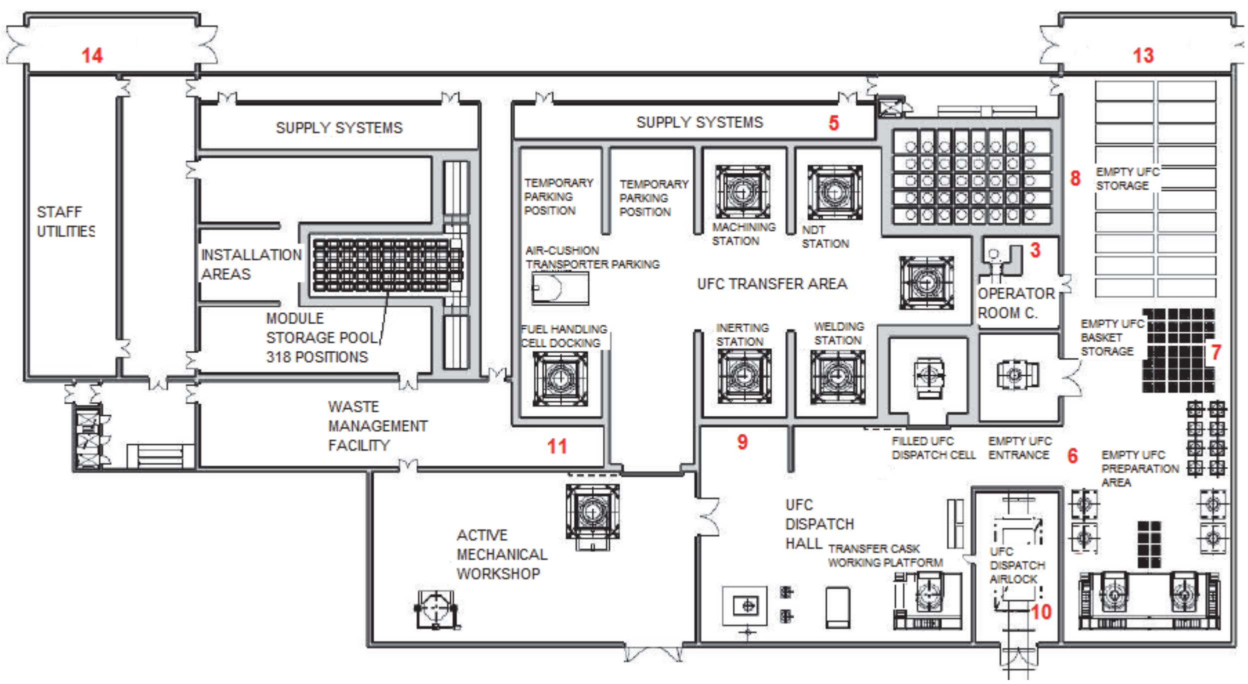
The following assumptions were made to estimate exposure durations for cleaning, maintenance and servicing personnel at the UFPP:

- 25% of each 8 hour shift is spent outside of areas related directly to UFPP processes (i.e., offices).
- No source (and therefore no exposure) is assumed during time spent near the empty basket storage area, the UFC dispatch airlock and the empty UFC transport airlock. These areas are part of the regular cleaning/maintenance/servicing rotation.
- Servicing and maintenance activities are assumed to take place in same locations as the cleaning activities and estimated exposure durations are similar.
- If an exposure distance has already been defined for another worker group in a particular area, the same distance is assumed for the cleaning, maintenance and servicing personnel.
- Of the time spent in the supply system rooms, 10% is assumed to be at the wall next to a UFC processing station in use.
- Exposure in the empty UFC preparation area is estimated to occur during the transfer of a filled transfer cask from the filled UFC dispatch cell to the transfer cask working platform.
- 10 % of time spent working in the UFC dispatch hall is assumed to be at the wall next to a UFC station in use.
- 10% of time spent in the waste management facility is assumed to be next to the fuel handling cell docking station in use.



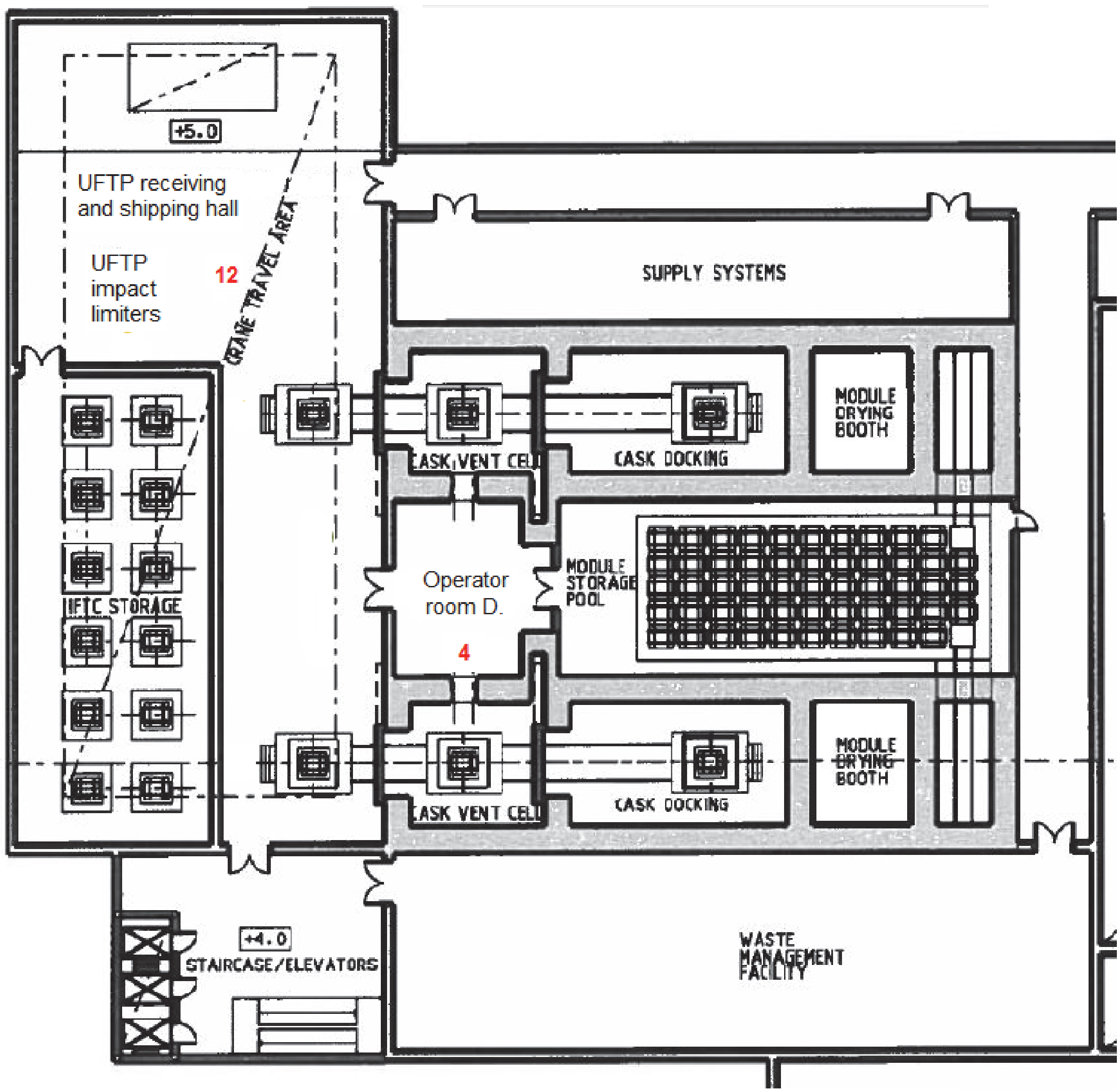
Note: Red numbers refer to steps in Appendix A.1.

Figure 37: Cleaning, Maintenance and Servicing Personal Exposure Locations, Operations Level



Note: Red numbers refer to steps in Appendix A.1.

Figure 38: Cleaning, Maintenance and Servicing Personnel Exposure Locations, Transfer Level



Note: Red numbers refer to steps in Appendix A.1.

Figure 39: Cleaning, Maintenance and Servicing Personnel Exposure Locations, UFTP Storage Level

4.2.3 Underground Operations for the Mark I (Crystalline) Concept

4.2.3.1 Reloading Station

Most reloading station operations are assumed to be remotely controlled from surface facilities, thus incurring no exposure. The only potential for worker exposure is to the tow vehicle driver during operations in the reloading station and to DGR maintenance workers. Maintenance activities are conservatively assumed to be performed in the reloading station while the transfer cask is towed in and lifted into the reloading cell, but they are assumed to vacate the area during reloading cell use when the transfer cask lid is open and the UFC is exposed. The maintenance personnel activities and exposure locations are described in Section 4.2.3.3.

Figure 40 presents an illustration of the reloading station for the steps described in Appendix A.1 regarding the reloading station activities and exposures.

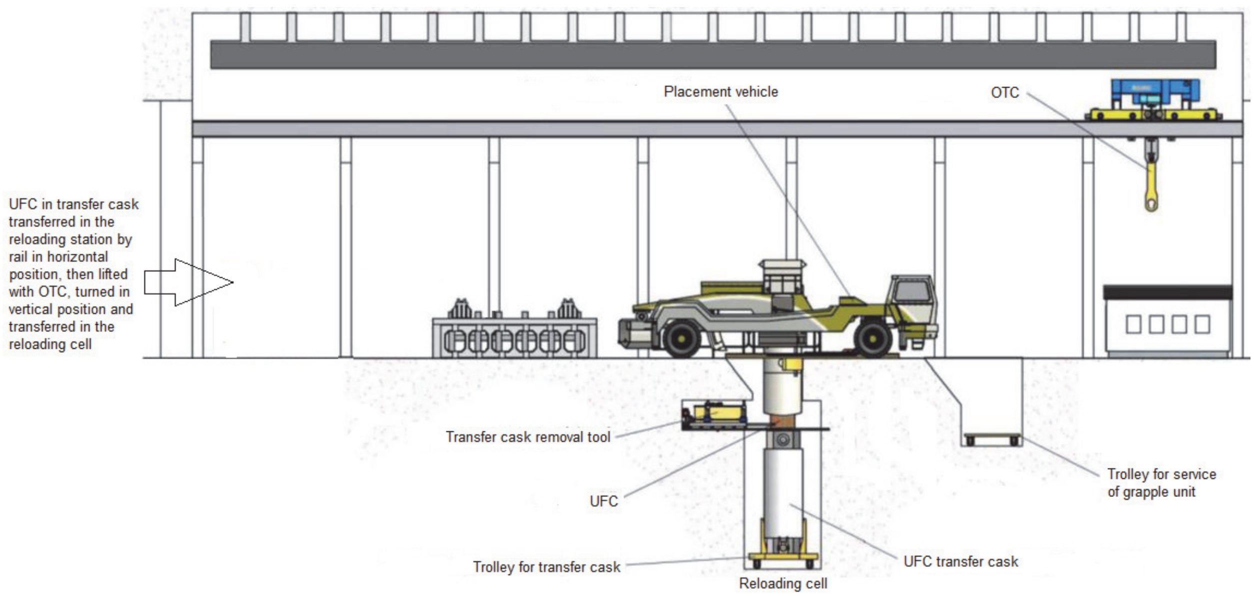


Figure 40: Mark I (Crystalline) Concept Reloading Station in DGR

4.2.3.2 Placement Room

UFC placement into the borehole is remotely controlled from the surface facilities, thus no exposure is incurred. However, once the bentonite buffer disks have been put in place, NEWs operate the equipment that backfills the deposition holes and the tunnels. Each type of backfilling machine is assumed to be operated by four NEWs. Since there are three types of machines to perform these tasks, a total of 12 workers are required. Possible exposure locations for placement room workers are presented in Figure 41. Appendix A.1 describes the placement room activities and exposures.

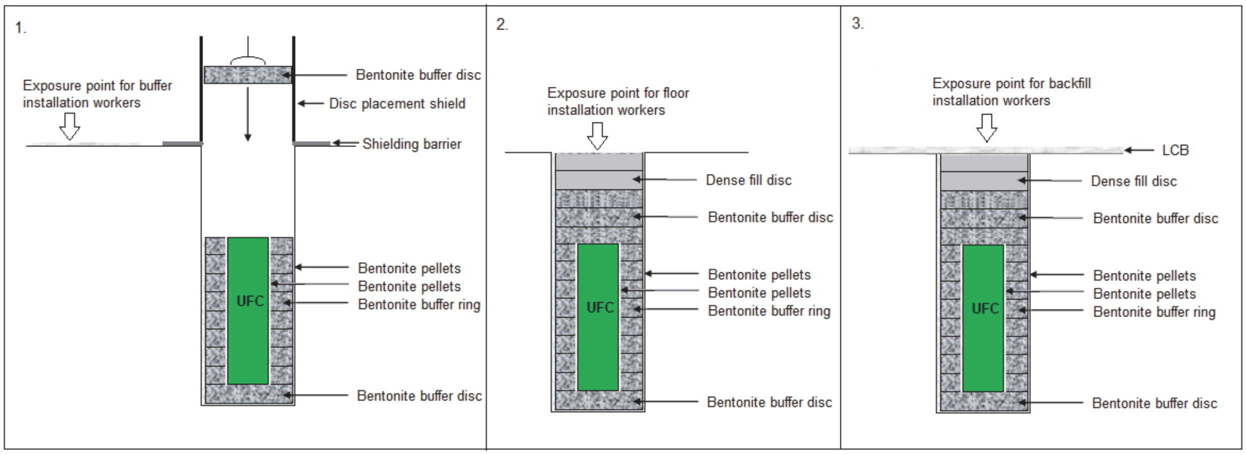


Figure 41: Mark I (Crystalline) Concept Placement Room Exposure Locations During Installation of Buffer and Backfill

4.2.3.3 Mark I (Crystalline) Concept DGR Maintenance Operations

Maintenance personnel are assumed to spend a portion of their time in the DGR. Two maintenance workers have tasks in the reloading station and two have tasks elsewhere in the DGR. Their exposure is estimated by assuming that their path is crossed by a tow vehicle with a transfer cask in tow. These exposures are of short duration but included in the preliminary ALARA assessment as a representative dose to maintenance personnel.

4.2.4 Underground Operations for the Mark I (Sedimentary) Concept

4.2.4.1 Placement Room Operations

In the Mark I (sedimentary) concept, the transfer cask is driven by a manned locomotive directly into the placement room. Most operations in the placement room are controlled by on-site personnel, with the aid of a shielding barrier that controls radiation exposure. The only operation that is remotely controlled from the surface facilities is pushing the UFC out of the transfer cask, through the radiation shield opening, and onto the placement cart bed. There are eight NEWs in total per shift in the underground facilities: Four NEWs operate pellet blowing equipment and four others perform other operations, like driving machines and attaching and detaching them from their load, installing pellets and installing pedestals. Generally, for underground operations, the UFCs are behind shielding barriers and distances are moderate. The Mark I (sedimentary) concept underground exposure locations are illustrated in Figure 42.

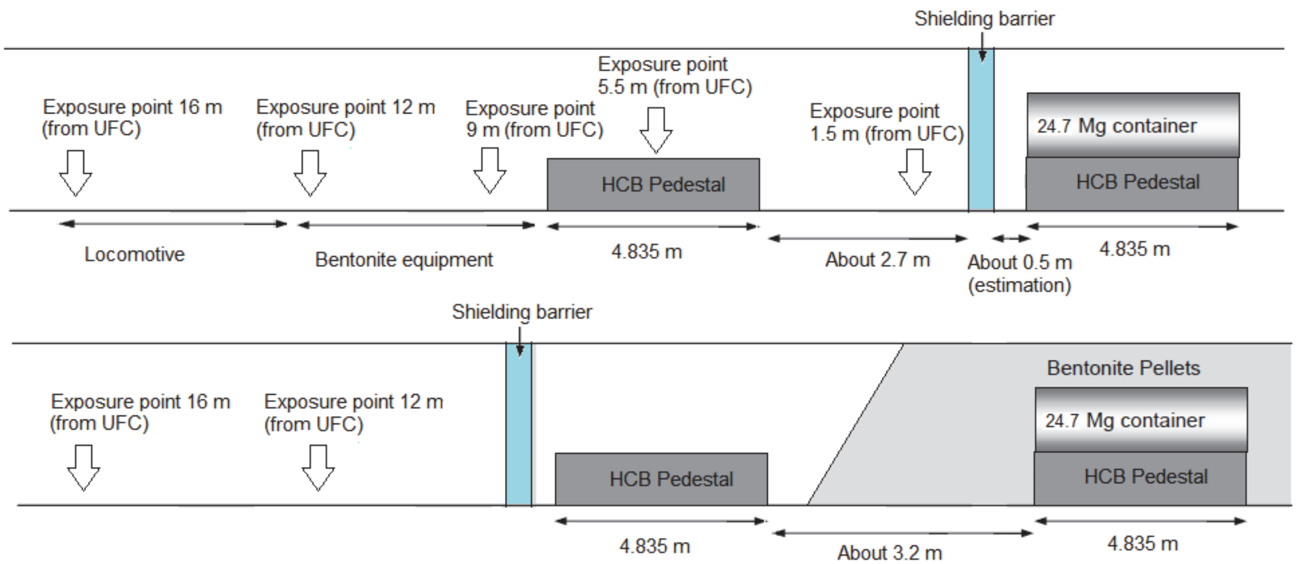


Figure 42: Mark I (Sedimentary) Concept Placement Room Exposure Locations Before and After the Start of Backfilling

4.2.4.2 Mark I (Sedimentary) Concept DGR Maintenance Operations

Two maintenance personnel are assumed to spend a portion of their time in the DGR. Though their exposure is assumed to be very short (the duration of a drive-by by a locomotive pulling a transfer cask), it is included in the preliminary ALARA as an estimate of dose to maintenance personnel.

4.3 MARK II CONCEPT WORKER EXPOSURES MODEL

Despite the differences between the Mark I and Mark II concept handling processes, there are some similarities. Therefore, for consistency, these similarities have been taken into account during the development of the Worker Exposure Model for the Mark II concept whenever possible.

4.3.1 Mark II Concept UFPP Activities

4.3.1.1 Main Assumptions

The Mark II concept is currently in an earlier stage of development than the other two concepts. As such, published documents that detail the concept are not available to support the Worker Exposure Model. However, there are a number of internal NWMO reports and working documents; these form the basis of the Worker Exposure Model. Gaps in the model were filled using expert judgement and similarities with the other two concepts.

The main difference between the Mark I and II concepts is the design of the UFC. Because the design is different, the handling process and the annual throughput are also different. For the

Mark II concept, the assumed estimated maximum annual throughput is 3000 UFCs, which corresponds to a daily throughput of 12 UFCs.

Worker groups and staffing estimates for the Mark II concept are listed in Table 9. The quantity of workers shown represents the number of workers per shift.

As in the Mark I concept, some sources of radiation are assumed to constantly expose workers of a particular area (operator and control rooms). These are referred to as ambient exposures and are assumed to be present for the duration of the workers' shifts. Sources for ambient radiation in operator and control rooms for the Mark II concept are given in Table 10.

The Worker Exposure Model for the Mark II concept is shown in Appendix A.2.

Table 9: Mark II Concept Worker Groups and Quantity of NEWs in One Work Shift

Worker Group	Quantity of workers
UFPP (by operator rooms)	
Control room #1 (UFTP handling and module handling)	2
Control room #2 (UFTP handling and module handling)	2
Control room #3 (Fuel handling and basket handling, line manager)	1+1
Operator Room #1 (UFTP handling and module handling, Fuel handling and basket handling)	1+1
Operator Room #2 (UFTP handling and module handling, Fuel handling and basket handling)	1+1
UFPP (by worker groups)	
UFTP transport	3
Shipping and receiving UFTP	3
UFTP handling and module handling	6
Fuel handling and basket handling	3+1
Empty UFC receiving and preparation	3
UFC Processing	11
UFC Dispatch	2
Empty module decontamination	2
Buffer box loading	2
Transfer to underground	
Transfer from UFPP to UG workers	3
Underground operations	
Placement room preparation (no exposure)	4
Placement	5
Maintenance	2
Other worker groups (UFPP)	
Cleaners	2
Radiation safety technicians	2
Servicing and maintenance	8

Table 10: Ambient Radiation for Operator and Control Rooms in Mark II Concept UFPP

Operator Room	Number of Workers	Specification of Personnel	Source of Ambient Radiation	Source	Distance from Wall (m)
Control Room #1	2	UFTP handling and module handling	Dry Storage	10 full modules	1
Control Room #2	2	UFTP handling and module handling	Dry Storage	10 full modules	1
Control Room #3	1	Fuel handling and basket handling	Module Handling Cell (ambient)	6 full modules	1
	1		Fuel Handling Cell (ambient)	1 module + 10 defective fuel bundles and 1 full basket	10
Operator Room #1	1	UFTP handling and module handling	Module Handling Cell	6 full modules	1
	1		Fuel Handling Cell	1 module + 10 defective fuel bundles and 1 full basket	10
	1	Fuel handling and basket handling	Module Handling Cell	6 full modules	1
	1		Fuel Handling Cell	1 module + 10 defective fuel bundles and 1 full basket	10
Operator Room #2	1	UFTP handling and module handling	Module Handling Cell	6 full modules	1
	1		Fuel Handling Cell	1 module + 10 defective fuel bundles and 1 full basket	10
	1	Fuel handling and basket handling	Module Handling Cell	6 full modules	1
	1		Fuel Handling Cell	1 module + 10 defective fuel bundles and 1 full basket	10

4.3.1.2 Shipping, Receiving and Handling UFTPs

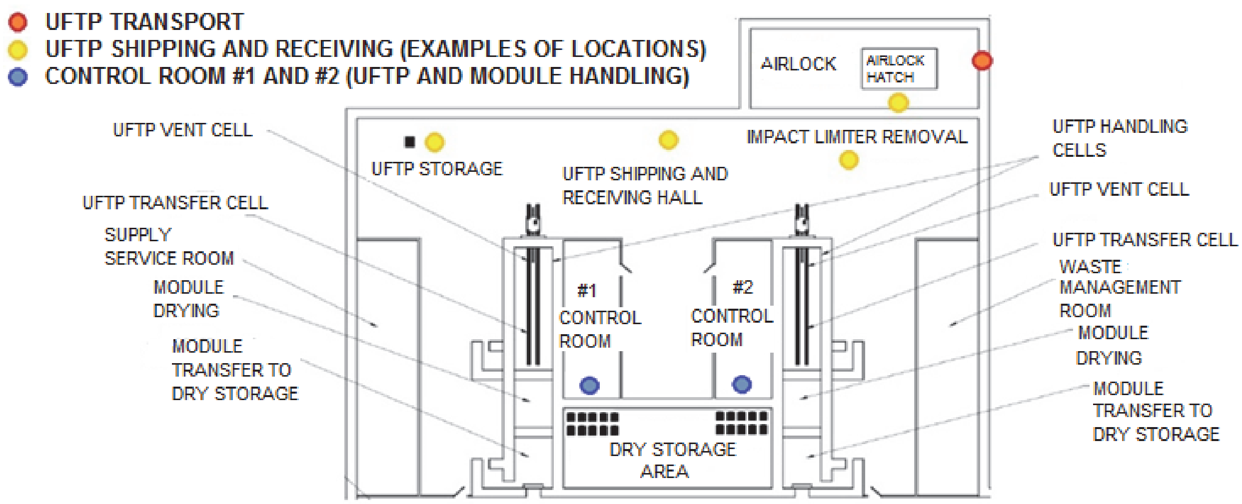
Since the same UFTPs are used for the Mark I and Mark II concept UFPPs, the process for handling UFTPs is similar. UFTP receipt occurs in the shipping and receiving hall, which also has a dedicated surge storage area (however, in that case there is no shielding wall) (Figure 34). The transport vehicle parking hall is a level below the main shipping and receiving hall, and the two are connected with an airlock. Lifting operations in this area are achieved using an OTC. As for the Mark I concept, two technicians and one crane operator are assigned for the tasks.

The UFTP handling cells, where the UFTPs are unloaded, are located on the same floor as the shipping and receiving hall. Before transferring the UFTPs to the UFTP handling cells, the impact limiter is removed and temporarily stored in a dedicated area in the shipping and receiving hall.

Once emptied, UFTPs are decontaminated (if required) and transferred back to the shipping and receiving hall. Impact limiters are then reinstalled and the empty UFTPs are moved to storage area or back to the transport trailer. Empty UFTPs are not assumed to be radioactive; therefore, empty UFTPs are not considered to be a source in the assessment. However, because activities related to empty UFTP handling are done in the vicinity of the UFTP storage, an exposure is assumed.

There is an option for dry storage in the Mark II concept process. However, the activities related to dry storage are not included in this assessment, because these activities would be handled from the control rooms. Because control room doses are ambient (that is, they are the same for every shift) and because ambient doses already consider dry storage as a source for ambient radiation, consideration of dry storage activities would not increase occupational or individual doses.

Figure 43 shows the assumed exposure locations of different types of NEWs working in the shipping and receiving area floor. All exposure locations are selected conservatively to have reasonable maximum exposure. Modules in the dry storage are assumed to be located close to the control room walls. The UFTP handling cells and the modules handling cells are controlled from Control Rooms #1 and #2.



Note: Exposures near the airlock (near the top right corner of the figure) are actually one floor down.

Figure 43: Exposure Locations in the Shipping and Receiving Area and from the UFTP Handling Cells

4.3.1.3 Module and Fuel Handling Activities

From the UFTP handling cells, modules are lifted with OTC to the module handling cell on the upper level. The module lay down area of the module handling call can store up to 6 modules at a time. From the lay down area, modules are transferred to the module distribution hall using a trolley. Once in the module distribution hall, modules are transferred via an OTC to module trolleys which lead to one of the three fuel handling cells.

In addition to handling full modules for the fuel handling cells, the distribution hall and module handling cells are also used to transfer the empty modules back to storage or recycling. The decontamination and disposal of empty modules is detailed in Section 4.3.1.6.

A fuel push system is used to transfer the fuel bundles from the modules to UFC baskets. The baskets are delivered to the fuel handling cells from the ground floor UFC transfer cell.

At full facility capacity, four baskets are filled per day in one fuel handling cell. Assuming no defective fuel bundle is detected, two baskets can be loaded before a change of module is required.

The module handling cell and fuel handling cell operations are controlled from Operator Rooms #1 and #2, located on the upper level (see Figure 44). Operators in Control room #3 control the operation of the fuel and basket handling cells. Figure 44 shows offices and lunch rooms in this area, but because a decision has been made to place these rooms elsewhere in the facility (away from hot cells), these exposures are not accounted for in the preliminary ALARA assessment.

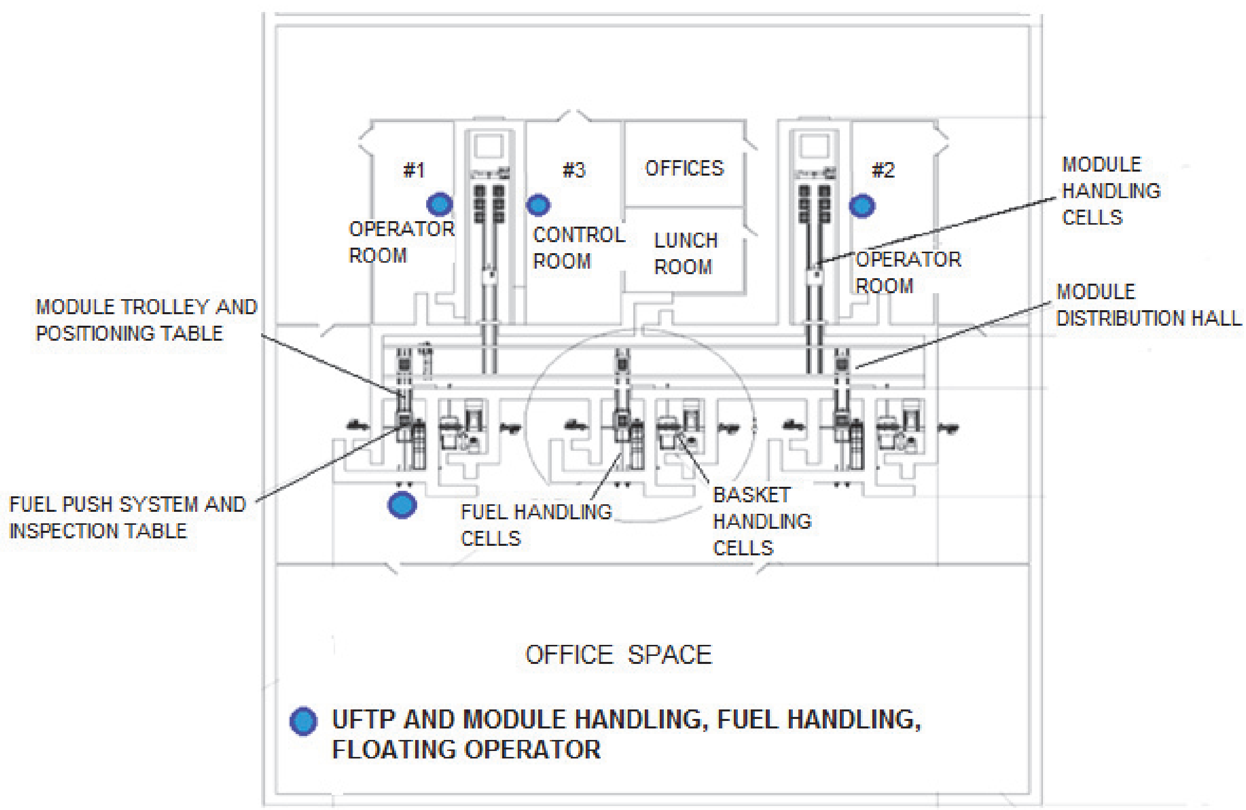


Figure 44: Exposure Locations for Module and Fuel Handling Cells

4.3.1.4 Empty UFC Handling

Empty UFCs are received, inspected and marked before use. Empty UFCs do not cause exposure for workers, but as some of these process steps are performed in radiation areas where exposure can be inflicted from another source, these are considered in the preliminary ALARA calculations. Figure 45 illustrates the exposure points of empty UFC handling activities.

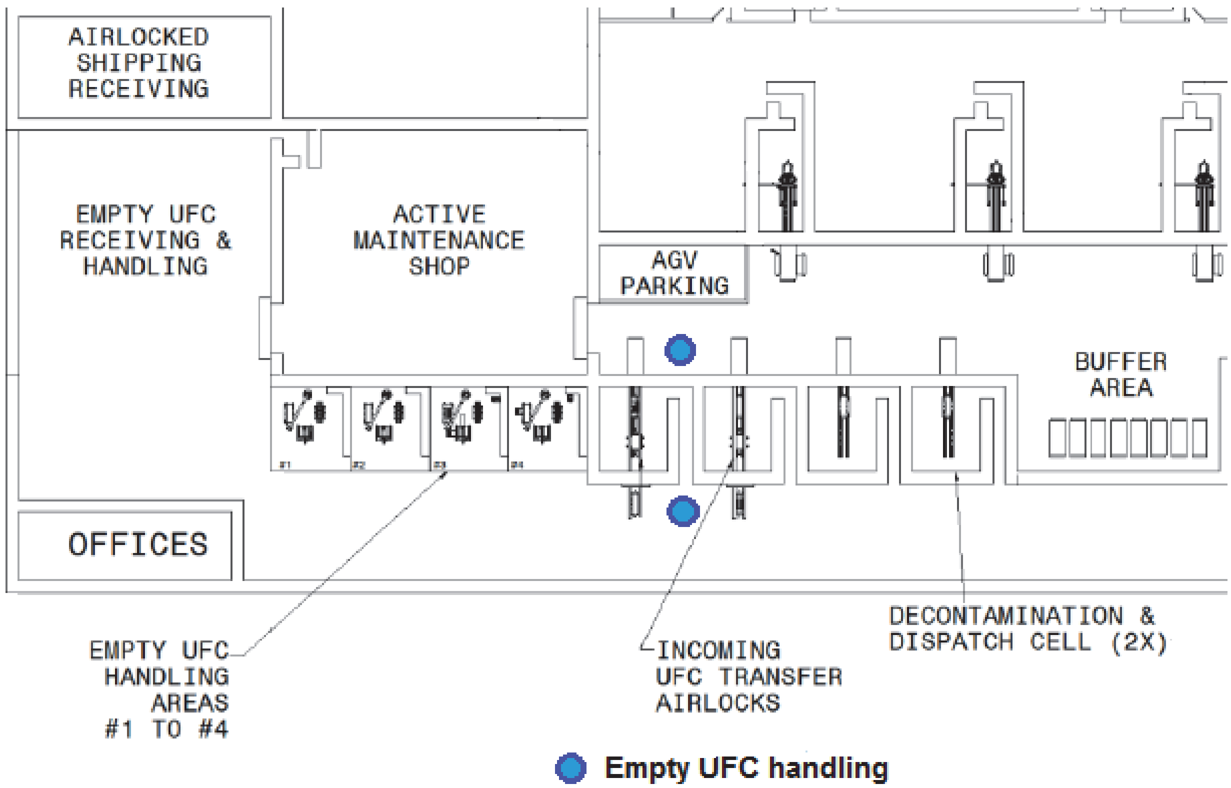


Figure 45: Exposure Locations for Empty UFC Handling Activities

4.3.1.5 UFC Processing

UFC processing activities refer specifically to activities required to seal a UFC after it has been loaded (welding, machining, non-destructive testing, copper application, etc.). These operations occur in UFC processing cells, which are closed to workers during their operation. Since the operation of the processing cell is essentially continuous, exposure to UFC processing activities are assumed to span the duration of each shift. In addition to UFC processing personnel, decontamination and dispatch personnel are working in the same vicinity (Figure 46).[3]

[3] Note that in a facility design update that became available after dose calculations were performed, the decontamination and buffer box assembly activities were relocated to the buffer box assembly area. Though the dose calculations reflect the configurations shown in Figure 46, the Worker Exposure Model reflects the requirements of the updated design. Doses points and exposure situations are not significantly different and do not affect the overall conclusions of the preliminary ALARA assessment.

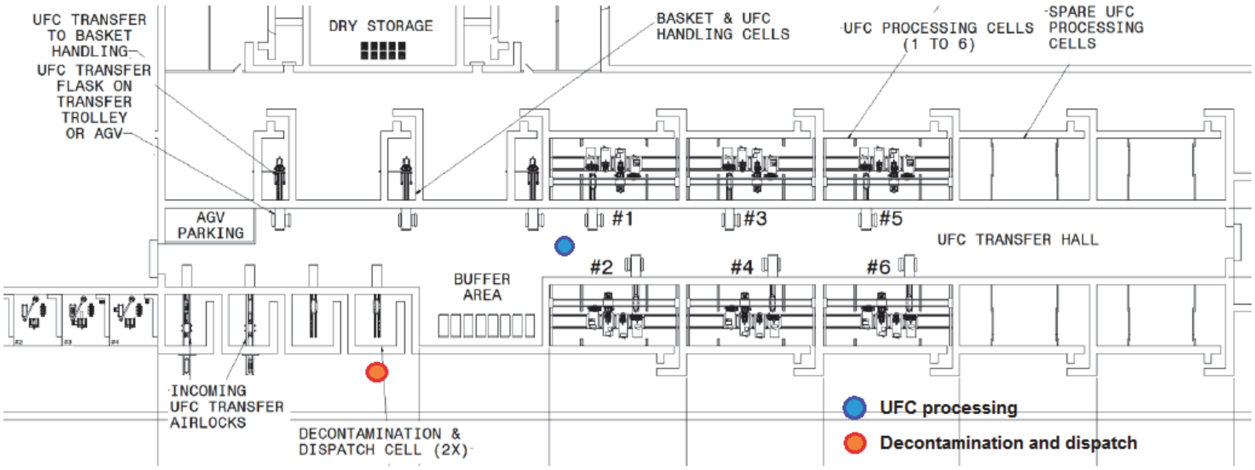


Figure 46: Exposure Locations for UFC Processing, Decontamination and Dispatch Personnel

4.3.1.6 Empty Module Handling

No decontamination cell exists for empty module decontamination in the current concept of the UFPP. However, for consistency with the Mark I concept operations, this operation is still assumed to take place. Therefore, though a dedicated decontamination cell is not shown in any figure, this cell is assumed to exist. Fuel handling operators are responsible for the initial visual inspection of the empty module, which is then transferred back to a storage area. Seeing as the doses to the operators of the fuel handling cell are accounted for by ambient radiation, this activity does not contribute to their cumulative dose estimates. However, the decontamination technician’s dose is attributed specifically to the empty module handling activities.

4.3.1.7 Buffer Box Loading and Transfer from UFPP

Figure 47 shows the exposure locations of the personnel working in the buffer box assembly area. The transfer of the empty transfer cask to the buffer box assembly area is not assumed to contribute to the occupational dose.

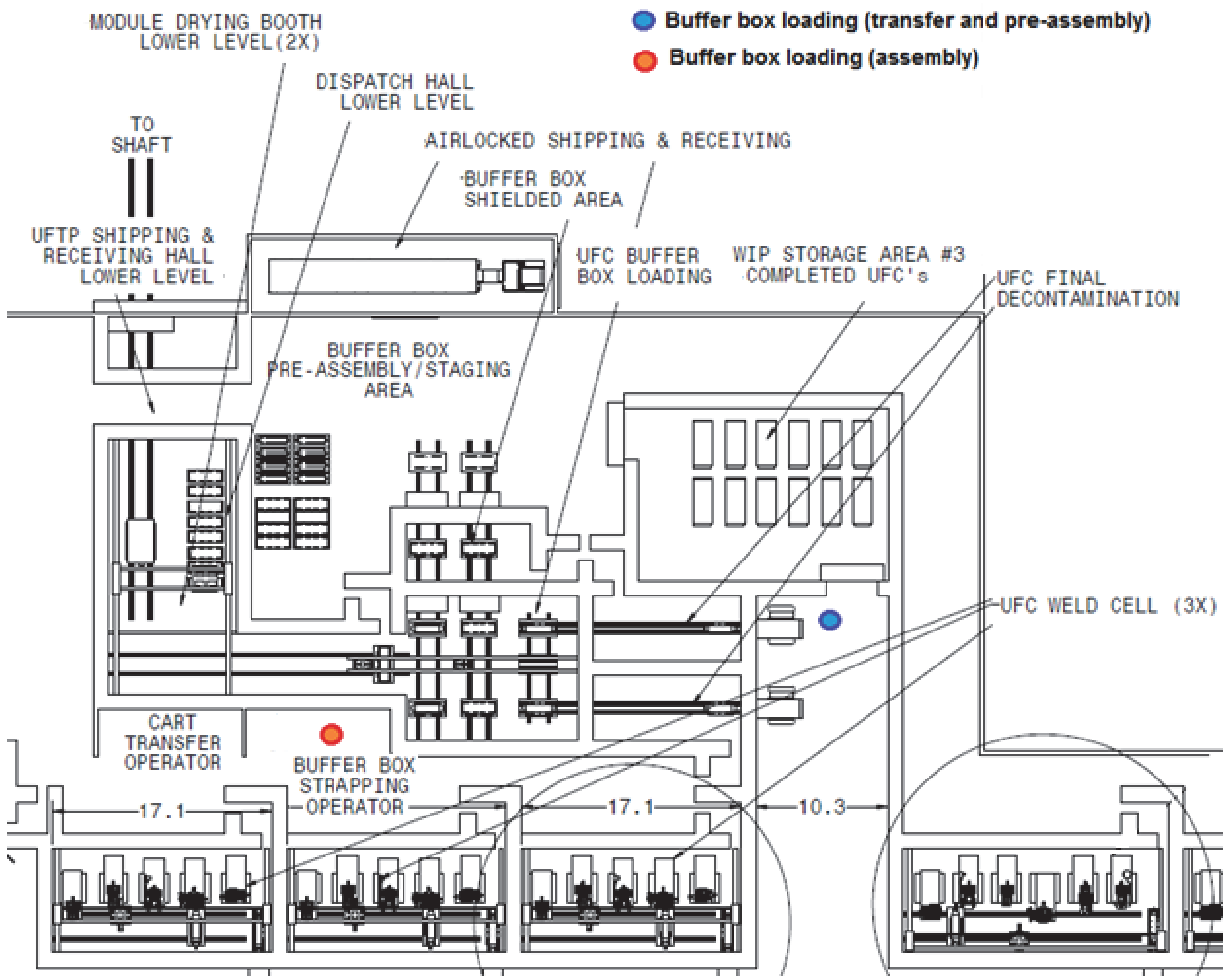


Figure 47: Exposure Locations in the Buffer Box Loading Area

4.3.2 Mark II Concept Support Operations

There are a variety of workers in the UFPP that perform tasks that are not directly related to the flow of UFPP operations, but that are required for support. The support personnel group includes cleaning, maintenance, radiation safety and service personnel. Cleaning, service and maintenance personnel and radiation safety technicians are assumed to be working in several locations in the facility. These workers are assumed to work in areas without radiation (i.e., offices) for 25% of time, while the rest of the time is spent in the facility.

The exposure locations for cleaners, service and maintenance personnel and radiation safety technicians are presented in Figure 48, Figure 49 and Figure 50. These groups of personnel rotate between 9 different locations.

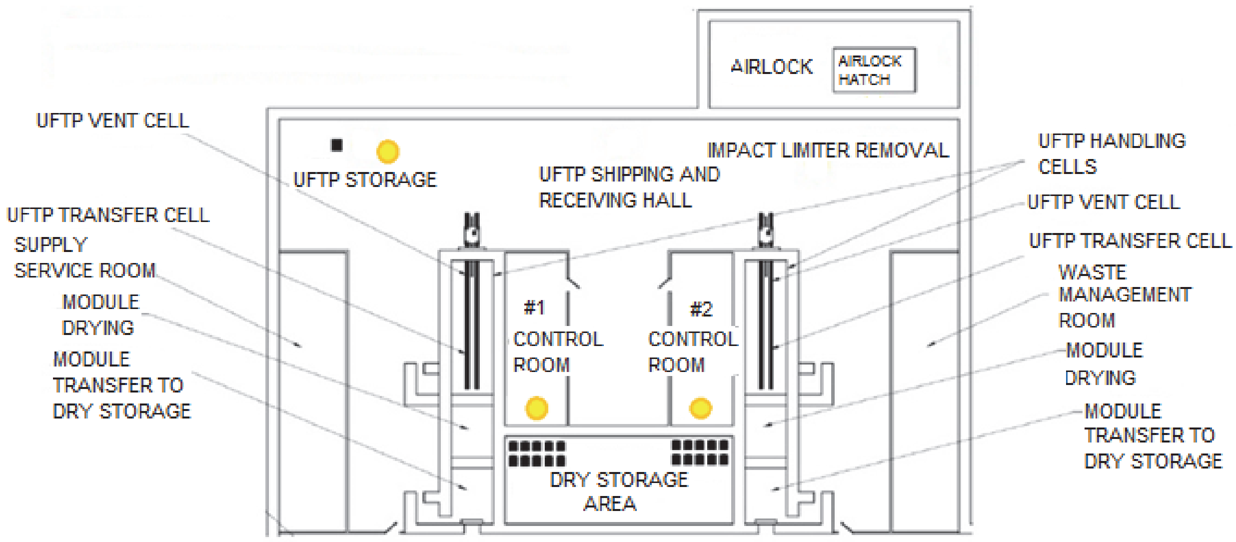


Figure 48: Exposure Locations for Support Personnel in the Shipping and Receiving Hall Area

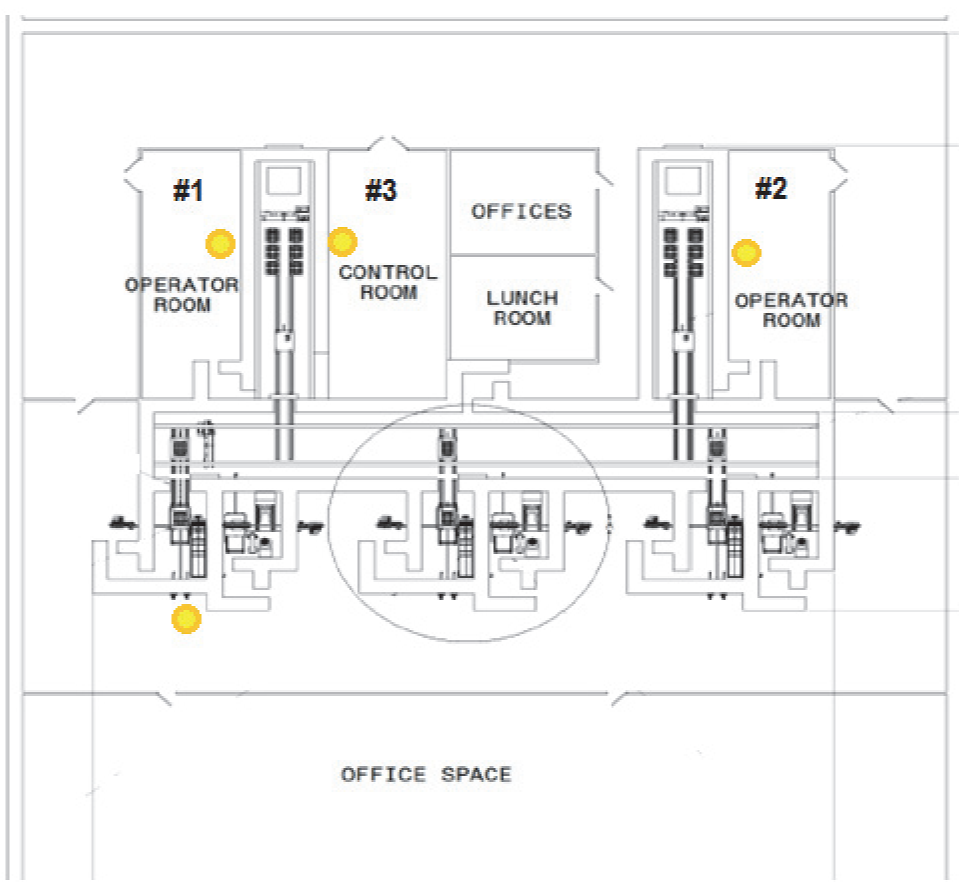


Figure 49: Exposure Locations for Support Personnel in the Module and Fuel Handling Areas

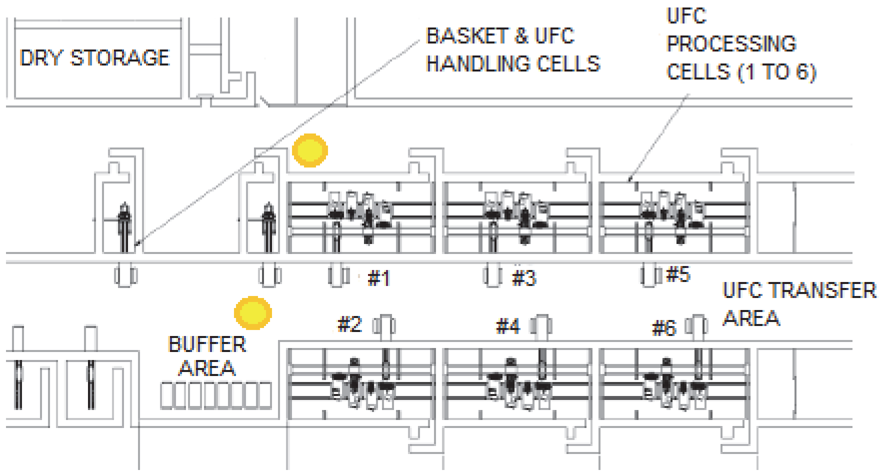


Figure 50: Exposure Locations for Support Personnel in the Processing Area

4.3.3 Mark II Concept Shaft Operations

The transfer cask with a filled UFC is remotely lowered to the repository. Hence, the only activities that are accounted for during aboveground shaft operations are the transfer to the shaft and securing of the UFC in the shaft.

4.3.4 Mark II Concept Underground Operations

The details of the underground layout level are not yet available for the Mark II concept. The Worker Exposure Model is therefore based on estimates in internal NWMO documents and expert judgement.

An underground storage area serves as overflow storage for UFCs in transfer casks that are awaiting placement. This storage is an ambient source of radiation to underground workers. Therefore, during the towing of transfer casks to the placement room, two source of radiation contribute to workers' exposure: the stored UFCs and the towed UFC. Activities required for the preparation of the placement rooms are not included in the assessment.

Once the UFC (in its transfer cask) has been towed to the placement room, the actual positioning of the boxes in the placement rooms is performed remotely. However, seeing as the tow vehicle driver is assumed to be outside the placement room, their doses are included in the preliminary ALARA calculations.

There are maintenance personnel in the DGR. The assumptions for the Mark II concept DGR follows closely that of the Mark I (crystalline) concept, with two maintenance workers in the storage area and two elsewhere in the DGR. Direct exposure to maintenance staff in the DGR is assumed to occur as the tow vehicle (pulling the filled transfer cask) drives by. These exposures are of short in duration but kept in the assessment to adequately assess the dose to maintenance personnel.

5. RADIOLOGICAL IMPACT IDENTIFICATIONS

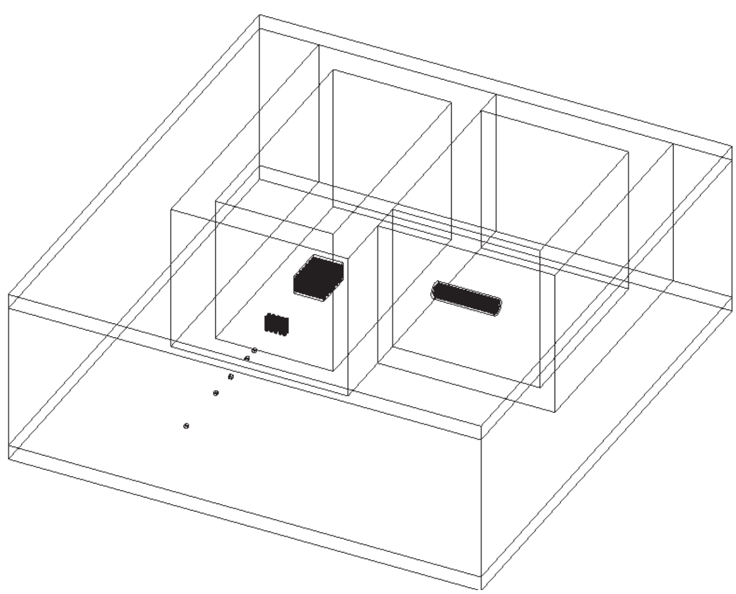
Once the exposure situations are fully described and accounted for, gamma and neutron dose rates are calculated using MAVRIC. MAVRIC is a code within Scale 6.1(ORNL 2011; ORNL 2013) package that performs complex radiation transport problems.

5.1 MODELLING

The Scale code package (ORNL 2011) is a comprehensive modelling and simulation suite for nuclear safety analysis and design that is developed and maintained by Oak Ridge National Laboratory (ORNL). Scale was originally created under the sponsorship of the U.S. Nuclear Regulatory Commission (NRC), and it continues to be supported by the NRC, as well as the U.S. Department of Energy (DOE).

For the purpose of this assessment, many different models have been developed for the fuel modules, the UFTP, the UFCs, the different shielding overpacks of the UFCs and the rooms in the UFPP and the underground facilities. Figure 51 is an example of one of the models created with MAVRIC, part of the Scale 6.1 suite of codes. All cases model the concrete floor and ceiling.

Wherever possible, calculations are designed to maximize the potential dose in each exposure situation. For instance, in the model shown in Figure 51, the centers of the sources (module, the basket and the 10 defective bundles) are at the same height as the dose calculation points. As a consequence, the doses in the preliminary ALARA assessment tend to overestimate the real doses.



Note: Black regions are the sources: one full module, one full basket and 10 damaged fuel bundles. Dots represent the points at which dose rates are calculated.

Figure 51: MAVRIC Model of a Mark II Fuel Handling Cell

All calculations are carried out for the two CANDU fuels discussed previously: 220 MWh/kgU burnup and 30 years of decay (220/30) and 280 MWh/kgU burnup and 10 years of decay (280/10).

Before performing the dose calculations for the different sources and components of the facilities, some simple calculations were carried out for a point source and a wall of concrete, to demonstrate the effect of the thickness of the concrete on gamma and neutron doses (see Figure 52 and Figure 53 for the four fuels considered in Table 2 and Table 3). These figures show the dose at 8 m from a point source inside a concrete box. The normalized dose rates are obtained by dividing the dose rate for a given thickness of concrete by the dose rate without concrete.

Figure 52 shows that the effectiveness of the concrete for shielding against gamma radiation depends on the photon energy. If the source contains Co-60 (which emits photons of 1.17 MeV and 1.33 MeV), the gamma dose reduction factor of 1 m of concrete is 50,000. For a source of Cs-137 (with photons of 0.65 MeV) the gamma dose reduction factor of 1 m of concrete is greater than 1 million. For CANDU fuels with several burnups and decay times, which present a complex gamma spectrum, the dose reduction factor of 1 m of concrete is around 1 million. The effect of a given thickness of concrete is greater for fuels with 30 years of decay than for fuels with 10 years of decay, while fuel burnup has no effect (at least in the range 220 MWh/kgU to 280 MWh/kgU).

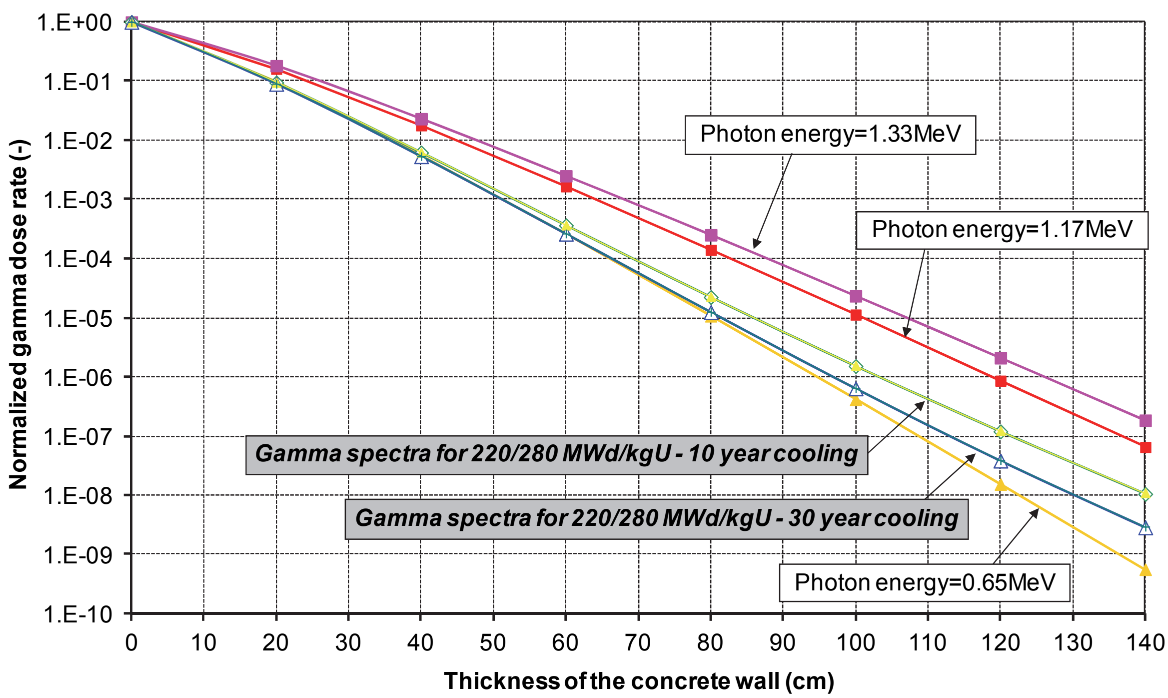


Figure 52: Normalized Gamma Dose Rate as a Function of Concrete Wall Thickness

Figure 53 shows that the effectiveness of concrete as a shield against neutron radiation is the same for the four fuels considered in Table 2 and Table 3. Every 30 cm of concrete reduces neutron dose rates (including secondary gammas) by a factor of 10, and 1 m of concrete reduces the neutron dose rates by a factor of 2,000.

For this preliminary assessment, it is assumed that the leaded glass windows are equally as effective as the concrete walls, and are thus are not explicitly modelled.

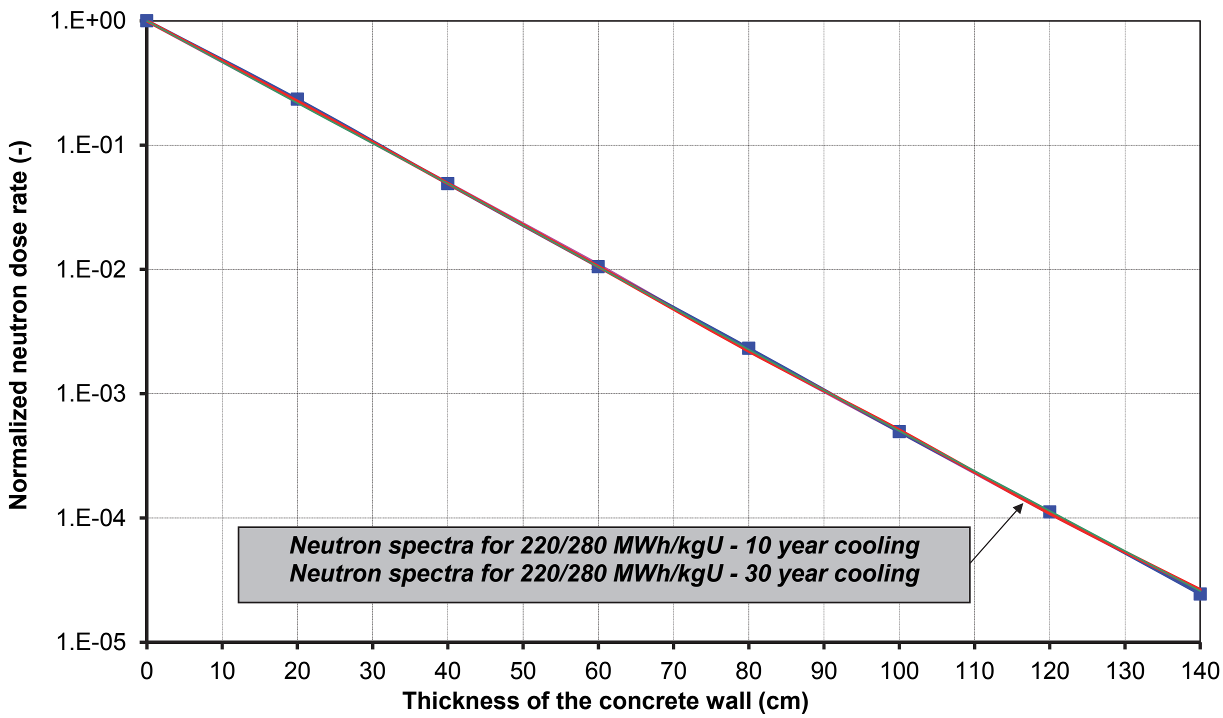


Figure 53: Normalized Neutron Dose Rate as a Function of Concrete Wall Thickness

It is noteworthy that in all the calculations for this assessment, the neutron dose rates (including secondary gammas) for the 280/10 (280 MWh/kgU burnup and 10 year decay) fuel are roughly 3.5 times the dose rates for the 220/30 fuel for identical geometries. This value is equal to the ratio of the neutron sources (neutron/sec per bundle) in the two fuels (Table 4) and is consistent with Figure 53, where the attenuation effect of the concrete for neutrons is the same for the four fuels considered. As a consequence, neutron calculations need only to be done for one fuel, and results for a different fuel can be obtained simply multiplying by the ratio of the neutron sources.

The gamma dose rates from the 280/10 fuel are always greater than for 220/30 fuel, but the difference between the two fuel types is case sensitive and always greater than the ratio of gamma sources (2.2, see Table 4). This result is consistent with Figure 52, which shows that the gamma radiation from fuels with 10 years of decay is less attenuated by a given thickness of concrete than the gamma radiation from fuels with 30 years of decay, because they have a slightly more energetic photon spectrum.

Gamma dose rates for fuels with the same decay time and different burnup are proportional to their total gamma sources, which is roughly proportional to the burnup. For fuels with 10 years of decay, the gamma dose rates for fuels with a burnup of 220 MWh/kgU are 0.8 times the gamma dose rates for fuels with a burnup of 280 MWh/kgU. For fuels with 30 years of decay, the gamma dose rate for fuels with a burnup of 280 MWh/kgU are 1.24 times the gamma dose rate for fuels with a burnup of 220 MWh/kgU.

These conclusions about the relative behaviour of fuel types reduce the overall number of calculations required for the preliminary ALARA assessment. For instance, the dose rate for 280/30 fuel will be the sum of 1.24 times the gamma dose rate for 220/30 fuel plus 2.09 times the neutron dose rate for 220/30 fuel (see Table 4).

5.2 DOSE RATES USED TO CALCULATE THE OPERATIONAL DOSES

The values of the total (gamma plus neutron) dose rates used to calculate the occupational doses to workers are summarised in Table 11 to Table 14 (Mark I) and Table 16 and Table 17 (Mark II). Results for the 220/30 and 280/10 fuels are presented, as well as the ratio of the dose rates for the two fuels. It was found that the dose rates for the 280/10 fuel are in most cases 5 to 8 times greater than the dose rates for the 220/30 fuel.

Table 11: Occupational Dose Rates in the Mark I Concept UFPP for 220/30 Fuel

Source/ Distance	Neutron Dose Rate (mSv/h)	Gamma Dose Rate (mSv/h)	Total Dose Rate (mSv/h)
UFTP (without impact limiter)			
0.5 m	2.0E-02	7.7E-03	2.8E-02
1 m	1.0E-02	4.9E-03	1.5E-02
5 m	7.9E-04	4.6E-04	1.2E-03
7.5 m	3.5E-04	2.1E-04	5.6E-04
UFTP in vent cell			
1 m	7.9E-07	4.6E-09	7.9E-07
UFTP storage (12 UFTPs with impact limiters)			
1 m	5.9E-04	2.4E-05	6.2E-04
5 m	6.6E-04	3.0E-05	6.9E-04
15 m	2.0E-04	8.5E-06	2.0E-04
UFTP storage (inside – 12 UFTPs with impact limiters)			
0.5 m	4.0E-02	1.2E-02	5.1E-02
Ambient dose rate in Operator Rooms (several sources)			
Operator Room A	8.7E-06	4.8E-04	4.9E-04
Operator Room B (fuel handling)	3.8E-06	2.0E-04	2.0E-04
Operator Room B (stations operation)	1.0E-06	4.7E-05	4.8E-05

Source/ Distance	Neutron Dose Rate (mSv/h)	Gamma Dose Rate (mSv/h)	Total Dose Rate (mSv/h)
Empty modules with Co-60 from the crud (0.5 m of concrete shielding)			
1 m	0.0E+00	2.6E-04	2.6E-04
UFC in a shielded frame/transfer cask (side)			
1 m	6.2E-04	4.1E-04	1.0E-03
5 m	1.4E-04	8.3E-05	2.2E-04
10 m	5.8E-05	2.8E-05	8.7E-05
15 m	3.4E-05	1.4E-05	4.8E-05
UFC in a shielded frame behind a wall of 0.5 m of concrete (side)			
1 m	7.2E-06	4.7E-07	7.6E-06
UFC in a shielded frame/transfer cask (lid/end)			
1 m	1.6E-04	2.8E-04	4.4E-04
UFC in a processing station			
1 m	6.6E-07	3.6E-07	1.0E-06
5 m (or more)	1.7E-07	6.7E-08	2.4E-07
UFC in the decontamination cell			
1 m	3.4E-06	1.2E-06	4.6E-06
UFC storage (40 UFCs) – Points shown in Figure 38			
1 m (point 3)	8.9E-06	2.0E-06	1.1E-05
1 m (point 8)	9.6E-06	3.2E-06	1.3E-05
3 m (point 5)	3.1E-06	9.2E-07	4.0E-06
Hallways (operation level) – Point 15 in Figure 37			
Ambient	8.7E-07	2.8E-05	2.9E-05

Table 12: Occupational Dose Rates in the Mark I Concept UFPP for 280/10 Fuel

Source/ Distance	Neutron Dose Rate (mSv/h)	Gamma Dose Rate (mSv/h)	Total Dose Rate (mSv/h)
UFTP (without impact limiter)			
0.5 m	7.2E-02	5.2E-02	1.2E-01
1 m	3.7E-02	3.3E-02	7.0E-02
5 m	2.8E-03	3.1E-03	5.9E-03
7.5 m	1.2E-03	1.4E-03	2.7E-03
UFTP in vent cell			
1 m	2.8E-06	3.1E-08	2.8E-06
UFTP storage (12 UFTPs with impact limiters)			
1 m	2.1E-03	1.7E-04	2.2E-03
5 m	2.3E-03	1.9E-04	2.5E-03
15 m	6.7E-04	5.5E-05	7.2E-04
UFTP storage (inside – 12 UFTPs with impact limiters)			
0.5 m	1.4E-01	8.3E-02	2.2E-01
Ambient dose rate in Operator Rooms (several sources)			
Operator Room A	3.0E-05	3.2E-03	3.3E-03
Operator Room B (fuel handling)	1.2E-05	1.3E-03	1.3E-03
Operator Room B (stations operation)	3.5E-06	3.3E-04	3.4E-04
Empty modules with Co-60 from the crud (0.5 m of concrete shielding)			
1 m	0.0E+00	3.3E-03	3.3E-03
UFC in a shielded frame/transfer cask (side)			
1 m	2.2E-03	3.1E-03	5.3E-03
5 m	4.9E-04	6.3E-04	1.1E-03
10 m	2.1E-04	2.2E-04	4.3E-04
15 m	1.2E-04	1.1E-04	2.3E-04
UFC in a shielded frame behind a wall of 0.5 m of concrete (side)			
1 m	2.2E-05	4.3E-06	2.6E-05
UFC in a shielded frame/transfer cask (lid/end)			
1 m	5.4E-04	2.0E-03	2.5E-03
UFC in a processing station			
1 m	2.4E-06	3.4E-06	5.7E-06

Source/ Distance	Neutron Dose Rate (mSv/h)	Gamma Dose Rate (mSv/h)	Total Dose Rate (mSv/h)
5 m (or more)	5.9E-07	6.6E-07	1.3E-06
UFC in the decontamination cell			
1 m	1.2E-05	1.2E-05	2.4E-05
UFC storage (40 UFCs) – Points shown in Figure 38			
1 m (point 3)	3.4E-05	2.0E-05	5.4E-05
1 m (point 8)	3.5E-05	3.0E-05	6.5E-05
3 m (point 5)	1.3E-05	6.8E-06	1.9E-05
Hallways (operation level) – Point 15 in Figure 37			
Ambient	3.0E-06	2.6E-04	2.6E-04

Table 13: Occupational Dose Rates in the Mark I (Crystalline) Concept

Source/ Distance	Neutron Dose Rate (mSv/h)	Gamma Dose Rate (mSv/h)	Total Dose Rate (mSv/h)
UFC in deposition hole (uncovered) – 220 MWh/kgU and 30 years of decay			
1 m to border of hole	1.1E-04	1.1E-03	1.2E-03
UFC in deposition hole (uncovered) – 280 MWh/kgU and 10 years of decay			
1 m to border of hole	3.9E-04	4.0E-03	4.4E-03
After placing 2 disks of HCB doses are zero			

Table 14: Occupational Dose Rates in the Mark I (Sedimentary) Concept DGR for 220/30 Fuel

Source/ Distance	Neutron Dose Rate (mSv/h)	Gamma Dose Rate (mSv/h)	Total Dose Rate (mSv/h)
UFC behind shielding barrier (UFC at 0.5 m of shielding barrier) see Figure 42 (upper)			
1.5 m	1.9E-04	2.8E-04	4.7E-04
5.5 m	2.6E-05	2.5E-05	5.2E-05
9 m	7.8E-06	9.0E-06	1.7E-05
12 m	3.6E-06	4.8E-06	8.5E-06
16 m	1.5E-06	2.4E-06	4.0E-06
UFC behind shielding barrier (UFC at 8 m of shielding barrier) see Figure 42 (lower)			

Source/ Distance	Neutron Dose Rate (mSv/h)	Gamma Dose Rate (mSv/h)	Total Dose Rate (mSv/h)
12 m	2.3E-06	4.6E-06	6.9E-06
16 m	5.9E-07	1.6E-06	2.2E-06

Table 15: Occupational Dose Rates in the Mark I (Sedimentary) Concept DGR for 280/10 Fuel

Source/ Distance	Neutron Dose Rate (mSv/h)	Gamma Dose Rate (mSv/h)	Total Dose Rate (mSv/h)
UFC behind shielding barrier (UFC at 0.5 m of shielding barrier) see Figure 42 (upper)			
1.5 m	6.3E-04	2.0E-03	2.6E-03
5.5 m	8.9E-05	1.9E-04	2.7E-04
9 m	2.8E-05	6.8E-05	9.6E-05
12 m	1.2E-05	3.6E-05	4.8E-05
16 m	5.3E-06	1.9E-05	2.4E-05
UFC behind shielding barrier (UFC at 8 m of shielding barrier) see Figure 42 (lower)			
12 m	8.4E-06	3.4E-05	4.2E-05
16 m	2.1E-06	1.2E-05	1.4E-05

Table 16: Occupational Dose rates in the Mark II Concept UFPP and DGR for 220/30 Fuel

Source/ Distance	Neutron Dose Rate (mSv/h)	Gamma Dose Rate (mSv/h)	Total Dose Rate (mSv/h)
UFTP without impact limiter			
0.5 m	2.0E-02	7.7E-03	2.8E-02
1 m	1.0E-02	4.9E-03	1.5E-02
5 m	7.9E-04	4.6E-04	1.2E-03
7.5 m	3.5E-04	2.1E-04	5.6E-04
UFTP in vent cell			
1m	7.9E-07	4.6E-09	7.9E-07
UFTP storage (12 UFTPs with impact limiters)			
1 m	1.0E-02	4.9E-03	1.5E-02
5 m	2.2E-03	6.3E-04	2.9E-03
10 m	9.3E-04	2.4E-04	1.2E-03
45 m	9.5E-05	2.2E-05	1.2E-04

Source/ Distance	Neutron Dose Rate (mSv/h)	Gamma Dose Rate (mSv/h)	Total Dose Rate (mSv/h)
60 m	4.3E-05	1.0E-05	5.3E-05
UFTP storage (inside – 12 UFTPs with impact limiters)			
0.5 m	4.0E-02	1.2E-02	5.1E-02
Dry storage - Dose in control room			
1 m	1.8E-05	5.6E-04	5.7E-04
Empty module with Co-60 from the crud (0.5 m of concrete shielding)			
1m	0.0E+00	2.6E-04	2.6E-04
Module handling cell			
1 m	1.3E-05	4.7E-04	4.9E-04
10 m	0.0E+00	0.0E+00	0.0E+00
Fuel handling cell			
1 m	3.2E-06	2.9E-04	2.9E-04
10 m	0.0E+00	0.0E+00	0.0E+00
Processing or decontamination cell			
1 m	2.3E-06	3.1E-05	3.3E-05
5 m	4.1E-07	4.5E-06	4.9E-06
10 m	1.6E-07	1.5E-06	1.6E-06
15 m	1.6E-07	1.5E-06	1.6E-06
Buffer area (8 UFCs)			
10 m	7.2E-05	5.1E-05	1.2E-04
50 m (ambient)	5.2E-07	7.8E-08	5.9E-07
Processing cells			
60 m (ambient)	8.2E-09	8.1E-08	8.9E-08
UFC in transfer flask			
1 m	4.1E-04	4.8E-04	9.0E-04
5 m	6.9E-05	5.7E-05	1.3E-04
Buffer box behind 1 m of concrete			
1 m	3.1E-07	2.4E-06	2.7E-06
Buffer box in transport cask			
1 m	1.8E-05	3.3E-05	5.1E-05
5 m	2.6E-06	3.9E-06	6.5E-06
Storage area for 12 UFCs in transfer flasks			
1 m	1.3E-06	1.1E-07	1.4E-06
Underground Storage (10 buffer boxes in transport casks)			

Source/ Distance	Neutron Dose Rate (mSv/h)	Gamma Dose Rate (mSv/h)	Total Dose Rate (mSv/h)
1 m	1.1E-05	1.4E-05	2.5E-05
5 m	4.5E-06	7.3E-06	1.2E-05
10 m	2.6E-06	3.7E-06	6.4E-06

Table 17: Occupational Dose Rates in the Mark II Concept UFPP and DGR for 280/10 Fuel

Source/ Distance	Neutron Dose Rate (mSv/h)	Gamma Dose Rate (mSv/h)	Total Dose Rate (mSv/h)
UFTP without impact limiter			
0.5 m	7.2E-02	5.2E-02	1.2E-01
1 m	3.7E-02	3.3E-02	7.0E-02
5 m	2.8E-03	3.1E-03	5.9E-03
7.5 m	1.2E-03	1.4E-03	2.7E-03
UFTP in vent cell			
1m	2.8E-06	3.1E-08	2.8E-06
UFTP storage (12 UFTPs with impact limiters)			
1 m	3.7E-02	3.3E-02	7.0E-02
5 m	7.8E-03	4.4E-03	1.2E-02
10 m	3.2E-03	1.6E-03	4.9E-03
45 m	3.2E-04	1.7E-04	4.9E-04
60 m	1.5E-04	6.7E-05	2.1E-04
UFTP storage (inside – 12 UFTPs with impact limiters)			
0.5 m	1.4E-01	8.3E-02	2.2E-01
Dry storage - Dose in control room			
1 m	6.1E-05	4.0E-03	4.0E-03
Empty module with Co-60 from the crud (0.5 m of concrete shielding)			
1 m	0.0E+00	3.3E-03	3.3E-03
Module handling cell			
1 m	4.4E-05	3.4E-03	3.4E-03
10 m	0.0E+00	0.0E+00	0.0E+00
Fuel handling cell			
1 m	1.1E-05	2.0E-03	2.0E-03
10 m	0.0E+00	0.0E+00	0.0E+00
Processing or decontamination cell			
1 m	8.1E-06	2.5E-04	2.6E-04

Source/ Distance	Neutron Dose Rate (mSv/h)	Gamma Dose Rate (mSv/h)	Total Dose Rate (mSv/h)
5 m	1.5E-06	3.8E-05	3.9E-05
10 m	5.9E-07	1.2E-05	1.3E-05
15 m	5.9E-07	1.2E-05	1.3E-05
Buffer area (8 UFCs)			
10 m	2.5E-04	3.4E-04	5.9E-04
50 m (ambient)	1.7E-06	4.7E-07	2.2E-06
Processing cells			
60 m (ambient)	2.9E-08	6.7E-07	7.0E-07
UFC in transfer flask			
1 m	1.4E-03	3.8E-03	5.2E-03
5 m	2.4E-04	4.4E-04	6.8E-04
Buffer box behind 1 m of concrete			
1 m	1.1E-06	2.3E-05	2.4E-05
Buffer box in transport cask			
1 m	6.2E-05	2.9E-04	3.6E-04
5 m	9.1E-06	3.6E-05	4.5E-05
Storage area for 12 UFCs in transfer flasks			
1 m	5.0E-06	9.9E-07	6.0E-06
Underground storage (10 buffer boxes in transport casks)			
1 m	4.0E-05	1.1E-04	1.5E-04
5 m	1.8E-05	6.0E-05	7.8E-05
10 m	9.2E-06	3.0E-05	4.0E-05

6. OCCUPATIONAL DOSE RATES

6.1 METHODOLOGY

The dose rates calculated for different locations in the UFPP and the DGR (Table 11 to Table 17) are multiplied by the corresponding annual exposure times in the Worker Exposure Models to obtain the dose for each activity. For each worker, the annual individual dose is calculated by summing the dose from each of their activities. The annual collective dose is estimated by summing the annual individual doses to all the workers for both shifts. Full lists of doses for each step are listed in the Worker Exposure Models in Appendix A.

6.2 RESULTS

The individual and collective doses are presented in Table 18 to Table 24. Note that doses in these tables have been calculated assuming that all the UFTPs received are sent first to the UFTP storage and, after some time, are lifted and sent to the pallet for processing.

6.2.1 Doses in the UFPP

The doses received by the workers in the UFPP are roughly 100 times higher than the doses in the DGR for the Mark I concept. For the Mark II concept, the doses received in the UFPP are approximately 1000 times higher than the doses in the DGR.

The only group of workers that has a risk of being exposed above the occupational dose limit are those involved in shipping and receiving UFTPs. In particular, if <u>all</u> the used fuel arriving at the UFPP has a burnup of 280 MWh/kgU and 10 years of decay, the calculated annual dose to a technician could reach 100 mSv. This is a conservative limiting case, and would not occur in practice.

The UFTP shipping and receiving workers (2 technicians and 1 OTC operator per shift) are directly exposed to the UFTPs and to ambient radiation from the UFTP storage, which is conservatively assumed to contain 12 full UFTPs with impact limiters. A breakdown of the doses to UFTP shipping and receiving workers are shown in Table 18 and Table 19.

The tables show that a significant dose is associated with moving the UFTPs in and out of storage. If the UFTPs received are sent to the UFTP storage instead of to the pallet to for the start of processing, the doses to UFTP shipping and receiving workers increase by about 30%, because the two technicians need to enter the UFTP storage to disconnect the lifting equipment and later to connect it again, and because the dose rates inside the UFTP storage area are high.

Table 18: Contributions to the Individual Annual Doses to the Workers of the UFTP Receiving and Shipping Group (mSv/year) in the Mark I Concept

Source	Technician	OTC Operator
220 MWh/kgU burnup and 30 years of decay		
UFTP being handled	1.4E+1	5.5E+0
Ambient dose from UFTP storage (12 UFTPs)	2.7E-1	3.4E-1
Sum	1.4E+1	5.8E+0
Extra dose if the UFTP is sent to the UFTP storage	6.7E+0	2.2E-1
Total	**2.1E+1**	**6.0E+0**
280 MWh/kgU burnup and 10 years of decay		
UFTP being handled	6.3E+1	2.5E+1
Ambient dose from UFTP storage (12 UFTPs)	1.0E+0	1.2E+0
Sum	6.4E+1	2.6E+1
Extra dose if the UFTP is sent to the UFTP storage	2.9E+1	9.2E-1
Total	**9.2E+1**	**2.7E+1**

Table 19: Contributions to the Individual Annual Doses to the Workers of the UFTP Receiving and Shipping Group (mSv/year) in the Mark II Concept

Source	Technician	OTC operator
220 MWh/kgU burnup and 30 years of decay		
UFTP being handled	1.4E+1	5.5E+0
UFTP storage (12 UFTPs)	1.6E+0	3.3E-1
Sum	1.5E+1	5.8E+0
Extra dose if the UFTP is sent to the UFTP storage	7.8E+0	6.0E-1
Total	**2.3E+1**	**6.4E+0**
280 MWh/kgU burnup and 10 years of decay		
UFTP being handled	6.3E+1	2.5E+1
UFTP storage (12 UFTPs)	7.5E+0	1.4E+0
Sum	7.0E+1	2.6E+1
Extra dose if the UFTP is sent to the UFTP storage	3.4E+1	2.7E+0
Total	**1.0E+2**	**2.9E+1**

In the Mark I concept UFPP, the UFTP storage is surrounded by shield walls and hence the doses received by these workers are largely due to the individual UFTPs being handled, since the dose contribution from the stored (and shielded) UFTPs is small. However, in the Mark II concept UFPP, the stored UFTPs are not shielded. Although the dose from the individual UFTPs being handled is still clearly dominant, the contribution from the stored UFTPs is significant. This topic is discussed in detail in Section 7.4.

The high doses to the UFTP shipping and receiving workers are mainly a consequence of the fact that the dose rates emanating from a UFTP are the highest of all the shielded packages. The workers in the operation and control rooms receive annual doses in the order of 1 mSv when the 220/30 fuel is processed and 7 mSv if the 280/10 fuel is processed. Dose rates in the operation and control rooms are dominated by gamma radiation; therefore, simply increasing the thickness of the walls to 1.2 m would decrease the dose rates by a factor of 10, lowering the annual doses to less than 1 mSv/year even for the 280/10 fuel. This topic is discussed further in Section 7.2.

Workers involved in cleaning, servicing and maintenance of the UFPP of the Mark II concept receive annual doses close to 1 mSv for 220/30 fuel and 6 mSv for 280/10 fuel, partly due to the unshielded UFTP storage.

The doses to the remaining workers of the UFPP are much lower due to the shielding provided by the walls of the UFPP and the different overpacks (shielded frame, transfer flask or transport cask) used to transport the filled UFCs through to the UFPP. This result confirms that the shielding designs for the UFCs are appropriate.

Table 20: Individual (I) and Collective (C) Annual Doses (mSv) to Workers of the UFPP (Mark I Concept)

Working Group	Workers		220/30 Fuel		280/10 Fuel	
	Identification	No.	I	C	I	C
Operation room A	Module Handling Cell operator, Line 1	1	9.8E-01	2.0E+00	6.5E+00	1.3E+01
	Module Handling Cell operator, Line 2	1	9.8E-01	2.0E+00	6.5E+00	1.3E+01
	Operator, additional	1	9.8E-01	2.0E+00	6.5E+00	1.3E+01
Operation room B	Station operator	2	9.8E-02	3.9E-01	6.8E-01	2.7E+00
	Additional station operator	1	9.8E-02	2.0E-01	6.8E-01	1.4E+00
	Fuel Handling Cell operator	2	4.0E-01	1.6E+00	2.6E+00	1.0E+01
	Operator, additional	1	4.0E-01	8.0E-01	2.6E+00	5.2E+00
Operation room C	Storage and Decontamination Cell operator	1	2.6E-02	5.2E-02	1.3E-01	2.6E-01
	Dispatch operator	1	2.6E-02	5.2E-02	1.3E-01	2.6E-01
	Operator, additional	1	2.6E-02	5.2E-02	1.3E-01	2.6E-01
Operation room D	Vent cell operator, Line 1	1	2.5E-04	5.0E-04	8.9E-04	1.8E-03
	Vent cell operator, Line 2	1	2.5E-04	5.0E-04	8.9E-04	1.8E-03
	Vent cell operator, additional	1	2.5E-04	5.0E-04	8.9E-04	1.8E-03

Working Group	Workers		220/30 Fuel		280/10 Fuel	
	Identification	No.	I	C	I	C
UFC Transfer Area	Air-cushion transporter operator	1	3.2E-01	6.5E-01	1.7E+00	3.3E+00
	Air-cushion transporter operator, additional	1	3.2E-01	6.5E-01	1.7E+00	3.3E+00
UFC Preparation	Technician	2	1.1E-01	4.3E-01	5.5E-01	2.2E+00
	Air-cushion transporter operator	1	9.3E-02	1.9E-01	4.8E-01	9.5E-01
	Air-cushion transporter operator, additional	1	9.3E-02	1.9E-01	4.8E-01	9.5E-01
UFTP Receiving and Shipping	Technician	2	2.1E+01	8.3E+01	9.2E+01	3.7E+02
	40 tonne OTC operator	1	6.0E+00	1.2E+01	2.7E+01	5.4E+01
UFC Dispatch	Tow vehicle operator	1	6.6E-02	1.3E-01	3.8E-01	7.6E-01
	Technician	2	1.3E-01	5.3E-01	6.9E-01	2.7E+00
	80 tonne OTC operator	1	1.0E-01	2.0E-01	5.1E-01	1.0E+00
Waste Management Facility	Decontamination technician	3	1.7E-01	1.0E+00	2.1E+00	1.3E+01
Cleaning	Cleaning	2	1.8E-01	7.3E-01	9.4E-01	3.8E+00
Servicing	Servicing	2	1.8E-01	7.3E-01	9.4E-01	3.8E+00
Maintenance, UFPP	Maintenance	4	1.8E-01	1.5E+00	9.4E-01	7.6E+00
Shaft Operations	Shaft hoist operator	1	6.5E-03	1.3E-02	3.3E-02	6.6E-02
Total collective dose (person-mSv)		**-**	**-**	**1.1E+02**	**-**	**5.3E+2**

Table 21: Individual (I) and Collective (C) Annual Doses (mSv) to Workers of the Mark II Concept UFPP

Working Group	Workers		220/30 Fuel		280/10 Fuel	
	Identification	No.	I	C	I	C
Control Room #1	UFTP handling and module handling operator	2	1.1E+00	4.6E+00	8.1E+00	3.2E+01
Control Room #2	UFTP handling and module handling operator	2	1.1E+00	4.6E+00	8.1E+00	3.2E+01
Control Room #3	Fuel handling and basket handling operator	1	9.7E-01	1.9E+00	6.9E+00	1.4E+01
	Line manager	1	9.7E-01	1.9E+00	6.9E+00	1.4E+01
Operator Room #1	UFTP handling and module handling operator	1	9.7E-01	1.9E+00	6.9E+00	1.4E+01
	Fuel handling and basket handling operator	1	9.7E-01	1.9E+00	6.9E+00	1.4E+01
Operator Room #2	UFTP handling and module handling operator	1	9.7E-01	1.9E+00	6.9E+00	1.4E+01
	Fuel handling and basket handling operator	1	9.7E-01	1.9E+00	6.9E+00	1.4E+01
Fuel Handling and Basket Handling	Floating operator in hallway	1	5.8E-01	1.2E+00	4.0E+00	7.9E+00
UFTP Receiving and Shipping	Technician	2	2.3E+01	9.3E+01	1.0E+02	4.2E+02
	40 tonne OTC operator	1	6.4E+00	1.3E+01	2.9E+01	5.8E+01
Empty UFC Receiving and Preparation	Technician	3	2.7E-03	1.6E-02	1.7E-02	1.0E-01
UFC Processing	Operator	2	2.7E-01	1.1E+00	1.3E+00	5.3E+00
	Technician	8	2.7E-01	4.3E+00	1.3E+00	2.1E+01
	Management	1	2.7E-01	5.4E-01	1.3E+00	2.7E+00
UFC Dispatch	Operator	2	5.3E-02	2.1E-01	4.1E-01	1.7E+00
Buffer box loading	Buffer box loading operator	2	2.8E-02	1.1E-01	1.6E-01	6.6E-01
Waste Management Facility	Decontamination technician	2	1.7E-01	6.7E-01	2.1E+00	8.3E+00
Transfer from UFPP to DGR	Technician (remote)	1	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Tow vehicle driver	1	8.9E-03	1.8E-02	6.2E-02	1.2E-01
	Fork lift driver	1	2.8E-02	5.6E-02	2.0E-01	3.9E-01
	Shaft operator	1	1.1E-03	2.3E-03	7.9E-03	1.6E-02
Cleaning	Cleaning	2	9.9E-01	3.9E+00	5.6E+00	2.2E+01

Working Group	Workers		220/30 Fuel		280/10 Fuel	
	Identification	No.	I	C	I	C
Other Technicians	Radiation safety technician	2	9.9E-01	3.9E+00	5.6E+00	2.2E+01
Other Operators and Maintenance Personnel	Maintenance and servicing	8	9.9E-01	1.6E+01	5.6E+00	8.9E+01
Total collective dose (person-mSv)		-	**-**	**1.6E+02**		**8.1E+02**

6.2.2 Doses in the DGR

Doses in the DGR are very small for all concepts and for all fuel types (even for the alternative fuel with a burnup of 280 MWh/kgU and a decay time of 10 years). This is because many operations are performed remotely and because of the shielding provided by the transfer casks.

For the Mark I (crystalline) concept, the underground doses are negligible for all the activities that occur after the second (of five) disk of HCB is placed in the deposition hole (Figure 41).

In the Mark II concept, the transport cask has been designed with the target of ensuring dose rates below 10 μSv/h at 1 m for the fuel of 280/10 fuel, without giving credit to the HCB used in the buffer boxes. Dose calculations for this preliminary ALARA assessment have taken into account the shielding effect of the bentonite in the buffer box, which reduces the doses by a factor of 10. This is one of the reasons why the doses are very low for the Mark II concept underground operations. A discussion of the potential effects of radiation streaming between the gaps in the bentonite block of the bentonite buffer box is given in Appendix B. The conclusion of the discussion is that the effect of streaming is negligible, and does not need to be considered in this assessment.

If credit is given to the bentonite in the buffer box when designing the transport cask, a lighter model could be designed. It may be possible to avoid the polyethylene layer for neutron shielding, since the HCB contains a significant amount of water (and hence hydrogen) to shield against neutrons.

Table 22: Individual (I) and Collective (C) Annual Doses (mSv) to Workers of the Mark I (Crystalline) Concept DGR

Working Group	Workers		220/30 Fuel		280/10 Fuel	
	Identification	No.	I	C	I	C
Underground Operations, Remote Controlled Steps	Shielding barrier remote operator	1	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Reloading Station OTC and reloading cell operator	1	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Deposition machine operator	1	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Underground Operations, Pellet Operations	Pellet equipment operator	2	1.4E-01	5.5E-01	5.1E-01	2.0E+00
	Tow vehicle driver	1	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Positioning and measurement	1	1.0E-01	2.1E-01	3.8E-01	7.7E-01
Underground Operations, Backfill Operations	Technician	2	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Backfill installation workers, measurements	1	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Backfill block installation vehicle driver	1	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Underground Operations, Buffer Operations	Bentonite forklift driver	1	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Tow vehicle driver	1	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Bentonite placement machine operator (in placement room)	2	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Underground Operations, Reloading Station	Tow vehicle driver	1	5.1E-02	1.0E-01	3.0E-01	5.9E-01
Maintenance, DGR	Maintenance	2	9.2E-03	3.7E-02	4.7E-02	1.9E-01
Maintenance, Reloading Station	Maintenance	2	6.9E-02	2.8E-01	3.5E-01	1.4E+00
Total collective dose (person-mSv)		**-**	**-**	**1.2E+0**	**-**	**5.0E+0**

Table 23: Individual (I) and Collective (C) Annual Doses to Workers (mSv) of the Mark I (Sedimentary) Concept DGR

Working Group	Workers		220/30 Fuel		280/10 Fuel	
	Identification	**No.**	**I**	**C**	**I**	**C**
Underground operations, remote operated steps	Placement cart operator	1	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Shielding door remote operator	1	0.0E+00	0.0E+00	0.0E+00	0.0E+00
	Cylinder and ram operator	1	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Underground operations, placement room operations	Locomotive driver	1	9.6E-02	1.9E-01	5.5E-01	1.1E+00
	Pedestal placement vehicle driver	1	1.5E-02	2.9E-02	8.1E-02	1.6E-01
	Technician	2	2.2E-01	8.9E-01	1.3E+00	5.1E+00
Underground operations, bentonite installation	Bentonite blowing equipment operator	2	3.0E-02	1.2E-01	1.7E-01	6.9E-01
	Measurements and inspection	1	8.2E-03	1.6E-02	4.4E-02	8.9E-02
Maintenance, DGR	Maintenance	2	9.3E-03	3.7E-02	4.7E-02	1.9E-01
Total collective dose (person-mSv)		**-**	**-**	**1.3E+0**	**-**	**7.3E+0**

Table 24: Individual (I) and Collective (C) Annual Doses (mSv) to Workers of the Mark II Concept DGR

Working Group	Workers		220/30 Fuel		280/10 Fuel	
	Identification	**No.**	**I**	**C**	**I**	**C**
Placement Room Preparation (no exposure)	Technician	4	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Placement	Tow vehicle driver	1	7.5E-02	1.5E-01	5.1E-01	1.0E+00
	Technician (remote operation)	4	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Maintenance, DGR	Maintenance	2	6.3E-03	2.5E-02	4.1E-02	1.6E-01
Total collective dose (person-mSv)		**-**	**-**	**1.8E-01**	**-**	**1.2E+00**

7. ELIMINATION, ABATEMENT AND CONTROL MEASURES

This section discusses some potential changes to the three APM DGR designs that could reduce the operational doses or simplify the operation of the facilities.

7.1 UFTP SHIPPING AND RECEIVING

The preliminary ALARA assessment presented in Section 6.2 has shown that operations related to the handling of the UFTPs in the UFPP could produce individual occupational doses close to or above the dose constraint (10 mSv/year). However, these are conservative calculations, and the operations involving UFTPs can be optimized to reduce the worker doses below the dose constraint.

The dose rate close to a UFTP (Table 25) are below the limits applicable to transportation packages (the dose rate at 1 m from the surface of the package does not exceed 0.1 mSv/h), even when fuels of 280 MWh/kgU burnup and 10 years of decay are loaded (Table 25). However, because so many UFTPs are processed every year, workers that work exclusively with these packages receive a considerable annual dose.

Table 25: Dose Rates (mSv/h) in the Vicinity of a UFTP

Distance (m)	Neutron		Gamma		Total Dose Rate (mSv/h)	
	Value	Error (%)	Value	Error (%)	Value	Ratio 280/10 to 220/30
220 MWh/kgU – 30 years of decay						
0.5	2.01E-02	0.6	7.42E-03	1.1	2.81E-02	1
1	1.03E-02	0.6	4.74E-03	0.9	1.54E-02	1
5	7.74E-04	0.6	4.45E-04	0.8	1.24E-03	1
7.5	3.43E-04	0.7	2.06E-04	0.8	5.61E-04	1
280 MWh/kgU – 10 years of decay						
0.5	7.00E-02	0.9	5.03E-02	0.9	1.24E-01	4.39
1	3.61E-02	1.0	3.22E-02	0.7	7.01E-02	4.56
5	2.71E-03	1.0	3.02E-03	0.6	5.87E-03	4.72
7.5	1.20E-03	1.1	1.40E-03	0.6	2.66E-03	4.75

The operations involving UFTPs should be optimized and reduced whenever possible. In the Mark I concept, the preliminary working procedure is to send the received UFTPs to the UFTP storage (instead of directly to the entrance of a module handling cells) and, after some time, from the UFTP storage to the processing line. This approach is considered beneficial for smooth operation of the facility (Section 3.2.2.1), but leads to additional doses to the technicians and OTC operators that handle the UFTPs.

The possibility of performing some of the UFTP receiving activities remotely should be explored.

Modifications to the UFTP should also be considered. The current design of the UFTP does not include any neutron shielding material and as shown in Table 25, the neutron dose rate is much greater than the gamma dose rate for the 220/30 fuel (and is not insignificant for the 280/10 fuel). Since neutron shielding materials are lighter than gamma shielding materials, adding a neutron shield could be an effective way of reducing the overall dose, without adding too much weight to the UFTP. Table 26 shows the contribution of neutron and gamma radiation to the annual doses to the workers involved in UFTP handling. If neutron radiation is eliminated, annual doses with 220/30 fuel would decrease and annual doses to the technicians involved in UFTP receptions would fall below the dose constraint of 10 mSv/year.

Table 26: Contribution of Neutron and Gamma Radiation to the Occupational Dose Rates of the Workers in the UFTP Shipping and Receiving Hall in the Mark I and Mark II Concepts

Case/Worker	Neutron Dose (mSv/year)	Gamma Dose (mSv/year)	Total Dose (mSv/year)
Mark I – Fuel 220/30			
Technician	1.5E+01	5.9E+00	2.1E+01
OTC operator	4.2E+00	1.8E+00	6.0E+00
Mark I – Fuel 280/10			
Technician	5.2E+01	4.0E+01	9.2E+01
OTC operator	1.5E+01	1.2E+01	2.7E+01
Mark II – Fuel 220/30			
Technician	1.7E+01	6.8E+00	2.3E+01
OTC operator	4.4E+00	2.0E+00	6.4E+00
Mark II – Fuel 280/10			
Technician	5.8E+01	4.6E+01	1.0E+02
OTC operator	1.6E+01	1.3E+01	2.9E+01

7.2 HOT CELL SHIELDING

Workers in the operator and control rooms are separated from the fuel modules and baskets by 1 m thick concrete walls (with leaded glass windows that provide the same protection level). The resulting annual individual doses are about 1 mSv if 220/30 fuel is processed and 7 mSv for 280/10 fuel.

Table 27 is an example of the dose rates in a control room adjacent to a dry storage containing 10 modules. Neutron radiation produces only 2% or 3% of the total dose rates.

Figure 52 and Figure 53 show that increasing the thickness of the concrete walls of the hot cells by 20 cm would reduce gamma dose rates by a factor of at least 10 and the neutron dose rate by a factor of at least 5. Given the dominant role of gamma radiation in this situation, using 1.2 m thick concrete walls for the module and fuel handling cells would reduce the individual doses to the workers in the operators and control rooms by a factor of at least 10.

Table 27: Dose Rates in Control Rooms #1 and #2 from Mark II Concept Dry Storage

Distance (m)	Neutron		Gamma		Total Dose Rate	
	Value (mSv/h)	Error (%)	Value (mSv/h)	Error (%)	Value (mSv/h)	Ratio 280/10 to 220/30
220 MWh/kgU – 30 years of decay						
0.5	2.11E-05	1.2	6.65E-04	1.9	7.25E-04	-
1	1.73E-05	1.0	5.32E-04	1.5	5.74E-04	-
2	1.22E-05	0.8	3.67E-04	1.3	3.94E-04	
3	8.99E-06	0.8	2.68E-04	1.2	2.87E-04	-
5	5.40E-06	0.9	1.58E-04	1.2	1.69E-04	-
280 MWh/kgU – 10 years of decay						
0.5	7.22E-05	1.2	4.76E-03	1.8	5.09E-03	7.03
1	5.95E-05	1.0	3.82E-03	1.3	4.03E-03	7.02
2	4.22E-05	0.8	2.64E-03	1.1	2.77E-03	7.03
3	3.12E-05	0.9	1.94E-03	1.0	2.03E-03	7.08
5	1.86E-05	0.9	1.14E-03	1.0	1.19E-03	7.05

7.3 CONTROL AND OPERATION ROOMS LAYOUT

Figure 54 graphically shows the dose rates in Control Room A of the Mark I concept. There are two different sources contributing the overall dose rate: The 4 modules stored in each of the module handling cells and the 12 baskets in the fuel handling cell. The figure shows that the dose rates vary significantly throughout the control room. This class of dose maps can be helpful when designing the control room layout to ensure that workers spend most of the time in the areas with lower dose rates.

Increasing the thickness of the wall facing the 12 baskets in Figure 54 by 20 cm would reduce the doses in this region to below 0.1 µSv/h.

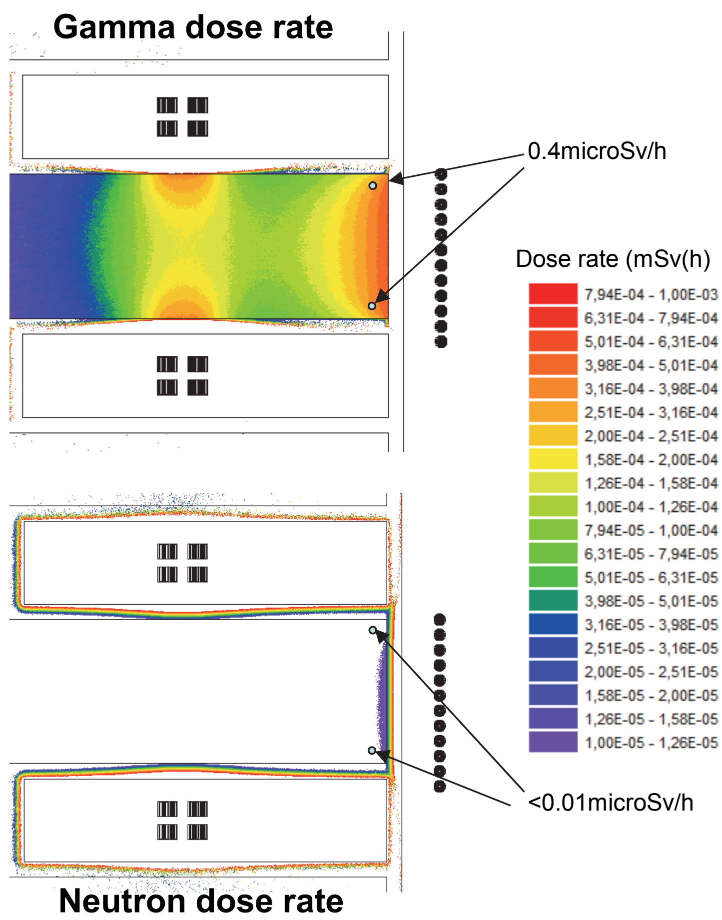


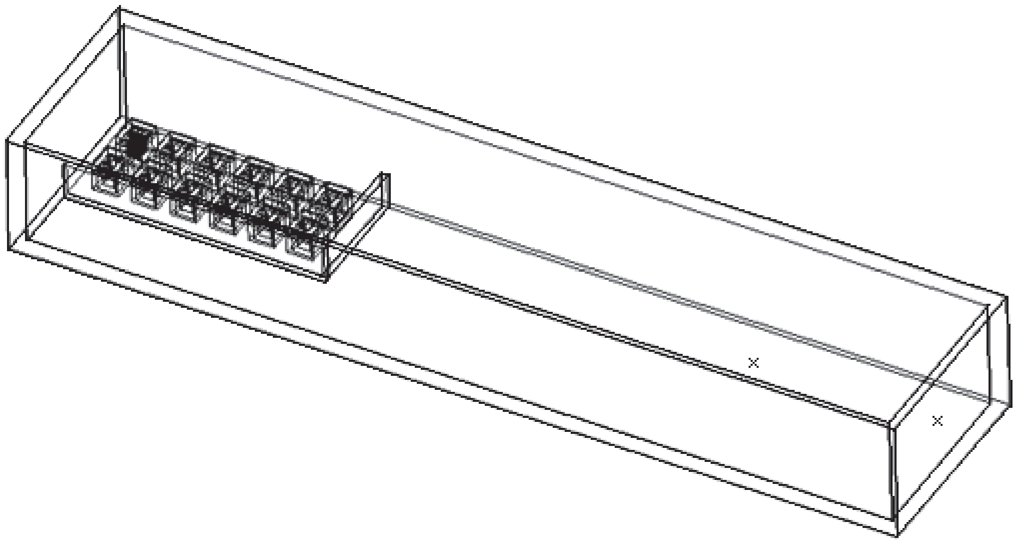
Figure 54: Map of Neutron and Gamma Dose Rates in Control Room A in the Mark I Concept UFPP

7.4 UFTP STORAGE IN THE MARK II CONCEPT

In the Mark I concept, the UFTP storage area is surrounded by 3 m high concrete walls, while the Mark II concept does not include such walls. The potential benefits of adding these concrete walls to the design of Mark II concept have been evaluated, assuming that there are 12 full UFTPs with impact limiters. The exposure configuration is shown in Figure 55.

Dose rates have been calculated with and without concrete walls (3 m high and 0.5 m thick). Because the height of the UFTP shipping and receiving hall is 9 m, these walls protect workers from the direct radiation but do not block all scattered radiation.

Table 28 shows that the walls provide significant protection from photons, while the effect on neutrons, though helpful, is much smaller. Adding walls around the UFTP storage would be a simple solution to decreasing the dose rates in the UFTP shipping and handling hall.



Note: Exposure points (x) at 45 m and 60 m of the center of the UFTP storage are shown.

Figure 55: Model Used for the Mark II Concept UFTP Storage Dose Calculations

Table 28: Dose Rate as a Function of Distance from the UFTP Storage

Distance (m)	Neutron		Gamma		Total Dose Rate (mSv/h)	
	Value	Error (%)	Value	Error (%)	Value	Ratio No Walls/ Walls
Without shielding walls						
1	1.03E-02	0.6	4.74E-03	0.9	1.54E-02	-
5	2.16E-03	1.0	6.14E-04	1.0	2.86E-03	-
10	8.92E-04	1.3	2.29E-04	1.0	1.16E-03	-
45	9.08E-05	1.5	2.06E-05	1.5	1.16E-04	-
60	4.11E-05	1.7	9.55E-06	1.8	5.33E-05	-
With shielding walls (3 m high and 0.5 m thick concrete walls)						
1 *	-	-	-	-	-	-
5	3.33E-04	1.4	1.80E-05	1.9	3.66E-04	7.81
10	2.51E-04	1.5	1.39E-05	1.8	2.77E-04	4.20
45	2.80E-05	1.8	1.60E-06	2.7	3.12E-05	3.73
60	1.17E-05	2.1	6.32E-07	2.8	1.31E-05	4.06

* To facilitate comparison of the results, detectors are placed at the same locations in the two calculations. Since detector at 1 m would be in one of walls, it has not been shown here. Since dispersed radiation is dominant outside the shielding walls, dose rates are similar at several distances around the walls (notice that the dose rates at 5 m and 10 m are quite similar).

Table 29 presents the individual and collective doses to the workers of the UFPP for shielded and unshielded UFTP storages. The table presents only the workers whose individual doses are affected by the characteristics of the UFTP storage (open or shielded), as well as the collective dose in the two cases. The shielded UFTP storage reduces the doses to UFTP shipping and receiving workers and the collective dose due to the operation of the UFPP by roughly a 10%.

As a comparison, the total occupational dose has been estimated with no contribution from the UFTP storage (assuming perfect UFTP storage shielding). The result is that the collective dose is only 1.7 mSv lower than the collective dose calculated with the shielding walls. Therefore, it is recommended that the design of the Mark II concept UFPP include some shielding around the UFTP storage to reduce the ambient dose. A simple design with two walls (3 m high and 0.5 m thick), as shown in Figure 55, is appropriate.

Table 29: Individual (I) and Collective (C) Annual Doses (mSv) to Workers of the Mark II Concept UFPP for Open and Shielded UFTP Storages (220/30 Fuel)

Working Group	Workers		Open UFTP Storage		Shielded UFTP Storage	
	Identification	No.	I	C	I	C
UFTP receiving and shipping	Technician	2	2.3E+01	9.3E+01	2.1E+01	8.2E+01
	OTC operator	1	6.4E+00	1.3E+01	5.7E+00	1.1E+01
Cleaning	Cleaning	2	9.9E-01	3.9E+00	5.7E-01	2.3E+00
Other technicians	Servicing	2	9.9E-01	3.90E+00	5.7E-01	2.3E+00
Other operators and maintenance personnel	Maintenance	8	9.9E-01	1.6E+01	5.7E-01	9.1E+00
Total collective dose in the UFPP (person-mSv)		-		**1.6E+02**		**1.4E+02**

7.5 PLACEMENT METHOD FOR THE MARK I (SEDIMENTARY) CONCEPT

In the UFC placement process for the Mark I (sedimentary) concept, a circular shielding barrier is used to close the tunnel and protect the workers from the nearby UFC placed horizontally on a pedestal of HCB blocks. The shielding barrier has a diameter of 2.25 m, but the diameter of the tunnel is 2.3 m. The current plan is to cover the small annular space around the shielded barrier perimeter with manually placed lead shielding packs to ensure that complete shielding is maintained and that no radiation shine comes around the edges.

Dose calculations for this preliminary ALARA assessment assume that there is no gap between the shielding barrier and the tunnel. However, the task of placing and removing the lead shielding packs are not included in the table of activities.

Calculations have been done to estimate the effect of leaving the gap between the shielding barrier and tunnel open. Results are obtained for the standard shielding barrier (22 cm thick) and a possible alternative design of shielding barrier modified to extend its rim 30 cm along the tunnel adding a 2.5 cm thick piece of carbon steel (this is considered as a potential design modification in order to meet ALARA doses) (Figure 56).

Table 30 shows that for all three cases (no gap, gap with and without rim extension), at a short distance from the shielded barrier, the doses with the gap open and the modified shielding barrier are not much higher than the dose rates without the gap. Individual and collective doses are shown in Table 31.

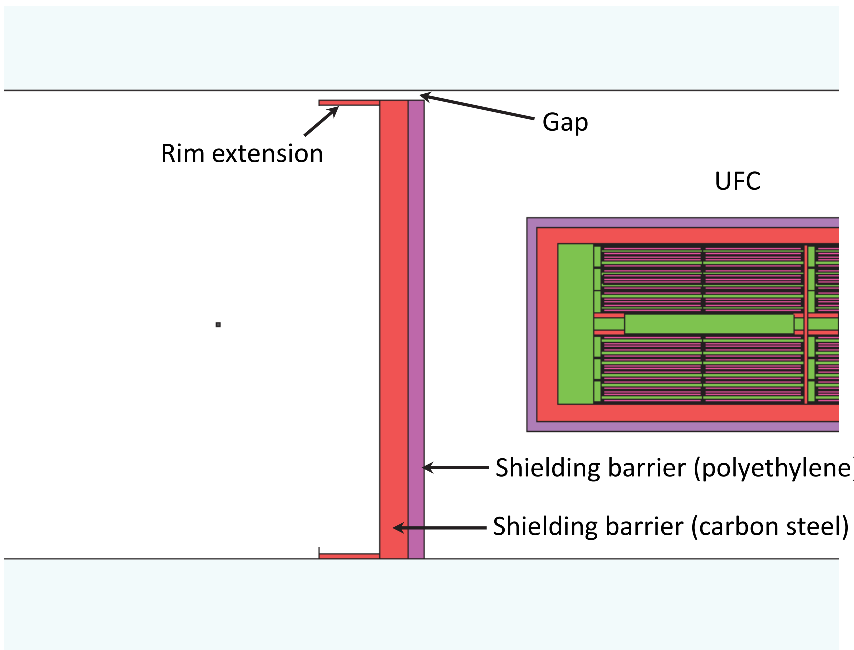


Figure 56: Model of a Disposal Tunnel in Sedimentary Rock Used to Study the Effect of the Gap between the Shielding Barrier and the Tunnel Wall

Table 30: Dose Rates on the Axis of a Placement Room for Different Shielding Configurations (220/30 Fuel)

Distance from UFC (cm)	Neutron		Gamma		Total Dose Rate (mSv/h)	
	Value	Error (%)	Value	Error (%)	Value	Ratio to NO GAP case
NO GAP - Standard Shielding Barrier (22 cm thick)						
1.5	1.81E-04	1.2	2.51E-04	3.8	4.67E-04	-
5.5	2.53E-05	1.5	2.28E-05	3.8	5.18E-05	-
9	7.45E-06	1.4	8.15E-06	3.5	1.68E-05	-
12	3.49E-06	1.4	4.33E-06	3.8	8.46E-06	-
16	1.47E-06	1.6	2.20E-06	3.3	3.96E-06	-
GAP - Standard Shielding Barrier (22 cm thick)						
1.5	3.11E-04	1.9	6.81E-04	7.0	1.15E-03	2.468
5.5	5.51E-05	2.1	2.11E-04	15.6	3.68E-04	7.105

Distance from UFC (cm)	Neutron		Gamma		Total Dose Rate (mSv/h)	
	Value	Error (%)	Value	Error (%)	Value	Ratio to NO GAP case
9	1.83E-05	2.2	9.39E-05	11.4	1.46E-04	8.678
12	8.51E-06	2.5	6.45E-05	19.4	1.11E-04	13.142
16	3.75E-06	3.1	3.23E-05	11.3	4.73E-05	11.962
GAP - Modified Shielding Barrier (22 cm thick + 30 cm rim extension)						
1.5	2.20E-04	2.0	2.91E-04	9.5	6.07E-04	1.300
5.5	3.24E-05	2.1	3.25E-05	8.7	7.54E-05	1.455
9	1.01E-05	2.3	1.57E-05	13.6	3.29E-05	1.962
12	4.63E-06	2.7	1.02E-05	6.9	1.73E-05	2.047
16	2.11E-06	2.8	7.94E-06	4.5	1.13E-05	2.855

Table 31: Individual and Collective Annual Doses to Workers (mSv) of the Mark I (Sedimentary) Concept DGR (220/30 Fuel)

Working Group	Workers		NO GAP	GAP	
	Identification	No.		Standard Shielding Barrier	Modified Shielding Barrier
Underground operations, remote operated steps	Placement cart operator	1	0.0E+00	0.0E+00	0.0E+00
	Shielding door remote operator	1	0.0E+00	0.0E+00	0.0E+00
	Cylinder and ram operator	1	0.0E+00	0.0E+00	0.0E+00
Underground operations, placement room operations	Locomotive driver	1	9.6E-02	1.2E-01	9.8E-02
	Pedestal placement vehicle driver	1	1.5E-02	1.2E-01	2.6E-02
	Technician	2	2.2E-01	5.0E-01	2.7E-01
Underground operations, bentonite installation	Bentonite blowing equipment operator	2	3.0E-02	1.0E-01	4.1E-02
	Measurements and inspection	1	8.2E-03	7.0E-02	1.3E-02
Maintenance, DGR	Maintenance	2	1.0E-03	1.0E-03	1.0E-03
Total collective dose (person-mSv)		**-**	**1.2E+00**	**3.0E+00**	**1.5E+00**

Since the doses in the DGR are controlled by the dose rate at 1.5 m from the shielding barrier, leaving the gap open leads to a 150% of increase in dose rates with the standard shielding barrier and only a 20% of increase with the modified shielding barrier.

The results obtained in this section show that the gap between tunnel and shielding barrier can be left open without incurring significant dose increases, especially if the design of the shielding barrier is optimized to this end. Eliminating the operations of placement/removal of lead shielding packs will simplify the UFC placement procedure. In addition, the doses associated with these tasks (which have not been quantified) will be avoided. In all cases, the collective doses are very small (between 1.2 and 3 person-mSv).

8. SUMMARY AND RECOMMENDATIONS

A preliminary ALARA assessment for the three APM concepts was prepared. The results were based on conservative assumptions and on preliminary concepts, such that they will be updated when a more detailed conceptual design for each concept becomes available or when one of the concepts is advanced forward. This report assesses all activities from receipt in the UFPP to final placement in the repository.

This assessment estimates the individual and collective worker doses from the operation of the UFPP and DGR for the Mark I (crystalline and sedimentary) and Mark II concepts (see Table 20 to Table 24).

These estimates were obtained by:

- Creating Worker Exposure Models. Worker Exposure Models are a breakdown of all the tasks that are required for the operation of the facility and which have the potential to expose workers to radiation. For each task identified, the Worker Exposure Models determine: the number of workers, the type of workers, the distance to the source(s), the exposure duration, the frequency of the exposure and the annual exposure time;
- Identifying a comprehensive set of exposure situations that specify the source, shielding configurations and exposure distances;
- For each of the exposure situations identified, calculating the neutron and gamma dose rates;
- Calculating the annual individual doses to the workers by multiplying the exposure times in the Worker Exposure Models by the corresponding dose rates and summing over all the activities; and
- Calculation of the collective dose by summing the annual individual doses to all workers.

This methodology has been used to obtain preliminary estimates of the individual and collective operational doses for the three APM concepts.

Dose rates in contact with an unshielded UFC are greater than 1 mSv/h both in the Mark I and Mark II concepts, but these UFCs are always inside shielding overpacks in situations where workers are required. These overpacks ensure that dose rates at 1 m are less than 10 μSv/h even for the fuel with 280 MWh/kgU burnup and 10 years of decay.

Dose rates at the accessible face of any structure in the UFPP and DGR are limited to less than 1 mSv/h. The situation with the highest dose rate is that of a worker standing in the UFTP storage area. This dose rate is 0.051 mSv/h for fuel with 220MWh/kgU burnup and 30 years of decay and 0.22 mSv/h for fuel with 280 MWh/kgU burnup and 10 years of decay (Table 11, Table 12, Table 16 and Table 17).

Dose rates in normally occupied areas (such as the control rooms) are always less than 10 μSv/h. When fuel with 220 MWh/kgU burnup and 10 years of decay is processed, dose rates are below 1 μSv/h, while for fuel with 280 Mwh/kgU burnup and 10 years of decay, dose rates are a few μSv/h at most.

The most significant result of the preliminary ALARA assessment is that the workers involved in UFTP receipt have the highest normal dose exposure, and could potentially receive doses above the dose constraint of 10 mSv/year (as introduced in Section 2), even if 220/30 fuel is processed. Doses to these workers would be even higher if 280/10 fuel is processed. This is due in part to the large volume of used fuel to be received and processed at the UFPP (about 3000 metric tons a year). However, the design of the UFTPs, which allow the highest dose rate of any container processed in the facility, is the principal reason for these higher doses.

Since the handling of the UFTP leads to the highest operational doses, a review of the design and operational procedures is recommended. The following should be considered:

- Performing some of the UFTP handling procedures remotely;
- Adding shielding around the UFTP storage area in the Mark II concept. The shielding already included in the Mark I concept is appropriate;
- Modifying the UFTP design, with the objective of lowering dose rates and reducing the need for workers to work in close proximity to it;
- Introducing a worker rotation schedule, such that high dose rate activities are not performed by the same workers year-round; and
- Infrequent use of the UFTP storage area, i.e., routine procedures should not include putting the UFTP in storage.

Although the other UFPP and DGR activities have smaller dose exposures, this preliminary ALARA assessment has also identified some further potential dose reduction techniques (Section 7), notably the use of thicker (1.2 m) concrete walls in the fuel and module handling cells for all three concepts.

Overall, these results indicate that doses can be within applicable dose constraints and as low as reasonably achievable through design measures developed using an iterative design approach and through the use of administrative controls and procedures that will be in place during operation.

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APPENDIX A: WORKER EXPOSURE MODELS FOR MARK I AND MARK II CONCEPTS

CONTENTS

APPENDIX A.1: MARK I WORKER EXPOSURE MODEL

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
UFPP											
MI-1	**Receiving and handling UFTP and fuel modules**										
MI-1.1	Drive transport trailer to airlock (Doses to these workers are not in the ALARA assessment)	1	Driver	UFTP Transport	UFTP	7.5	20	315	6300	5.61E-04	5.89E-02
		1	Co-driver	UFTP Transport	UFTP	7.5	20	315	6300	5.61E-04	5.89E-02
		1	Guard	UFTP Transport	UFTP	7.5	20	315	6300	5.61E-04	5.89E-02
MI-1.2	Inspect UFTP transport vehicle	3	2 Technicians + 1 OTC operator	UFTP shipping and receiving	UFTP	1	30	315	9450	1.54E-02	2.42E+00
MI-1.3	Open weather cover on UFTP transport vehicle	3	2 Technicians + 1 OTC operator	UFTP shipping and receiving	UFTP	1	15	315	4725	1.54E-02	1.21E+00
MI-1.4	Perform smear test	3	2 Technicians + 1 OTC operator	UFTP shipping and receiving	UFTP	1	15	315	4725	1.54E-02	1.21E+00
MI-1.5	Perform pre-lifting inspection	2	Technician	UFTP shipping and receiving	UFTP	1	15	315	4725	1.54E-02	1.21E+00
		1	40 tonne OTC operator	UFTP shipping and receiving	UFTP	5	15	315	4725	1.24E-03	9.79E-02
MI-1.6	Detach tie-downs of (loaded) UFTP	2	Technician	UFTP shipping and receiving	UFTP	1	30	315	9450	1.54E-2	2.43E+00
		1	40 tonne OTC operator	UFTP shipping and receiving	UFTP	5	30	315	9450	1.24E-3	1.95E-01
MI-1.7	Attach of UFTP lifting device (40 tonne OTC)	2	Technician	UFTP shipping and receiving	UFTP	0.5	10	315	3150	2.81E-02	1.48E+00
		1	40 tonne OTC operator	UFTP shipping and receiving	UFTP	5	10	315	3150	1.24E-03	6.53E-02
		2	Technician	UFTP shipping and receiving	UFTP storage	15	10	315	3150	2.05E-04	1.07E-02
		1	40 tonne OTC operator	UFTP shipping and receiving	UFTP storage	15	10	315	3150	2.05E-04	1.07E-02
MI-1.8	Move UFTP into storage with 40 tonne	2	Technician	UFTP shipping and receiving	UFTP	1	20	315	6300	1.54E-02	1.61E+00

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
	OTC (from airlock)	1	40 tonne OTC operator	UFTP shipping and receiving	UFTP	5	20	315	6300	1.24E-03	1.31E-01
		2	Technician	UFTP shipping and receiving	UFTP storage	1	20	315	6300	6.18E-04	6.49E-02
		1	40 tonne OTC operator	UFTP shipping and receiving	UFTP storage	5	20	315	6300	6.87E-04	7.21E-02
MI-1.9	Detach UFTP from OTC in UFTP storage	2	Technician	UFTP shipping and receiving	UFTP storage (inside)	0.5	10	315	3150	5.14E-02	2.70E+00
		1	40 tonne OTC operator	UFTP shipping and receiving	UFTP storage	5	10	315	3150	6.87E-04	3.61E-02
MI-1.10	Attach OTC on UFTP in UFTP storage	2	Technician	UFTP shipping and receiving	UFTP storage (inside)	0.5	10	315	3150	5.14E-02	2.70E+00
		1	40 tonne OTC operator	UFTP shipping and receiving	UFTP storage	5	10	315	3150	6.87E-04	3.61E-02
MI-1.11	Transfer UFTP on a pallet with 40 tonne OTC (either from UFTP storage or from transport trailer) to shipping and receiving work area	2	Technician	UFTP shipping and receiving	UFTP	1	15	315	4725	1.54E-02	1.21E+00
		1	40 tonne OTC operator	UFTP shipping and receiving	UFTP	5	15	315	4725	1.24E-03	9.79E-02
		2	Technician	UFTP shipping and receiving	UFTP storage	1	15	315	4725	6.18E-04	4.87E-02
		1	40 tonne OTC operator	UFTP shipping and receiving	UFTP storage	5	15	315	4725	6.87E-04	5.41E-02
MI-1.12	Detach impact limiter from the UFTP	2	Technician	UFTP shipping and receiving	UFTP	0.5	10	315	3150	2.81E-02	1.48E+00
		1	40 tonne OTC operator	UFTP shipping and receiving	UFTP	5	10	315	3150	1.24E-03	6.53E-02
		2	Technician	UFTP shipping and receiving	UFTP storage	1	10	315	3150	6.18E-04	3.24E-02
		1	40 tonne OTC operator	UFTP shipping and receiving	UFTP storage	5	10	315	3150	6.87E-04	3.61E-02
MI-2	**Vent cell process steps**										
MI-2.1	Remove impact limiter from the UFTP and transfer to the impact limiter storage area	2	Technician	UFTP shipping and receiving	UFTP	1	10	315	3150	1.54E-02	8.06E-01
		1	40 tonne OTC operator	UFTP shipping and receiving	UFTP	5	10	315	3150	1.24E-03	6.53E-02
		2	Technician	UFTP shipping and receiving	UFTP storage	1	10	315	3150	6.18E-04	3.24E-02

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		1	40 tonne OTC operator	UFTP shipping and receiving	UFTP storage	5	10	315	3150	6.87E-04	3.61E-02
MI-2.2	Move pallet with UFTP into the cask vent cell (from UFTP receiving and shipping hall)	1	Vent cell operator, Line 1	Operator Room D	UFTP in Vent cell	1	10	315	3150	7.93E-07	4.16E-05
		1	Vent cell operator, Line 2	Operator Room D	UFTP in Vent cell	1	10	315	3150	7.93E-07	4.16E-05
		1	Vent cell operator, additional	Operator Room D	UFTP in Vent cell	1	10	315	3150	7.93E-07	4.16E-05
MI-2.3	Inspect UFTP	1	Vent cell operator, Line 1	Operator Room D	UFTP in Vent cell	1	20	315	6300	7.93E-07	8.32E-05
		1	Vent cell operator, Line 2	Operator Room D	UFTP in Vent cell	1	20	315	6300	7.93E-07	8.32E-05
		1	Vent cell operator, additional	Operator Room D	UFTP in Vent cell	1	20	315	6300	7.93E-07	8.32E-05
MI-2.4	Vent UFTP	1	Vent cell operator, Line 1	Operator Room D	UFTP in Vent cell	1	10	315	3150	7.93E-07	4.16E-05
		1	Vent cell operator, Line 2	Operator Room D	UFTP in Vent cell	1	10	315	3150	7.93E-07	4.16E-05
		1	Vent cell operator, additional	Operator Room D	UFTP in Vent cell	1	10	315	3150	7.93E-07	4.16E-05
MI-2.5	Remove lid bolts	1	Vent cell operator, Line 1	Operator Room D	UFTP in Vent cell	1	20	315	6300	7.93E-07	8.32E-05
		1	Vent cell operator, Line 2	Operator Room D	UFTP in Vent cell	1	20	315	6300	7.93E-07	8.32E-05
		1	Vent cell operator, additional	Operator Room D	UFTP in Vent cell	1	20	315	6300	7.93E-07	8.32E-05
MI-2.6	Transfer impact limiters from impact limiter storage area back on the UFTP with 40 tonne OTC	2	Technician	UFTP shipping and receiving	UFTP storage	1	10	315	3150	6.18E-04	3.24E-02
		1	40 tonne OTC operator	UFTP shipping and receiving	UFTP storage	5	10	315	3150	6.87E-04	3.61E-02
MI-2.7	Attach impact limiter on the empty UFTP	2	Technician	UFTP shipping and receiving	UFTP storage	1	10	315	3150	6.18E-04	3.24E-02
		1	40 tonne OTC operator	UFTP shipping and receiving	UFTP storage	5	10	315	3150	6.87E-04	3.61E-02

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
MI-3	**Module handling (from UFTP to fuel handling cell)**										
MI-3.1	Attach UFTP lifting device (40 tonne OTC) on the empty UFTP	2	Technician	UFTP shipping and receiving	UFTP storage	1	10	315	3150	6.18E-04	3.24E-02
		1	40 tonne OTC operator	UFTP shipping and receiving	UFTP storage	5	10	315	3150	6.87E-04	3.61E-02
MI-3.2	Transfer empty UFTP from the pallet to storage position, or transport trailer, with 40 tonne OTC	2	Technician	UFTP shipping and receiving	UFTP storage	1	10	315	3150	6.18E-04	3.24E-02
		1	40 tonne OTC operator	UFTP shipping and receiving	UFTP storage	5	20	315	6300	6.87E-04	7.21E-02
MI-3.3	Lift cask with scissor lift integrated in the pallet, open gamma gate and containment door and raise lid into the Module Handling Cell	1	Vent cell operator, Line 1	Operator Room D	none	-	0	-	0	0	0
		1	Vent cell operator, Line 2	Operator Room D	none	-	0	-	0	0	0
		1	Vent cell operator, additional	Operator Room D	none	-	0	-	0	0	0
		3	Module Handling Cell operators, Lines 1, 2 and additional	Operator Room A	Module Handling Cell, Line 1	1	Ambient (Table 8)				
		3	Module Handling Cell operators, Lines 1, 2 and additional	Operator Room A	Module Handling Cell, Line 2	7	Ambient (Table 8)				
		3	Module Handling Cell operators, Lines 1, 2 and additional	Operator Room A	Fuel Handling Cell	1	Ambient (Table 8)				
MI-3.4	Lift top module with the module crane from the UFTP in the module handling cell	3	Module Handling Cell operators, Lines 1, 2 and additional	Operator Room A	Module Handling Cell, Line 1	1	Ambient (Table 8)				
		3	Module Handling Cell operators, Lines 1, 2 and additional	Operator Room A	Module Handling Cell, Line 2	7	Ambient (Table 8)				

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		3	Module Handling Cell operators, Lines 1, 2 and additional	Operator Room A	Fuel Handling Cell	1	Ambient (Table 8)				
MI-3.5	Lift bottom module with the module crane from the UFTP to the module handling cell	3	Module Handling Cell operators, Lines 1, 2 and additional	Operator Room A	Module Handling Cell, Line 1	1	Ambient (Table 8)				
		3	Module Handling Cell operators, Lines 1, 2 and additional	Operator Room A	Module Handling Cell, Line 2	7	Ambient (Table 8)				
		3	Module Handling Cell operators, Lines 1, 2 and additional	Operator Room A	Fuel Handling Cell	1	Ambient (Table 8)				
MI-3.6	Transfer module to the inclined elevator on the module transfer cart with the module crane	3	Module Handling Cell operators, Lines 1, 2 and additional	Operator Room A	Module Handling Cell, Line 1	1	Ambient (Table 8)				
		3	Module Handling Cell operators, Lines 1, 2 and additional	Operator Room A	Module Handling Cell, Line 2	7	Ambient (Table 8)				
		3	Module Handling Cell operators, Lines 1, 2 and additional	Operator Room A	Fuel Handling Cell	1	Ambient (Table 8)				
MI-3.7	Transfer module with the module crane from the inclined elevator to the drying station	3	Module Handling Cell operators, Lines 1, 2 and additional	Operator Room A	Module Handling Cell, Line 1	1	Ambient (Table 8)				
		3	Module Handling Cell operators, Lines 1, 2 and additional	Operator Room A	Module Handling Cell, Line 2	7	Ambient (Table 8)				

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		3	Module Handling Cell operators, Lines 1, 2 and additional	Operator Room A	Fuel Handling Cell	1	Ambient (Table 8)				
MI-3.8	Dry module in the drying station, then transfer out on the transfer cart (normal procedure continues)	3	Module Handling Cell operators, Lines 1, 2 and additional	Operator Room A	Module Handling Cell, Line 1	1	Ambient (Table 8)				
		3	Module Handling Cell operators, Lines 1, 2 and additional	Operator Room A	Module Handling Cell, Line 2	7	Ambient (Table 8)				
		3	Module Handling Cell operators, Lines 1, 2 and additional	Operator Room A	Fuel Handling Cell	1	Ambient (Table 8)				
MI-3.9	Transfer the module transfer cart (with module) through a door into the Fuel Handling Cell.	3	Module Handling Cell operators, Lines 1, 2 and additional	Operator Room A	Module Handling Cell, Line 1	1	Ambient (Table 8)				
		3	Module Handling Cell operators, Lines 1, 2 and additional	Operator Room A	Module Handling Cell, Line 2	7	Ambient (Table 8)				
		3	Module Handling Cell operators, Lines 1, 2 and additional	Operator Room A	Fuel Handling Cell	1	Ambient (Table 8)				
MI-3.10	Lift module and transfer to the fuel handling	2	Fuel Handling Cell operator	Operator Room B	Fuel Handling Cell	1	Ambient (Table 8)				

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
	machine, fuel bundles are removed (two at a time) and inserted into a basket. This process is repeated three times for each UFC, since three modules are required to fill four baskets.	1	Operator, additional	Operator Room B	Fuel Handling Cell	1	Ambient (Table 8)				
MI-3.11	Visually inspect empty module(s) before dispatch to decontamination (to ensure no loose fragments are in the modules)	2	Fuel Handling Cell operator	Operator Room B	Fuel Handling Cell	1	Ambient (Table 8)				
		1	Operator, additional	Operator Room B	Fuel Handling Cell	1	Ambient (Table 8)				
MI-3.12	Transfer empty module from the Fuel Handling Cell to the Waste Management Facility through empty module exit port for decontamination and then dispatch for compaction in an off-site metals recycling facility	3	Decontamination technician	Waste management facility	Empty module (before decontamination)	1	60	630	37800	2.64E-04	1.66E-01
MI-3.13		3	Decontamination technician	Waste management facility	Fuel Handling Cell Docking Station (UFC in shielded frame)	1	90	250	22500	7.64E-06	2.87E-03
MI-4	**UFC processing, exit from fuel handling cell docking station and circulation between processing cells**										
MI-4.1	Transfer baskets into a UFC with the in-cell crane (four baskets in one UFC)	2	Fuel Handling Cell operator	Operator Room B	Fuel Handling Cell	1	Ambient (Table 8)				
		1	Operator, additional	Operator Room B	Fuel Handling Cell	1	Ambient (Table 8)				
MI-4.2	Replace inner vessel lid, close containment	2	Fuel Handling Cell operator	Operator Room B	Fuel Handling Cell	1	Ambient (Table 8)				

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
	door, close gamma gate and undock UFC and lower into the shielded frame in the Fuel Handling Cell Docking Station	1	Operator, additional	Operator Room B	Fuel Handling Cell	1	Ambient (Table 8)				
MI-4.3	Lift empty UFC and sleeve with a 30 tonne OTC from entrance , via filled UFC storage cell into shielded frame waiting in the UFC Entrance and Exit Station in UFC Transfer Area	1	Storage and Decontamination Cell operator	Operator Room C	Filled UFC Storage (ambient)	1	Ambient (Table 8)				
		1	Dispatch operator	Operator Room C	Filled UFC Storage	1	Ambient (Table 8)				
		1	Operator, additional	Operator Room C	Filled UFC Storage	1	Ambient (Table 8)				
MI-4.4	Transfer empty UFC with air-cushioned transporter from the UFC Entrance and Exit Station and through the UFC Transfer Area into the Fuel Handling Cell Docking station	2	Fuel Handling Cell operator	Operator Room B	Fuel Handling Cell	1	Ambient (Table 8)				
		1	Operator, additional	Operator Room B	Fuel Handling Cell	1	Ambient (Table 8)				
MI-4.5	Raise UFC, open gate, remove inner vessel lid and place in the Fuel Handling Cell	2	Fuel Handling Cell operator	Operator Room B	Fuel Handling Cell	1	Ambient (Table 8)				
		1	Operator, additional	Operator Room B	Fuel Handling Cell	1	Ambient (Table 8)				
MI-4.6	Unload three empty baskets from (empty) UFC into the Fuel Handling Cell and place in empty basket positions	2	Fuel Handling Cell operator	Operator Room B	Fuel Handling Cell	1	Ambient (Table 8)				
		1	Operator, additional	Operator Room B	Fuel Handling Cell	1	Ambient (Table 8)				
MI-4.7	Empty basket will be transferred with an in-cell crane for filling with bundles	2	Fuel Handling Cell operator	Operator Room B	Fuel Handling Cell	1	Ambient (Table 8)				
		1	Operator, additional	Operator Room B	Fuel Handling Cell	1	Ambient (Table 8)				

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
MI-4.8	Transfer Filled UFC in the shielded frame from the Fuel Handling Cell Docking Station, through the UFC Transfer Area, to the Inerting Station using an air-cushion transporter	1	Air-cushion transporter operator	UFC Transfer Area	Filled UFC in shielded frame	1	15	250	3750	1.03E-03	6.46E-02
		1	Air-cushion transporter operator, additional	UFC Transfer Area	Filled UFC in shielded frame	1	15	250	3750	1.03E-03	6.46E-02
MI-4.9	Raise UFC from the shielded frame in the Inerting Station, bolt lid, change atmosphere, lower UFC back into the shielded frame	3	Two station operators and an additional operator	Operator Room B	Fuel Handling Cell	20	Ambient (Table 8)				
		3	Two station operators and an additional operator	Operator Room B	Filled UFC Storage	1	Ambient (Table 8)				
		3	Two station operators and an additional operator	Operator Room B	UFC in inerting station	10	300	250	75000	2.37E-07	2.96E-04
MI-4.10	Transfer Filled UFC in the shielded frame from the Inerting Station, through UFC Transfer Area, to the Welding Station using an air-cushion transporter	1	Air-cushion transporter operator	UFC Transfer Area	Filled UFC in shielded frame	1	15	250	3750	1.03E-03	6.46E-02
		1	Air-cushion transporter operator, additional	UFC Transfer Area	Filled UFC in shielded frame	1	15	250	3750	1.03E-03	6.46E-02
MI-4.11	Raise UFC from the shielded frame into the Welding Station, weld, lower UFC back into the shielded frame	3	Two station operators and an additional operator	Operator Room B	Fuel Handling Cell (ambient)	20	Ambient (Table 8)				
		3	Two station operators and an additional operator	Operator Room B	Filled UFC Storage (ambient)	1	Ambient (Table 8)				

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		3	Two station operators and an additional operator	Operator Room B	UFC in Welding Station	7	120	250	30000	2.37E-07	1.19E-04
MI-4.12	Transfer filled UFC in shielded frame from the Welding Station, through UFC Transfer Area, to the Machining station using an air-cushion transporter	1	Air-cushion transporter operator	UFC Transfer Area	Filled UFC in shielded frame	1	15	250	3750	1.03E-03	6.46E-02
		1	Air-cushion transporter operator, additional	UFC Transfer Area	Filled UFC in shielded frame	1	15	250	3750	1.03E-03	6.46E-02
MI-4.13	Raise UFC from the shielded frame in the Machining Station, machine flange the weld area, lower UFC back in the shielded frame	3	Two station operators and an additional operator	Operator Room B	Fuel Handling Cell (ambient)	20	Ambient (Table 8)				
		3	Two station operators and an additional operator	Operator Room B	Filled UFC Storage (ambient)	1	Ambient (Table 8)				
		3	Two station operators and an additional operator	Operator Room B	UFC in Machining Station	7	310	250	77500	2.37E-07	3.06E-04
MI-4.14	Transfer filled UFC in shielded frame from the Machining Station, through UFC Transfer Area, to the NDT station using an air-cushion transporter	1	Air-cushion transporter operator	UFC Transfer Area	Filled UFC in shielded frame	1	15	250	3750	1.03E-03	6.46E-02
		1	Air-cushion transporter operator, additional	UFC Transfer Area	Filled UFC in shielded frame	1	15	250	3750	1.03E-03	6.46E-02
MI-4.15	Raise UFC from the shielded frame into the NDT Station, inspect the weld, lower UFC	3	Two station operators and an additional operator	Operator Room B	Fuel Handling Cell (ambient)	20	Ambient (Table 8)				

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
	back in the shielded frame	3	Two station operators and an additional operator	Operator Room B	Filled UFC Storage (ambient)	1	Ambient (Table 8)				
		3	Two station operators and an additional operator	Operator Room B	UFC in NDT Station	1	340	250	85000	1.01E-06	1.44E-03
MI-4.16	Transfer filled UFC in shielded frame from the NDT Station, through the UFC Transfer Area, to the UFC Entrance and Exit Station using an air-cushion transporter	1	Air-cushion transporter operator	UFC Transfer Area	Filled UFC in shielded frame	1	15	250	3750	1.03E-03	6.46E-02
		1	Air-cushion transporter operator, additional	UFC Transfer Area	Filled UFC in shielded frame	1	15	250	3750	1.03E-03	6.46E-02
MI-5	**UFC transfer into filled UFC storage, decontamination and dispatch airlock**										
MI-5.1	Lift UFC with a 30 tonne OTC out of the shielded frame and from the UFC Entrance and Exit Station into filled UFC storage cell	3	Storage and Decontamination Cell operator, Dispatch operator and additional operator	Operator Room C	Filled UFC Storage (ambient)	1	Ambient (Table 8)				
MI-5.2	Transfer empty sleeve from the now empty shielded frame in the UFC Entrance and Exit Station using the 30 tonne OTC	3	Storage and Decontamination Cell operator, Dispatch operator and additional operator	Operator Room C	Filled UFC Storage (ambient)	1	Ambient (Table 8)				
MI-5.3	Transfer UFC with the 30 tonne OTC from the filled UFC storage to the decontamination cell	3	Storage and Decontamination Cell operator, Dispatch operator and additional operator	Operator Room C	Filled UFC Storage (ambient)	1	Ambient (Table 8)				

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		3	Storage and Decontamination Cell operator, Dispatch operator and additional operator	Operator Room C	Decontamination Cell	1	10	250	2500	4.63E-06	1.93E-04
MI-5.4	Monitor UFC with swipe tests in the decontamination cell and decontaminate	3	Storage and Decontamination Cell operator, Dispatch operator and additional operator	Operator Room C	Filled UFC Storage (ambient)	1	Ambient (Table 8)				
		3	Storage and Decontamination Cell operator, Dispatch operator and additional operator	Operator Room C	Decontamination Cell	1	210	250	52500	4.63E-06	4.05E-03
MI-5.5	UFC lifted with the 30 tonne OTC from the decontamination cell and positioned above a port to the filled UFC dispatch cell (or storage position)	3	Storage and Decontamination Cell operator, Dispatch operator and additional operator	Operator Room C	Filled UFC Storage (ambient)	1	Ambient (Table 8)				
MI-5.6	Remove transfer cask lid bolts at the working platform	1	Dispatch operator	Operator Room C	Filled UFC Storage (ambient)	1	Ambient (Table 8)				
		1	Operator, additional	Operator Room C	Filled UFC Storage (ambient)	1	Ambient (Table 8)				
MI-5.7	Move pallet and transfer cask from the working platform into the filled UFC dispatch cell using air-cushion transporter	1	Dispatch operator	Operator Room C	Filled UFC Storage (ambient)	1	Ambient (Table 8)				
		1	Operator, additional	Operator Room C	Filled UFC Storage (ambient)	1	Ambient (Table 8)				
MI-5.8	Open gamma gate of the UFC dispatch cell	1	Dispatch operator	Operator Room C	Filled UFC Storage (ambient)	1	Ambient (Table 8)				

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
	and remove transfer cask lid using the 30 tonne OTC	1	Operator, additional	Operator Room C	Filled UFC Storage (ambient)	1	Ambient (Table 8)				
MI-6	**UFC in transfer cask handled in dispatch hall and airlock, and dispatch to DGR**										
MI-6.1	Move transfer cask on pallet (with filled UFC) to the working platform in the UFC Dispatch Hall using the air-cushion transporter	2	Technician (empty UFC and copper lid receiving, inspecting and preparing at the same time)	UFC preparation	Filled UFC in Transfer Cask	10	20	250	5000	8.66E-05	7.22E-03
		2	Air-cushion transporter operators	UFC preparation	Filled UFC in Transfer Cask	10	20	250	5000	8.66E-05	7.22E-03
MI-6.2	Bolt lid back onto transfer cask at the working platform	1	Dispatch operator	Operator Room C	Filled UFC Storage	1	Ambient (Table 8)				
		1	Operator, additional	Operator Room C	Filled UFC Storage	1	Ambient (Table 8)				
		2	Technician (empty UFC and copper lid receiving, inspecting and preparing at the same time)	UFC preparation	Filled UFC in transfer cask	15	60	250	15000	4.82E-05	1.21E-02
MI-6.3	Inspect transfer cask at the working platform from sides and ends	2	Technician	UFC Dispatch	UFC in transfer cask (end)	1	7.5	250	1875	4.38E-04	1.37E-02
		2	Technician	UFC Dispatch	UFC in transfer cask (side)	1	7.5	250	1875	1.03E-03	3.23E-02
		1	80 tonne OTC operator	UFC Dispatch	UFC in transfer cask (side)	5	15	250	3750	2.22E-04	1.39E-02
		2	Copper lid receiving, inspecting and preparing, technician	UFC preparation	Filled UFC in transfer cask	15	15	250	3750	4.82E-05	3.01E-03
MI-6.4	Transfer cask is transferred on an awaiting rail wagon in	1	80 tonne OTC operator	UFC Dispatch	Filled UFC in transfer cask in UFC Dispatch Airlock	1	20	250	5000	1.03E-03	8.61E-02

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
	the airlock and tilted horizontally on it using the 80 tonne OTC	2	Technician	UFC Dispatch	Filled UFC in transfer cask in UFC Dispatch Airlock	1	20	250	5000	1.03E-03	8.61E-02
		2	Technician	UFC preparation	Filled UFC in transfer cask in UFC Dispatch Airlock	1	20	250	5000	1.03E-03	8.61E-02
		2	Air-cushion transporter operators	UFC preparation	Filled UFC in transfer cask in UFC Dispatch Airlock	1	20	250	5000	1.03E-03	8.61E-02
MI-6.5	Connect tow vehicle with transfer cask and trolley at UFPP	1	Tow vehicle/ locomotive driver	UFC Dispatch	UFC in transfer cask, exposure from end point	1	7	250	1750	4.38E-04	1.28E-02
MI-6.6	Move trolley with transfer cask to main shaft hoist area	1	Tow vehicle/ locomotive driver	UFC Dispatch	UFC in transfer cask, exposure from end point	1	22	250	5500	4.38E-04	4.01E-02
MI-6.7	Move trolley with transfer cask onto shaft hoist and secure	1	Tow vehicle/ locomotive driver	UFC Dispatch	UFC in transfer cask, exposure from end point	1	7	250	1750	4.38E-04	1.28E-02
		1	Shaft hoist operator	Shaft Operations	UFC in transfer cask	5	7	250	1750	2.22E-04	6.47E-03
MI-7	**Mark I (Crystalline) Placement Room Activities**										
MI-7.1	Unsecure and move trolley with transfer cask out of shaft cage	1	Tow vehicle driver	Underground operations, reloading station	UFC in transfer cask, exposure from end point	1	7	250	1750	4.38E-04	1.28E-02
MI-7.2	Move trolley with transfer cask into reloading hall	1	Tow vehicle driver	Underground operations, reloading station	UFC in transfer cask, exposure from end point	1	14	250	3500	4.38E-04	2.55E-02
MI-7.3	Position trolley with transfer cask in its proper position the reloading station	1	Tow vehicle driver	Underground operations, reloading station	UFC in transfer cask, exposure from end point	1	7	250	1750	4.38E-04	1.28E-02
MI-7.4	Connect bentonite pellet blowing equipment to services	2	Pellet equipment operator	Underground operations, pellet operations	UFC in hole, distance from the borehole edge	1	7	250	1750	1.17E-03	3.42E-02

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		1	Positioning and measurement	Underground operations, pellet operations	UFC in hole, distance from the borehole edge	1	7	250	1750	1.17E-03	3.42E-02
MI-7.5	Blow pellets in the annulus of the buffer rings and UFC and between the buffer rings and borehole wall	2	Pellet equipment operator	Underground operations, pellet operations	UFC in hole, distance from the borehole edge	1	14	250	3500	1.17E-03	6.85E-02
		1	Positioning and measurement	Underground operations, pellet operations	UFC in hole, distance from the borehole edge	1	14	250	3500	1.17E-03	6.85E-02
MI-7.6	Disconnect bentonite pellet blowing equipment from services	2	Pellet equipment operator	Underground operations, pellet operations	UFC in hole, distance from the borehole edge	1	7	250	1750	1.17E-03	3.42E-02
MI-8	**Mark I (Sedimentary) Placement Room Activities**										
MI-8.1	Unsecure and move trolley with transfer cask out of shaft cage	1	Locomotive driver	Underground operations, reloading station	UFC in transfer cask, exposure from end point	1	7	250	1750	4.38E-04	1.28E-02
MI-8.2	Move trolley with transfer cask to the underground storage area or shielding barrier in placement room	1	Locomotive driver	Underground operations, placement room operations	UFC in transfer cask on trolley, end exposure	1	22	250	5500	4.38E-04	4.01E-02
MI-8.3	Connect transfer cask to shielding barrier	1	Shielding door remote operator	Underground operations, remote operated steps	None	-	0	-	0	0	0
		1	Locomotive driver	Underground operations, placement room operations	UFC in transfer cask on trolley, end exposure	1	14	250	3500	4.38E-04	2.55E-02

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
MI-8.4	Disconnect locomotive from trolley for transfer cask in storage	1	Locomotive driver	Underground operations, placement room operations	UFC in transfer cask on trolley, end exposure	1	7	250	1750	4.38E-04	1.28E-02
MI-8.5	Connect transfer cask to services	2	Technician	Underground operations, placement room operations	UFC in transfer cask, end exposure	1	7	250	1750	4.38E-04	1.28E-02
MI-8.6	Connect hydraulic cylinder cart to transfer cask trolley	2	Technician	Underground operations, placement room operations	UFC in transfer cask, end exposure	1	7	250	1750	4.38E-04	1.28E-02
MI-8.7	Connect hydraulic cylinder cart to services	2	Technician	Underground operations, placement room operations	UFC in transfer cask, end exposure	1	7	250	1750	4.38E-04	1.28E-02
MI-8.8	Install coupling between cylinder and ram on transfer cask	2	Technician	Underground operations, placement room operations	UFC in transfer cask, end exposure	1	7	250	1750	4.38E-04	1.28E-02
MI-8.9	Open shielding doors on shielding barrier and transfer cask	2	Technician	Underground operations, placement room operations	UFC in transfer cask, end exposure	1	7	250	1750	4.38E-04	1.28E-02
MI-8.10	Remove coupling between cylinder and ram	2	Technician	Underground operations, placement room operations	UFC behind shielding barrier on pedestal (no outer shielding door), distance to UFC (distance to shielding barrier 1 m)	1.5	7	250	1750	4.67E-04	1.36E-02

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
MI-8.11	Disconnect hydraulic cylinder cart from services	2	Technician	Underground operations, placement room operations	UFC behind shielding barrier on pedestal (no outer shielding door), distance to UFC (distance to shielding barrier 1 m)	1.5	7	250	1750	4.67E-04	1.36E-02
MI-8.12	Disconnect hydraulic cylinder cart from transfer cask trolley	2	Technician	Underground operations, placement room operations	UFC behind shielding barrier on pedestal (no outer shielding door), distance to UFC (distance to shielding barrier 1 m)	1.5	7	250	1750	4.67E-04	1.36E-02
MI-8.13	Connect locomotive to cylinder cart	1	Locomotive driver	Underground operations, placement room operations	UFC behind shielding barrier on pedestal, distance to UFC (distance to shielding barrier 5 m)	5.5	7	250	1750	5.18E-05	1.51E-03
MI-8.14	Disconnect transfer cask from services	2	Technician	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier, distance to UFC (distance to shielding barrier 1 m)	1.5	7	250	1750	4.67E-04	1.36E-02
MI-8.15	Disconnect transfer cask from shielding barrier	2	Technician	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier (without outer shielding door), distance to UFC (distance to shielding barrier 1 m)	1.5	7	250	1750	4.67E-04	1.36E-02
MI-8.16	Connect locomotive to transfer cask trolley	1	Locomotive driver	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier, distance to UFC (distance to shielding barrier 5 m)	5.5	7	250	1750	5.18E-05	1.51E-03

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
MI-8.17	Using pedestal placement trolley move outer shielding door to shielding barrier	1	Pedestal placement vehicle driver	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 5 m)	5.5	22	250	5500	5.18E-05	4.75E-03
MI-8.18	Connect pedestal placement trolley to services	1	Pedestal placement vehicle driver	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 5 m)	5.5	7	250	1750	5.18E-05	1.51E-03
		2	Technician	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 1 m)	1.5	7	250	1750	4.67E-04	1.36E-02
MI-8.19	Attach outer shielding door to shielding barrier	2	Technician	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 1 m)	1.5	36	250	9000	4.67E-04	7.01E-02
MI-8.20	Move pedestal placement trolley	1	Pedestal placement vehicle driver	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 8.5 m)	9	7	250	1750	1.68E-05	4.89E-04
MI-8.21	Extend gantry crane beam and legs	3	1 Pedestal placement vehicle driver, 2 technicians	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 8.5 m)	9	7	250	1750	1.68E-05	4.89E-04

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
MI-8.22	Lift rails and bottom plate into cart	3	1 Pedestal placement vehicle driver, 2 technicians	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 8.5 m)	9	36	250	9000	1.68E-05	2.52E-03
MI-8.23	Retract beam and legs	3	1 Pedestal placement vehicle driver, 2 technicians	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 5 m)	9	7	250	1750	1.68E-05	4.89E-04
MI-8.24	Disconnect pedestal placement trolley from services	3	1 Pedestal placement vehicle driver, 2 technicians	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 8.5 m)	9	7	250	1750	1.68E-05	4.89E-04
MI-8.25	Connect pedestal placement trolley to services	3	1 Pedestal placement vehicle driver, 2 technicians	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 8.5 m)	9	7	250	1750	1.68E-05	4.89E-04
MI-8.26	Extend gantry beam and legs	3	1 Pedestal placement vehicle driver, 2 technicians	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 8.5 m)	9	7	250	1750	1.68E-05	4.89E-04
MI-8.27	Place pedestal	3	1 Pedestal placement vehicle driver, 2 technicians	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 8.5 m)	9	29	250	7250	1.68E-05	2.03E-03

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		1	Measurements and inspection	Underground operations, bentonite installation	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 5 m)	5.5	29	250	7250	5.18E-05	6.26E-03
MI-8.28	Retract beam and legs	1	Pedestal placement vehicle driver	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 8.5 m)	9	7	250	1750	1.68E-05	4.89E-04
MI-8.29	Disconnect pedestal placement trolley from services	3	1 Pedestal placement vehicle driver, 2 technicians	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 8.5 m)	9	7	250	1750	1.68E-05	4.89E-04
MI-8.30	Move bentonite blowing equipment cart to shielding barrier	1	Locomotive driver	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier from 15.5 m)	16	36	250	9000	3.96E-06	5.94E-04
		2	Bentonite blowing equipment operators	Underground operations, bentonite installation	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 11.5 m)	12	36	250	9000	8.46E-06	1.27E-03
MI-8.31	Connect bentonite blowing equipment to shielding barrier	2	Bentonite blowing equipment operators	Underground operations, bentonite installation	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (about next to shielding barrier)	1.5	14	250	3500	4.67E-04	2.72E-02

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
MI-8.32	Connect bentonite blowing equipment to services	2	Bentonite blowing equipment operators	Underground operations, bentonite installation	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 11.5 m)	12	14	250	3500	8.46E-06	4.94E-04
MI-8.33	Blow in bentonite pellets	2	Bentonite blowing equipment operators	Underground operations, bentonite installation	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 11.5 m)	12	14	250	3500	8.46E-06	4.94E-04
		1	Measurements and inspection	Underground operations, bentonite installation	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 11.5 m)	12	14	250	3500	8.46E-06	4.94E-04
MI-8.34	Connect locomotive to shielding barrier with cable	1	Locomotive driver	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier changes)	16	7	250	1750	3.96E-06	1.15E-04
MI-8.35	Move barrier and placement cart to pedestal	1	Locomotive driver	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier changes)	16	7	250	1750	3.96E-06	1.15E-04
MI-8.36	Continue blowing bentonite pellets	2	Bentonite blowing equipment operators	Underground operations, bentonite installation	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 11.5 m)	12	14	250	3500	8.46E-06	4.94E-04

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		1	Measurements and inspection	Underground operations, bentonite installation	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 11.5 m)	12	14	250	3500	8.46E-06	4.94E-04
MI-8.37	Move shielding barrier and UFC placement cart over pedestal	1	Locomotive driver	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier changes)	16	7	250	1750	3.96E-06	1.15E-04
MI-8.38	Continue blowing bentonite pellets	2	Bentonite blowing equipment operators	Underground operations, bentonite installation	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 11.5 m)	12	14	250	3500	8.46E-06	4.94E-04
		1	Measurements and inspection	Underground operations, bentonite installation	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 11.5 m)	12	14	250	3500	8.46E-06	4.94E-04
MI-8.39	Move shielding barrier and UFC placement cart into Position	1	Locomotive driver	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier changes)	16	7	250	1750	3.96E-06	1.15E-04
MI-8.40	Continue blowing bentonite pellets	2	Bentonite blowing equipment operators	Underground operations, bentonite installation	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 11.5 m)	12	14	250	3500	8.46E-06	4.94E-04

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		1	Measurements and inspection	Underground operations, bentonite installation	UFC on pedestal, behind shielding barrier and outer shielding door, distance to UFC (distance to shielding barrier 11.5 m)	12	14	250	3500	8.46E-06	4.94E-04
MI-8.41	Disconnect bentonite blowing equipment from shielding barrier	2	Bentonite blowing equipment operators	Underground operations, bentonite installation	UFC on pedestal, behind shielding barrier and outer shielding door, in bentonite pellet fill, distance to UFC (distance to shielding barrier 4 m)	12	14	250	3500	6.90E-06	4.03E-04
MI-8.42	Disconnect bentonite blowing equipment from services	2	Bentonite blowing equipment operators	Underground operations, bentonite installation	UFC on pedestal, behind shielding barrier and outer shielding door, in bentonite pellet fill, distance to UFC (distance to shielding barrier 4 m)	12	7	250	1750	6.90E-06	2.01E-04
MI-8.43	Move trolley to shielding barrier	1	Locomotive driver	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, in bentonite pellet fill, distance to UFC (distance to shielding barrier 4 m)	12	22	250	5500	6.90E-06	6.33E-04
MI-8.44	Remove pedestal shielding box and outer shielding door and load onto trolley	1	Locomotive driver	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, in bentonite pellet fill, distance to UFC (distance to shielding barrier 4 m)	12	14	250	3500	6.90E-06	4.03E-04

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		2	Technician	Underground operations, placement room operations	UFC on pedestal, behind shielding barrier and outer shielding door, in bentonite pellet fill, distance to UFC (distance to shielding barrier 4 m)	12	14	250	3500	6.90E-06	4.03E-04
Mi-9	**Mark I Support Activities (Cleaning, Maintenance, Service) (numbers in activity place refer to exposure points in Figures 34, 35 or 36)**										
MI-9.1	Operator Room A	8	2 cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	Module Handling Cell, Line 1	1	23	250	5625	4.89E-04	4.58E-02
		8	2 cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	Module Handling Cell, Line 2	7	23	250	5625		
		8	2 cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	Fuel Handling Cell	1	23	250	5625		
MI-9.2	Operator Room B	8	2 cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	Fuel Handling Cell (ambient)	20	23	250	5625	2.00E-04	1.88E-02
		8	2 cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	Filled UFC Storage (ambient)	1	23	250	5625	4.80E-05	4.50E-03
		8	2 cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	1 of 4 UFC handling stations with UFC in processing	1	23	250	5625	1.01E-06	9.47E-05
MI-9.3	Operator Room C	8	2 cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	Filled UFC Storage	1	23	250	5625	1.09E-05	1.02E-03

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		8	2 cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	Decontamination Cell	1	23	250	5625	4.63E-06	4.34E-04
MI-9.4	Operator Room D	8	2 cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	UFTP in Vent Cell	1	23	250	5625	7.93E-07	7.43E-05
MI-9.5	Supply Systems Rooms	8	2 cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	Filled UFC Storage	3	2	250	563	3.98E-06	3.73E-05
		8	2 cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	UFC in handling cell (machining or NDT)	1	2	250	563	7.64E-06	7.16E-05
MI-9.6	Empty UFC Preparation Area	8	2 Cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	UFC in transfer cask	15	20	250	5000	4.82E-05	4.02E-03
MI-9.7	Empty Basket Storage Area	8	2 Cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	none	-	0	-	0	0	0
MI-9.8	Empty UFC Storage Area	8	2 cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	Filled UFC Storage	1	23	250	5625	1.28E-05	1.20E-03
MI-9.9	UFC Dispatch Hall	8	2 cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	Filled UFC in shielded frame behind wall	1	2	250	563	7.64E-06	7.16E-05
MI-9.10	UFC Dispatch Airlock	8	2 cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	none	-	0	-	0	0	0

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
MI-9.11	Waste Management Facility	8	2 cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	Fuel Handling Station Docking Station with filled UFC in Shielded frame	1	2	250	563	7.64E-06	7.16E-05
MI-9.12	UFTP Receiving and Shipping Hall	8	2 cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	UFTP storage	5	23	250	5625	6.87E-04	6.44E-02
MI-9.13	Empty UFC Transport Airlock	8	2 cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	none	-	0	-	0	0.00E+00	0.00E+00
MI-9.14	UFTP Receiving Hall Airlock	8	2 cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	UFTP storage	15	23	250	5625	2.05E-04	1.92E-02
MI-9.15	Hallways, Operation level	8	2 cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	Module Handling Cell	1	23	250	5625	2.92E-05	2.74E-03
MI-9.16	Operator room B, fuel handling side of the room.	8	2 cleaning, 4 maintenance, 2 servicing	Cleaning, maintenance, servicing; UFPP	Fuel Handling Cell	1	23	250	5625	2.00E-04	1.88E-02
MI-10	**Mark I (Crystalline) Maintenance in Placement Room**										
MI-10.1	Maintenance activities in Reloading Station	2	Maintenance	Maintenance, Reloading Station	Reloading station, UFC in transport cask	5	54	250	13500	2.22E-04	4.99E-02
MI-10.2	Maintenance activities in Reloading Station	2	Maintenance	Maintenance, Reloading Station	Reloading station, UFC in placement vehicle radiation shield	5	21	250	5250	2.22E-04	1.94E-02
MI-10.3	Maintenance activities in underground, tunnel near placement rooms that are in use	2	Maintenance	Maintenance, DGR	Exposure to UFC in placement vehicle radiation shield drives by (twice a day/5 min each time)	5	10	250	2500	2.22E-04	9.24E-03

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total* Dose
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
MI-11	**Mark I (Sedimentary) Maintenance in Placement Room**										
MI-11.1	Underground maintenance in tunnels near placement rooms that are in use	2	Maintenance	Maintenance, DGR	Exposure to UFC in transfer cask when transported in placement room (twice a day/5 min each time)	5	10	250	2500	2.22E-04	9.25E-3

* Dose rates and doses are for 220/30 fuel.

APPENDIX A.2: MARK II WORKER EXPOSURE MODEL

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
UFPP											
MII-1	**Receiving and handling UFTP and fuel modules**										
MII-1.1	Drive transport trailer to airlock (Doses to these workers are not in the ALARA assessment)	1	Driver	UFTP transport	UFTP	7.5	20	315	6300	5.61E-04	5.89E-02
		1	Co-driver	UFTP transport	UFTP	7.5	20	315	6300	5.61E-04	5.89E-02
		1	Guard	UFTP transport	UFTP	7.5	20	315	6300	5.61E-04	5.89E-02
MII-1.2	Inspect UFTP transport vehicle	3	2 Technicians + 1 OTC	Shipping and receiving UFTP	UFTP	1	30	315	9450	1.54E-02	2.42E+00
MII-1.3	Open weather cover on UFTP transport vehicle	3	2 Technicians + 1 OTC	Shipping and receiving UFTP	UFTP	1	15	315	4725	1.54E-02	1.21E+00
MII-1.4	Perform smear test	3	2 Technicians + 1 OTC	Shipping and receiving UFTP	UFTP	1	15	315	4725	1.54E-02	1.21E+00
MII-1.5	Perform pre-lifting inspection	2	Technician	Shipping and receiving UFTP	UFTP	1	15	315	4725	1.54E-02	1.21E+00
		1	Crane operator	Shipping and receiving UFTP	UFTP	5	15	315	4725	1.24E-03	9.79E-02
MII-1.6	Detach tie-downs of (loaded) UFTP	2	Technician	Shipping and receiving UFTP	UFTP	1	30	315	9450	1.54E-02	2.42E+00
		1	Crane operator	Shipping and receiving UFTP	UFTP	5	30	315	9450	1.24E-03	1.96E-01
MII-1.7	Attach UFTP to OTC lifting device	2	Technician	Shipping and receiving UFTP	UFTP	0.5	10	315	3150	2.81E-02	1.48E+00
		1	Crane operator	Shipping and receiving UFTP	UFTP	5	10	315	3150	1.24E-03	6.53E-02
		2	Technician	Shipping and receiving UFTP	UFTP storage	45	10	315	3150	1.16E-04	6.11E-03
		1	Crane operator	Shipping and receiving UFTP	UFTP storage	45	10	315	3150	1.16E-04	6.11E-03
MII-2	**UFTP activities, UFTP Receiving and Shipping Hall**										
MII-2.1	Move UFTP from transport trailer to	2	Technician	Shipping and receiving UFTP	UFTP	1	20	315	6300	1.54E-02	1.61E+00

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
	UFTP storage using OTC	1	Crane operator	Shipping and receiving UFTP	UFTP	5	20	315	6300	1.24E-03	1.31E-01
		2	Technician	Shipping and receiving UFTP	UFTP storage	1	20	315	6300	1.54E-02	1.61E+00
		1	Crane operator	Shipping and receiving UFTP	UFTP storage	5	20	315	6300	2.86E-03	3.00E-01
MII-2.2	Detaching UFTP from OTC in UFTP storage	2	Technician	Shipping and receiving UFTP	UFTP storage (inside)	0.5	10	315	3150	5.14E-02	2.70E+00
		1	Crane operator	Shipping and receiving UFTP	UFTP storage	5	10	315	3150	2.86E-03	1.50E-01
MII-2.3	Attaching UFTP on OTC in UFTP storage	2	Technician	Shipping and receiving UFTP	UFTP storage (inside)	0.5	10	315	3150	5.14E-02	2.70E+00
		1	Crane operator	Shipping and receiving UFTP	UFTP storage	5	10	315	3150	2.86E-03	1.50E-01
MII-2.4	Move UFTP from storage to transfer cart using OTC	2	Technician	Shipping and receiving UFTP	UFTP	1	15	315	4725	1.54E-02	1.21E+00
		1	Crane operator	Shipping and receiving UFTP	UFTP	5	15	315	4725	1.24E-03	9.79E-02
		2	Technician	Shipping and receiving UFTP	UFTP storage	1	15	315	4725	1.54E-02	1.21E+00
		1	Crane operator	Shipping and receiving UFTP	UFTP storage	5	15	315	4725	2.86E-03	2.25E-01
MII-2.5	Manually remove impact limiter with the assistance of the OTC	2	Technician	Shipping and receiving UFTP	UFTP	0.5	10	315	3150	2.81E-02	1.48E+00
		1	Crane operator	Shipping and receiving UFTP	UFTP	5	10	315	3150	1.24E-03	6.53E-02
		2	Technician	Shipping and receiving UFTP	UFTP storage	60	10	315	3150	5.33E-05	2.80E-03
		1	Crane operator	Shipping and receiving UFTP	UFTP storage	60	10	315	3150	5.33E-05	2.80E-03
MII-2.6	Manually transfer the impact limiter to the storage area with assistance of the OTC	2	Technician	Shipping and receiving UFTP	UFTP	1	10	315	3150	1.54E-02	8.06E-01
		1	Crane operator	Shipping and receiving UFTP	UFTP	5	10	315	3150	1.24E-03	6.53E-02
		2	Technician	Shipping and receiving UFTP	UFTP storage	60	10	315	3150	5.33E-05	2.80E-03
		1	Crane operator	Shipping and receiving UFTP	UFTP storage	60	10	315	3150	5.33E-05	2.80E-03

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
MII-3	**UFTP activities, vent cell**										
MII-3.1	Move the transfer cart into the cask vent cell	2	Operator, control room #1	UFTP handling and module handling	Vent cell	1	10	157.5	1575	7.93E-07	2.08E-05
		2	Operator, control room #2	UFTP handling and module handling	Vent cell	1	10	157.5	1575	7.93E-07	2.08E-05
		2	Operator, control room #1	UFTP handling and module handling	dry storage (ambient)	1	480	250	120000	5.74E-04	1.15E+00
		2	Operator, control room #2	UFTP handling and module handling	dry storage (ambient)	1	480	250	120000	5.74E-04	1.15E+00
MII-3.2	Inspect UFTP	2	Operator, control room #1	UFTP handling and module handling	Vent cell	1	20	157.5	3150	7.93E-07	4.16E-05
		2	Operator, control room #2	UFTP handling and module handling	Vent cell	1	20	157.5	3150	7.93E-07	4.16E-05
		2	Operator, control room #1	UFTP handling and module handling	dry storage (ambient)	1	Ambient (Table 10)				
		2	Operator, control room #2	UFTP handling and module handling	dry storage (ambient)	1	Ambient (Table 10)				
MII-3.3	Vent UFTP	2	Operator, control room #1	UFTP handling and module handling	Vent cell	1	10	157.5	1575	7.93E-07	2.08E-05
		2	Operator, control room #2	UFTP handling and module handling	Vent cell	1	10	157.5	1575	7.93E-07	2.08E-05
		2	Operator, control room #1	UFTP handling and module handling	dry storage (ambient)	1	Ambient (Table 10)				
		2	Operator, control room #2	UFTP handling and module handling	dry storage (ambient)	1	Ambient (Table 10)				
MII-3.4	Remove lid bolts	2	Operator, control room #1	UFTP handling and module handling	Vent cell	1	20	157.5	3150	7.93E-07	4.16E-05
		2	Operator, control room #2	UFTP handling and module handling	Vent cell	1	20	157.5	3150	7.93E-07	4.16E-05
		2	Operator, control room #1	UFTP handling and module handling	dry storage (ambient)	1	Ambient (Table 10)				
		2	Operator, control room #2	UFTP handling and module handling	dry storage (ambient)	1	Ambient (Table 10)				
MII-3.5	Move UFTP to transfer position and open interface to module handling cell	2	Operator, control room #1	UFTP handling and module handling	Vent cell	1	10	157.5	1575	7.93E-07	2.08E-05
		2	Operator, control room #2	UFTP handling and module handling	Vent cell	1	10	157.5	1575	7.93E-07	2.08E-05
		2	Operator, control room #1	UFTP handling and module handling	dry storage (ambient)	1	Ambient (Table 10)				

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		2	Operator, control room #2	UFTP handling and module handling	dry storage (ambient)	1	Ambient (Table 10)				
MII-3.6	Remove UFTP lid	2	Operator, control room #1	UFTP handling and module handling	Vent cell	1	15	157.5	2362.5	7.93E-07	3.12E-05
		2	Operator, control room #2	UFTP handling and module handling	Vent cell	1	15	157.5	2362.5	7.93E-07	3.12E-05
		2	Operator, control room #1	UFTP handling and module handling	dry storage (ambient)	1	Ambient (Table 10)				
		2	Operator, control room #2	UFTP handling and module handling	dry storage (ambient)	1	Ambient (Table 10)				
MII-3.7	Replace UFTP lid	2	Operator, control room #1	UFTP handling and module handling	None	-	15	250	-	-	-
		2	Operator, control room #2	UFTP handling and module handling	None	-	15	250	-	-	-
		2	Operator, control room #1	UFTP handling and module handling	dry storage (ambient)	1	Ambient (Table 10)				
		2	Operator, control room #2	UFTP handling and module handling	dry storage (ambient)	1	Ambient (Table 10)				
MII-4	**Empty UFTP activities**										
MII-4.1	Close access to module handling cell and move empty UFTP to the vent cell	2	Operator, control room #1	UFTP handling and module handling	dry storage (ambient)	1	Ambient (Table 10)				
		2	Operator, control room #2	UFTP handling and module handling	dry storage (ambient)	1	Ambient (Table 10)				
MII-4.2	Measure contamination of the empty UFTP, decontaminate if required, and attach lid bolts on empty UFTP	2	Operator, control room #1	UFTP handling and module handling	dry storage (ambient)	1	Ambient (Table 10)				
		2	Operator, control room #2	UFTP handling and module handling	dry storage (ambient)	1	Ambient (Table 10)				
MII-4.3	Transfer empty UFTP from vent cell to the shipping and receiving hall	2	Operator, control room #1	UFTP handling and module handling	dry storage (ambient)	1	Ambient (Table 10)				
		2	Operator, control room #2	UFTP handling and module handling	dry storage (ambient)	1	Ambient (Table 10)				
MII-4.4	Transfer impact limiter from storage back to the empty UFTP	2	Technician	Shipping and receiving UFTP	UFTP storage	60	10	315	3150	5.33E-05	2.80E-03
		1	Crane operator	Shipping and receiving UFTP	UFTP storage	60	10	315	3150	5.33E-05	2.80E-03

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
MII-4.5	Attach impact limiter on empty UFTP	2	Technician	Shipping and receiving UFTP	UFTP storage	60	10	315	3150	5.33E-05	2.80E-03
		1	Crane operator	Shipping and receiving UFTP	UFTP storage	60	10	315	3150	5.33E-05	2.80E-03
MII-4.6	Attach OTC lifting device on the empty UFTP	2	Technician	Shipping and receiving UFTP	UFTP storage	60	10	315	3150	5.33E-05	2.80E-03
		1	Crane operator	Shipping and receiving UFTP	UFTP storage	60	10	315	3150	5.33E-05	2.80E-03
MII-4.7	Transfer empty UFTP to storage area position or to transport trailer	2	Technician	Shipping and receiving UFTP	UFTP storage	60	30	315	9450	5.33E-05	8.39E-03
		1	Crane operator	Shipping and receiving UFTP	UFTP storage	60	30	315	9450	5.33E-05	8.39E-03
MII-5	**Module distribution**										
MII-5.1	Unload upper module with crane to module handling cell in upper level	1	Operator, operator room #1	UFTP handling and module handling	Module handling cell (ambient)	1	480	250	120000	4.86E-04	9.72E-01
		1	Operator, operator room #2	UFTP handling and module handling	Module handling cell (ambient)	1	480	250	120000	4.86E-04	9.72E-01
		1	Operator, operator room #1	UFTP handling and module handling	Fuel handling cell (ambient)	10	480	250	120000	0.00E+00	0.00E+00
		1	Operator, operator room #2	UFTP handling and module handling	Fuel handling cell (ambient)	10	480	250	120000	0.00E+00	0.00E+00
MII-5.2	Unload lower module with crane to module handling cell in upper level	1	Operator, operator room #1	UFTP handling and module handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Operator, operator room #2	UFTP handling and module handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Operator, operator room #1	UFTP handling and module handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Operator, operator room #2	UFTP handling and module handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
MII-5.3	Transfer module from lay down area to transfer cart	1	Operator, operator room #1	UFTP handling and module handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Operator, operator room #2	UFTP handling and module handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Operator, operator room #1	UFTP handling and module handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Operator, operator room #2	UFTP handling and module handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Operator, operator room #1	UFTP handling and module handling	Module handling cell (ambient)	1	Ambient (Table 10)				

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
MII-5.4	Move transfer cart from module handling cell to distribution hall	1	Operator, operator room #2	UFTP handling and module handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Operator, operator room #1	UFTP handling and module handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Operator, operator room #2	UFTP handling and module handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
MII-5.5	Exchange module in distribution hall (full module / empty module)	1	Operator, operator room #1	UFTP handling and module handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Operator, operator room #2	UFTP handling and module handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Operator, operator room #1	UFTP handling and module handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Operator, operator room #2	UFTP handling and module handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
MII-6	**Transfer fuel from modules to baskets**										
MII-6.1	Receive full module from distribution hall	1	Fuel handling operator, operator room #1	Fuel handling and basket handling	Module handling cell (ambient)	1	480	250	120000	4.86E-04	9.72E-01
		1	Fuel handling operator, operator room #2	Fuel handling and basket handling	Module handling cell (ambient)	1	480	250	120000	4.86E-04	9.72E-01
		1	Fuel handling operator, control room #3	Fuel handling and basket handling	Module handling cell (ambient)	1	480	250	120000	4.86E-04	9.72E-01
		1	Fuel handling operator, operator room #1	Fuel handling and basket handling	Fuel handling cell (ambient)	10	480	250	120000	0.00E+00	0.00E+00
		1	Fuel handling operator, operator room #2	Fuel handling and basket handling	Fuel handling cell (ambient)	10	480	250	120000	0.00E+00	0.00E+00
		1	Fuel handling operator, control room #3	Fuel handling and basket handling	Fuel handling cell (ambient)	10	480	250	120000	0.00E+00	0.00E+00
MII-6.2	Transfer bundles from modules to baskets (96 bundles in module, enough to fill two	1	Fuel handling operator, operator room #1	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, operator room #2	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
	baskets) (10 min operation / bundle, calculated as a continuous operation)	1	Fuel handling operator, control room #3	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Floating operator in hallway	Fuel handling and basket handling	Module handling cell (ambient)	10	480	250	120000	0.00E+00	0.00E+00
		1	Fuel handling operator, operator room #1	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Fuel handling operator, operator room #2	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Fuel handling operator, control room #3	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Floating operator in hallway	Fuel handling and basket handling	Fuel handling cell (ambient)	1	480	250	120000	2.89E-04	5.78E-01
MII-6.3	Transfer empty module To distribution hall	1	Fuel handling operator, operator room #1	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, operator room #2	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, control room #3	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, operator room #1	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Fuel handling operator, operator room #2	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Fuel handling operator, control room #3	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
MII-7	**Receiving UFC and extracting the basket for loading with fuel bundles**										
MII-7.1	Receive and transfer empty UFC to the upper	1	Fuel handling operator, operator room #1	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
	level access port	1	Fuel handling operator, operator room #2	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, control room #3	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, operator room #1	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Fuel handling operator, operator room #2	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Fuel handling operator, control room #3	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
MII-7.2	Remove hemispherical head	1	Fuel handling operator, operator room #1	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, operator room #2	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, control room #3	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, operator room #1	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Fuel handling operator, operator room #2	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Fuel handling operator, control room #3	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
MII-7.3	Transfer basket from UFC to the positioning worktable	1	Fuel handling operator, operator room #1	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, operator room #2	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		1	Fuel handling operator, control room #3	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, operator room #1	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Fuel handling operator, operator room #2	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Fuel handling operator, control room #3	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
MII-7.4	Transfer basket from positioning worktable back into the UFC	1	Fuel handling operator, operator room #1	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, operator room #2	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, control room #3	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, operator room #1	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Fuel handling operator, operator room #2	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Fuel handling operator, control room #3	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
MII-7.5	Install hemispherical head	1	Fuel handling operator, operator room #1	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, operator room #2	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, control room #3	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		1	Fuel handling operator, operator room #1	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Fuel handling operator, operator room #2	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Fuel handling operator, control room #3	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
MII-7.6	Transfer of the UFC to the ground level	1	Fuel handling operator, operator room #1	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, operator room #2	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, control room #3	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, operator room #1	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Fuel handling operator, operator room #2	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Fuel handling operator, control room #3	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
MII-7.7	Flask exchange at the transfer hall	1	Fuel handling operator, operator room #1	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, operator room #2	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, control room #3	Fuel handling and basket handling	Module handling cell (ambient)	1	Ambient (Table 10)				
		1	Fuel handling operator, operator room #1	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		1	Fuel handling operator, operator room #2	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
		1	Fuel handling operator, control room #3	Fuel handling and basket handling	Fuel handling cell (ambient)	10	Ambient (Table 10)				
MII-8	**Empty UFC activities (two parallel cells)**										
MII-8.1	Transfer marked and qualified UFC assembly** on a cart to the processing area loading station	3	Technician, empty UFC receiving group (at air lock)	Empty UFC receiving and preparation	Decontamination cells	10	20	750	15000	1.62E-06	4.05E-04
MII-8.2	Open the shielding door (A UFC transfer flask has already been docked opposite the loading site, on the other side of the shielding door)	3	Technician, empty UFC receiving group (at air lock)	Empty UFC receiving and preparation	Decontamination cells	10	20	750	15000	1.62E-06	4.05E-04
MII-8.3	Grip the UFC assembly using an overhead inter-airlock trolley and transfer into the loading area.	3	Technician, empty UFC receiving group (in transfer hall)	Empty UFC receiving and preparation	UFC transfer to baskets handling cells	10	10	750	7500	0	0
		3	Technician, empty UFC receiving group (in transfer hall)	Empty UFC receiving and preparation	Decontamination cells	15	10	750	7500	1.62E-06	2.02E-04
		3	Technician, empty UFC receiving group (in transfer hall)	Empty UFC receiving and preparation	Buffer area (ambient)	50	480	250	120000	5.94E-07	1.19E-03
		3	Technician, empty UFC receiving group (in transfer hall)	Empty UFC receiving and preparation	UFC Processing cells (ambient)	60	480	250	120000	8.89E-08	1.78E-04

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
MII-8.4	Lower the UFC assembly onto the trolley and retract the inter-airlock trolley	3	Technician, empty UFC receiving group (in transfer hall)	Empty UFC receiving and preparation	UFC transfer to baskets handling cells	10	5	750	3750	0	0
		3	Technician, empty UFC receiving group (in transfer hall)	Empty UFC receiving and preparation	Decontamination cells	15	5	750	3750	1.62E-06	1.01E-04
		3	Technician, empty UFC receiving group (in transfer hall)	Empty UFC receiving and preparation	Buffer area (ambient)	50	Ambient (Table 10)				
		3	Technician, empty UFC receiving group (in transfer hall)	Empty UFC receiving and preparation	UFC Processing cells (ambient)	60	Ambient (Table 10)				
MII-8.5	Close the shielding door and open the UFC processing shielding door	3	Technician, empty UFC receiving group (in transfer hall)	Empty UFC receiving and preparation	UFC transfer to baskets handling cells	10	5	750	3750	0	0
		3	Technician, empty UFC receiving group (in transfer hall)	Empty UFC receiving and preparation	Decontamination cells	15	5	750	3750	1.62E-06	1.01E-04
		3	Technician, empty UFC receiving group (in transfer hall)	Empty UFC receiving and preparation	Buffer area (ambient)	50	Ambient (Table 10)				
		3	Technician, empty UFC receiving group (in transfer hall)	Empty UFC receiving and preparation	UFC Processing cells (ambient)	60	Ambient (Table 10)				
MII-8.6	Retract the flask trolley into the transfer flask and close the transfer flask shielding	3	Technician, empty UFC receiving group (in transfer hall)	Empty UFC receiving and preparation	UFC transfer to baskets handling cells	10	4	750	3000		
		3	Technician, empty UFC receiving group (in transfer hall)	Empty UFC receiving and preparation	Decontamination cells	15	4	750	3000	1.62E-06	8.09E-05

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		3	Technician, empty UFC receiving group (in transfer hall)	Empty UFC receiving and preparation	Buffer area (ambient)	50	Ambient (Table 10)				
		3	Technician, empty UFC receiving group (in transfer hall)	Empty UFC receiving and preparation	UFC Processing cells (ambient)	60	Ambient (Table 10)				
MII-8.7	Transfer UFC assembly in transfer flask to UFC loading process	3	Technician, empty UFC receiving group (in transfer hall)	Empty UFC receiving and preparation	UFC transfer to baskets handling cells	10	3	750	2250	0	0
		3	Technician, empty UFC receiving group (in transfer hall)	Empty UFC receiving and preparation	Decontamination cells	15	3	750	2250	1.62E-06	6.07E-05
		3	Technician, empty UFC receiving group (in transfer hall)	Empty UFC receiving and preparation	Buffer area (ambient)	50	Ambient (Table 10)				
		3	Technician, empty UFC receiving group (in transfer hall)	Empty UFC receiving and preparation	UFC Processing cells (ambient)	60	Ambient (Table 10)				
MII-9	**UCF Processing cell activities (assumed conservatively, that workers are close to UFC processing cells in transfer hall close to buffer area, although some may be located in control rooms)**										
MII-9.1	Transfer UFC to processing cell door	8	Operator	UFC Processing	UFC in transfer flask	5	4	250	1000	1.26E-04	2.10E-03
		2	Technician	UFC Processing	UFC in transfer flask	5	4	250	1000	1.26E-04	2.10E-03
		1	Management	UFC Processing	UFC in transfer flask	5	4	250	1000	1.26E-04	2.10E-03
		8	Operator	UFC Processing	Buffer area in transfer hall (ambient)	10	480	250	120000	1.23E-04	2.46E-01
		2	Technician	UFC Processing	Buffer area in transfer hall (ambient)	10	480	250	120000	1.23E-04	2.46E-01

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		1	Management	UFC Processing	Buffer area in transfer hall (ambient)	10	480	250	120000	1.23E-04	2.46E-01
		8	Operator	UFC Processing	UFC Processing cell (ambient)	5	480	250	120000	4.89E-06	9.78E-03
		2	Technician	UFC Processing	UFC Processing cell (ambient)	5	480	250	120000	4.89E-06	9.78E-03
		1	Management	UFC Processing	UFC Processing cell (ambient)	5	480	250	120000	4.89E-06	9.78E-03
MII-9.2	Transfer UCF into processing cell	8	Operator	UFC Processing	UFC in transfer flask	5	8	250	2000	1.26E-04	4.20E-03
		2	Technician	UFC Processing	UFC in transfer flask	5	8	250	2000	1.26E-04	4.20E-03
		1	Management	UFC Processing	UFC in transfer flask	5	8	250	2000	1.26E-04	4.20E-03
		8	Operator	UFC Processing	Buffer area in transfer hall (ambient)	10	Ambient (Table 10)				
		2	Technician	UFC Processing	Buffer area in transfer hall (ambient)	10	Ambient (Table 10)				
		1	Management	UFC Processing	Buffer area in transfer hall (ambient)	10	Ambient (Table 10)				
		8	Operator	UFC Processing	UFC Processing cell (ambient)	5	Ambient (Table 10)				
		2	Technician	UFC Processing	UFC Processing cell (ambient)	5	Ambient (Table 10)				
		1	Management	UFC Processing	UFC Processing cell (ambient)	5	Ambient (Table 10)				
MII-9.3	Perform UFC processing operations	8	Operator	UFC Processing	UFC Processing cell (ambient)	5	Ambient (Table 10)				
		2	Technician	UFC Processing	UFC Processing cell (ambient)	5	Ambient (Table 10)				
		1	Management	UFC Processing	UFC Processing cell (ambient)	5	Ambient (Table 10)				
		8	Operator	UFC Processing	Buffer area in transfer hall (ambient)	10	Ambient (Table 10)				

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		2	Technician	UFC Processing	Buffer area in transfer hall (ambient)	10	Ambient (Table 10)				
		1	Management	UFC Processing	Buffer area in transfer hall (ambient)	10	Ambient (Table 10)				
MII-9.4	Transfer UFC out of processing cell	8	Operator	UFC Processing	UFC in transfer flask	5	8	250	2000	1.26E-04	4.20E-03
		2	Technician	UFC Processing	UFC in transfer flask	5	8	250	2000	1.26E-04	4.20E-03
		1	Management	UFC Processing	UFC in transfer flask	5	8	250	2000	1.26E-04	4.20E-03
		8	Operator	UFC Processing	Buffer area in transfer hall (ambient)	10	Ambient (Table 10)				
		2	Technician	UFC Processing	Buffer area in transfer hall (ambient)	10	Ambient (Table 10)				
		1	Management	UFC Processing	Buffer area in transfer hall (ambient)	10	Ambient (Table 10)				
		8	Operator	UFC Processing	UFC Processing cell (ambient)	5	Ambient (Table 10)				
		2	Technician	UFC Processing	UFC Processing cell (ambient)	5	Ambient (Table 10)				
		1	Management	UFC Processing	UFC Processing cell (ambient)	5	Ambient (Table 10)				
MII-9.5	Transfer to Decontamination cell	8	Operator	UFC Processing	UFC in transfer flask	5	4	250	1000	1.26E-04	2.10E-03
		2	Technician	UFC Processing	UFC in transfer flask	5	4	250	1000	1.26E-04	2.10E-03
		1	Management	UFC Processing	UFC in transfer flask	5	4	250	1000	1.26E-04	2.10E-03
		8	Operator	UFC Processing	Buffer area in transfer hall (ambient)	10	Ambient (Table 10)				
		2	Technician	UFC Processing	Buffer area in transfer hall (ambient)	10	Ambient (Table 10)				

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		1	Management	UFC Processing	Buffer area in transfer hall (ambient)	10	Ambient (Table 10)				
		8	Operator	UFC Processing	UFC Processing cell (ambient)	5	Ambient (Table 10)				
		2	Technician	UFC Processing	UFC Processing cell (ambient)	5	Ambient (Table 10)				
		1	Management	UFC Processing	UFC Processing cell (ambient)	5	Ambient (Table 10)				
MII-10	**Decontamination cell activities**										
MII-10.1	Transfer UFC transfer into decontamination cell	2	Operator (UFC dispatch), Area B.	UFC Dispatch	UFC decontamination cell	1	4	1500	6000	3.30E-05	3.30E-03
MII-10.2	Survey UFC and disposition results	2	Operator (UFC dispatch), Area B.	UFC Dispatch	UFC decontamination cell	1	30	1500	45000	3.30E-05	2.47E-02
MII-10.3	Decontaminate UFC	2	Operator (UFC dispatch), Area B.	UFC Dispatch	UFC decontamination cell	1	30	1500	45000	3.30E-05	2.47E-02
MII-11	**Disposing of empty modules**										
MII-11.1	An empty module transferred for decontamination and then dispatched for compaction in an off-site metals recycling facility	2	Decontamination technician	Decontamination of modules	Empty module before decontamination	1	60	630	37800	2.64E-04	1.66E-01
MII-12	**Buffer box loading**										
MII-12.1	Transfer UFC to buffer box loading area in transfer flask	2	Operator, buffer box loading (transfer & preassembly)	Buffer box loading	Filled UFC in transfer flask	1	1	1500	1500	8.97E-04	2.24E-02

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		2	Operator, buffer box loading (transfer & preassembly)	Buffer box loading	Storage area (transfer flasks with UFCs beside buffer box loading) (ambient)	1	480	250	120000	1.44E-06	2.88E-03
MII-12.2	Place UFC on the bottom half of the buffer box using a lifting tool	2	Operator, buffer box loading (assembly)	Buffer box loading	UFC buffer box behind 100cm concrete wall	1	5	1500	7500	2.73E-06	3.41E-04
MII-12.3	Assemble upper buffer block	2	Operator, buffer box loading (assembly)	Buffer box loading	UFC buffer box behind 100cm concrete wall	1	5	1500	7500	2.73E-06	3.41E-04
MII-12.4	Install steel cover	2	Operator, buffer box loading (assembly)	Buffer box loading	UFC buffer box behind 100cm concrete wall	1	5	1500	7500	2.73E-06	3.41E-04
MII-12.5	Transfer buffer box transfer to transfer area	2	Operator, buffer box loading (assembly)	Buffer box loading	UFC buffer box behind 100cm concrete wall	1	1	1500	1500	2.73E-06	6.83E-05
MII-12.6	Perform final preparation operations	2	Operator, buffer box loading (assembly)	Buffer box loading	UFC buffer box behind 100cm concrete wall	1	10	1500	15000	2.73E-06	6.83E-04
MII-12.7	Transfer buffer box to completed buffer box transfer position	2	Operator, buffer box loading (assembly)	Buffer box loading	UFC buffer box behind 100cm concrete wall	1	1	1500	1500	2.73E-06	6.83E-05
MII-12.8	Transfer buffer box to dispatch	2	Operator, buffer box loading (assembly)	Buffer box loading	UFC buffer box behind 100cm concrete wall	1	1	1500	1500	2.73E-06	6.83E-05
MII-13	**Loading the UFC into transfer cask**										
MII-13.1	Place the buffer box (with UFC) into transfer cask	2	Operator, buffer box loading (next to loading cell)	Buffer box loading	UFC buffer box behind 100cm concrete wall	1	10	1500	15000	2.73E-06	6.83E-04
MII-14	**Shaft operation activities (from UFPP to UG)**										
MII-14.1	Connect tow vehicle to filled UFC transfer cask & trolley at UFPP	1	Tow vehicle driver	Transfer from UFPP to UG workers	UFC buffer box in transfer cask	1	7	1500	10500	5.07E-05	8.87E-03

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
MII-14.2	Dispatch transfer cask from the UFPP and move to the main shaft	1	Fork lift driver	Transfer from UFPP to UG workers	UFC buffer box in transfer cask	1	22	1500	33000	5.07E-05	2.79E-02
MII-14.3	Secure transfer cask in shaft	1	Shaft Operator	Transfer from UFPP to UG workers	UFC buffer box in transfer cask	5	7	1500	10500	6.52E-06	1.14E-03
Underground operation activities											
MII-15	**Buffer box and bentonite spacer placement operation**										
MII-15.1	Unsecure and move trolley with filled UFC transfer cask out of shaft cage using two vehicle	1	Tow vehicle driver	Placement	UFC buffer box in transfer cask	1	7	1500	10500	5.07E-05	8.87E-03
MII-15.2	Move trolley with filled UFC transfer cask to shielding canopy at placement room	1	Tow vehicle driver	Placement	UFC buffer box in transfer cask	1	22	1500	33000	5.07E-05	2.79E-02
MII-15.3	Secure UFC transfer cask to shielding canopy transfer window	1	Tow vehicle driver	Placement	UFC buffer box in transfer cask	1	7	1500	10500	5.07E-05	8.87E-03
MII-15.4	Connect tow vehicle to hydraulic cylinder cart in underground storage	1	Tow vehicle driver	Placement	Underground storage	10	7	1500	10500	6.36E-06	1.11E-03
MII-15.5	Move hydraulic cylinder cart to UFC transfer cask trolley	1	Tow vehicle driver	Placement	UFC buffer box in transfer cask	5	7	1500	10500	6.52E-06	1.14E-03
MII-15.6	Connect hydraulic cylinder cart to UFC transfer cask trolley	1	Tow vehicle driver	Placement	UFC buffer box in transfer cask	5	7	1500	10500	6.52E-06	1.14E-03

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
MII-15.7	Connect hydraulic cart to services	1	Tow vehicle driver	Placement	UFC buffer box in transfer cask	5	7	1500	10500	6.52E-06	1.14E-03
MII-15.8	Install Coupling between cylinder and ram on UFC transfer cask	1	Tow vehicle driver	Placement	UFC buffer box in transfer cask	5	7	1500	10500	6.52E-06	1.14E-03
MII-15.9	Open UFC transfer cask shielding door	1	Tow vehicle driver	Placement	UFC buffer box in transfer cask	5	7	1500	10500	6.52E-06	1.14E-03
MII-15.10	Push buffer box from UFC transfer cask	1	Tow vehicle driver	Placement	UFC buffer box in transfer cask	5	14	1500	21000	6.52E-06	2.28E-03
MII-15.11	Verify position of buffer box on the placement vehicle wedge tray	1	Tow vehicle driver	Placement	UFC buffer box in transfer cask	5	7	1500	10500	6.52E-06	1.14E-03
MII-15.12	Retract ram through UFC transfer cask	1	Tow vehicle driver	Placement	UFC buffer box in transfer cask	5	7	1500	10500	6.52E-06	1.14E-03
MII-15.13	Close UFC transfer cask doors	1	Tow vehicle driver	Placement	UFC buffer box in transfer cask	5	7	1500	10500	6.52E-06	1.14E-03
MII-15.14	Move trolley with empty UFC transfer cask to underground storage	1	Tow vehicle driver	Placement	Underground storage	10	22	1500	33000	6.36E-06	3.50E-03
MII-15.15	Connect tow vehicle to trolley with bentonite spacer block in underground storage	1	Tow vehicle driver	Placement	Underground storage	10	7	1500	10500	6.36E-06	1.11E-03
MII-15.16	Move trolley for bentonite Spacer block to underground storage	1	Tow vehicle driver	Placement	Underground storage	10	22	1500	33000	6.36E-06	3.50E-03

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
MII-16	**Floor plate/ventilation duct removal**										
MII-16.1	Connect tow vehicle to trolley with floor plate handling system in underground storage	1	Tow vehicle driver	Placement	Underground storage	1	7	750	5250	2.52E-05	2.20E-03
Mii-16.2	Return floor plate system with floor plate to underground storage	1	Tow vehicle driver	Placement	Underground storage	1	22	750	16500	2.52E-05	6.93E-03
MII-17	**Facility Support Activities**										
MII-17.1	First line manager overseeing fuel handling, basket handling and UFTP operations	1	Control room #3	Fuel handling and basket handling (Manager)	Module handling cell (ambient)	1	480	250	120000	4.86E-04	9.72E-01
		1	Control room #3	Fuel handling and basket handling (Manager)	Fuel handling cell (ambient)	10	480	250	120000	0.00E+00	0.00E+00
MII-17.2	Cleaning, maintenance and radiation safety technicians of the shipping and receiving hall	2	Shipping and receiving hall	Cleaners	UFTP storage (assumed to be done when no UFTPs are moved in the space)	5	40	250	10000	2.86E-03	4.76E-01
		8	Shipping and receiving hall	Servicing and maintenance personnel	UFTP storage (assumed to be done when no UFTPs are moved in the space)	5	40	250	10000	2.86E-03	4.76E-01
		2	Shipping and receiving hall	Radiation safety technicians	UFTP storage (assumed to be done when no UFTPs are moved in the space)	5	40	250	10000	2.86E-03	4.76E-01
MII-17.3	Cleaning, maintenance and radiation safety technicians of the hallway of fuel	2	Hallway of fuel handling floor	Cleaners	Module handling cell	10	40	250	10000	0.00E+00	0.00E+00
		8	Hallway of fuel handling floor	Servicing and maintenance personnel	Module handling cell	10	40	250	10000	0.00E+00	0.00E+00

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
	handling floor	2	Hallway of fuel handling floor	Radiation safety technicians	Module handling cell	10	40	250	10000	0.00E+00	0.00E+00
		2	Hallway of fuel handling floor	Cleaners	Fuel handling cell	1	40	250	10000	2.89E-04	4.82E-02
		8	Hallway of fuel handling floor	Servicing and maintenance personnel	Fuel handling cell	1	40	250	10000	2.89E-04	4.82E-02
		2	Hallway of fuel handling floor	Radiation safety technicians	Fuel handling cell	1	40	250	10000	2.89E-04	4.82E-02
MII-17.4	Cleaning, maintenance and radiation safety technicians of the UFC processing area	2	UFC processing area	Cleaners	UFC Processing cell	1	40	250	10000	3.30E-05	5.50E-03
		8	UFC processing area	Servicing and maintenance personnel	UFC Processing cell	1	40	250	10000	3.30E-05	5.50E-03
		2	UFC processing area	Radiation safety technicians	UFC Processing cell	1	40	250	10000	3.30E-05	5.50E-03
MII-17.5	Cleaning, maintenance and radiation safety technicians of Operator Room #1	2	Operator Room #1	Cleaners	Module handling cell	1	40	250	10000	4.86E-04	8.10E-02
		8	Operator Room #1	Servicing and maintenance personnel	Module handling cell	1	40	250	10000	4.86E-04	8.10E-02
		2	Operator Room #1	Radiation safety technicians	Module handling cell	1	40	250	10000	4.86E-04	8.10E-02
		2	Operator Room #1	Cleaners	Fuel handling cell	10	40	250	10000	0.00E+00	0.00E+00
		8	Operator Room #1	Servicing and maintenance personnel	Fuel handling cell	10	40	250	10000	0.00E+00	0.00E+00
		2	Operator Room #1	Radiation safety technicians	Fuel handling cell	10	40	250	10000	0.00E+00	0.00E+00
MII-17.6	Cleaning, maintenance and radiation safety technicians of Operator Room #2	2	Operator Room #2	Cleaners	Module handling cell	1	40	250	10000	4.86E-04	8.10E-02
		8	Operator Room #2	Servicing and maintenance personnel	Module handling cell	1	40	250	10000	4.86E-04	8.10E-02
		2	Operator Room #2	Radiation safety technicians	Module handling cell	1	40	250	10000	4.86E-04	8.10E-02
		2	Operator Room #2	Cleaners	Fuel handling cell	10	40	250	10000	0.00E+00	0.00E+00

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		8	Operator Room #2	Servicing and maintenance personnel	Fuel handling cell	10	40	250	10000	0.00E+00	0.00E+00
		2	Operator Room #2	Radiation safety technicians	Fuel handling cell	10	40	250	10000	0.00E+00	0.00E+00
MII-17.7	Cleaning, maintenance and radiation safety technicians of Control Room #1	2	Control room #1	Cleaners	Dry storage	1	40	250	10000	5.74E-04	9.56E-02
		8	Control room #1	Servicing and maintenance personnel	Dry storage	1	40	250	10000	5.74E-04	9.56E-02
		2	Control room #1	Radiation safety technicians	Dry storage	1	40	250	10000	5.74E-04	9.56E-02
		2	Control room #1	Cleaners	Vent cell (1/10 for total radiation)	5	40	250	10000	7.93E-07	1.32E-04
		8	Control room #1	Servicing and maintenance personnel	Vent cell (1/10 for total radiation)	5	40	250	10000	7.93E-07	1.32E-04
		2	Control room #1	Radiation safety technicians	Vent cell (1/10 for total radiation)	5	40	250	10000	7.93E-07	1.32E-04
MII-17.8	Cleaning, maintenance and radiation safety technicians of Control Room #2	2	Control room #2	Cleaners	Dry storage	1	40	250	10000	5.74E-04	9.56E-02
		8	Control room #2	Servicing and maintenance personnel	Dry storage	1	40	250	10000	5.74E-04	9.56E-02
		2	Control room #2	Radiation safety technicians	Dry storage	1	40	250	10000	5.74E-04	9.56E-02
		2	Control room #2	Cleaners	Vent cell (1/10 for total radiation)	5	40	250	10000	7.93E-07	1.32E-04
		8	Control room #2	Servicing and maintenance personnel	Vent cell (1/10 for total radiation)	5	40	250	10000	7.93E-07	1.32E-04
		2	Control room #2	Radiation safety technicians	Vent cell (1/10 for total radiation)	5	40	250	10000	7.93E-07	1.32E-04
MII-17.9	Cleaning, maintenance and radiation safety technicians of Control Room #3	2	Control room #3	Cleaners	Module handling cell	1	40	250	10000	4.86E-04	8.10E-02
		8	Control room #3	Servicing and maintenance personnel	Module handling cell	1	40	250	10000	4.86E-04	8.10E-02
		2	Control room #3	Radiation safety technicians	Module handling cell	1	40	250	10000	4.86E-04	8.10E-02
		2	Control room #3	Cleaners	Fuel handling cell	10	40	250	10000	0.00E+00	0.00E+00

Step	Activities	NEWs	Specification of Personnel		Source	Distance to Sources	Exposure Time	Annual Rate/Shift	Annual Exposure Time	Dose Rate / Activity*	Total Dose*
		no.	Worker	Working Group		m	min	no.	min	mSv/h	mSv
		8	Control room #3	Servicing and maintenance personnel	Fuel handling cell	10	40	250	10000	0.00E+00	0.00E+00
		2	Control room #3	Radiation safety technicians	Fuel handling cell	10	40	250	10000	0.00E+00	0.00E+00
MII-17.10	Cleaning, maintenance and radiation safety technicians of the Transfer Hall	2	Transfer hall	Cleaners	UFC processing cell	5	40	250	10000	4.89E-06	8.15E-04
		8	Transfer hall	Servicing and maintenance personnel	UFC processing cell	5	40	250	10000	4.89E-06	8.15E-04
		2	Transfer hall	Radiation safety technicians	UFC processing cell	5	40	250	10000	4.89E-06	8.15E-04
		2	Transfer hall	Cleaners	Buffer area	10	40	250	10000	1.23E-04	2.05E-02
		8	Transfer hall	Servicing and maintenance personnel	Buffer area	10	40	250	10000	1.23E-04	2.05E-02
		2	Transfer hall	Radiation safety technicians	Buffer area	10	40	250	10000	1.23E-04	2.05E-02
MII-17.11	Maintenance, underground	2	Maintenance	Maintenance, underground	Underground storage	5	110	250	27500	1.19E-05	5.45E-03
		2	Maintenance	Maintenance, underground	Exposure to UFC in transfer cask when tow vehicle drives by (six a day/5 min each time)	5	30	250	7500	6.52E-06	8.15E-04

* Dose rates and doses are for 220/30 fuel.

**A UFC assembly refers to the assembly of all components of the UFC, without prior to being loaded with fuel. It has been preassembled to ensure that all components are an acceptable fit.

APPENDIX B: EFFECT OF RADIATION STREAMING THROUGH THE BLOCKS OF THE BENTONITE BUFFER BOX INSIDE A TRANSPORT CASK (MARK II)

In the Mark II concept, buffer boxes are placed inside transport casks. These transport casks provide the necessary shielding to facilitate handling in the UFPP and the DGR. In the preliminary ALARA Assessment, the dose rates are calculated under the assumption that the blocks of highly compacted bentonite fill all the space between the UFC and the transport cask. These results are shown in Table 32 and Figure 57 (Base Case).

However, this does not take into account the potential effect of radiation streaming between the gaps between the different blocks of highly compacted bentonite in a buffer box. Therefore, to assess the effect of the radiation streaming, the following cases have been modeled:

- Mark II UFC inside a transport cask with no bentonite buffer box (Table 33)
- Mark II UFC inside a transport cask with a bentonite buffer box having a 4 cm gap to allow for radiation streaming (Table 34). The gap is 20 cm above the center of the UFC so that it is in front of active used fuel, not at the ends of the used fuel bundles.

All the calculations have been done for fuel of 220 MWh/kgU burnup and 30 years of decay. The dose rates increase by a factor of 15 as compared to the base case when the bentonite box is not accounted for. The same fuel shows a maximum increase in dose rate of 35% in the case of a 4 cm gap in the bentonite buffer box as compared to the base case.

Table 32: Dose Rates (mSv/h) from a UFC in a Seamless Buffer Box and a Transport Cask

Distance (m)	Neutron		Gamma		Total Dose Rate
	Value	Error (%)	Value	Error (%)	
0.5	3.17E-05	1.0	5.09E-05	3.2	8.84E-05
1	1.73E-05	0.9	3.07E-05	2.4	5.07E-05
2	7.83E-06	0.8	1.46E-05	2.1	2.35E-05
3	4.73E-06	0.8	8.39E-06	2.1	1.38E-05
5	2.52E-06	0.8	3.73E-06	1.9	6.52E-06

Table 33: Dose Rates (mSv/h) from a UFC in a Transport Cask (No Shielding Credit Given to Bentonite Buffer Box)

Distance (m)	Neutron		Gamma		Total dose rate	
	Value	Error (%)	Value	Error (%)	Value	Ratio to Base Case
0.5	4.77E-04	0.7	6.84E-04	3.6	1.24E-03	14.08
1	2.74E-04	0.7	4.23E-04	2.3	7.32E-04	14.44
2	1.28E-04	0.6	2.04E-04	2.0	3.47E-04	14.72
3	7.74E-05	0.6	1.17E-04	1.8	2.02E-04	14.69
5	4.19E-05	0.6	5.32E-05	1.8	9.87E-05	15.14

Table 34: Dose rates (mSv/h) from a UFC in a Bentonite Buffer Box with a 4 cm Air Gap and in a Transfer Cask

Distance (m)	Neutron		Gamma		Total dose rate	
	Value	Error (%)	Value	Error (%)	Value	Ratio to Base Case
0.5	3.90E-05	0.4	7.16E-05	3.8	1.19E-04	1.35
1	2.02E-05	0.3	3.83E-05	2.7	6.18E-05	1.22
2	8.98E-06	0.3	1.69E-05	2.1	2.70E-05	1.15
3	5.39E-06	0.3	9.48E-06	2.0	1.55E-05	1.13
5	2.88E-06	0.3	4.24E-06	1.9	7.39E-06	1.13

Figure 57 shows that a 4 cm gap in the bentonite around a UFC inside a transport cask has little effect on the neutron dose rates outside the transport cask. Dose rates increase only in a small region just in from of the gap and the increase is small. Figure 57 also illustrates the effect of having a 30 cm gap in the bentonite. As expected the effect is much more pronounced than for a 4 cm gap.

These results support the use of the model having no gap between the bentonite blocks for the preliminary ALARA Assessment. The streaming effect of the gap is limited, and the dose rates obtained without accounting for the shielding of the bentonite are disproportionately higher than the case where the 4 cm gap is accounted for. Furthermore, since it is expected that any gap that does exist would be smaller than 4 cm in width, it is reasonable to assume that actual doses would be much closer to the dose rates calculated for a bentonite buffer box with no gaps between blocks. Finally, because the goal is to obtain realistic operational dose estimates, the case with no gap in the bentonite, which is considered to be the most realistic, has been adopted for preliminary ALARA calculations.

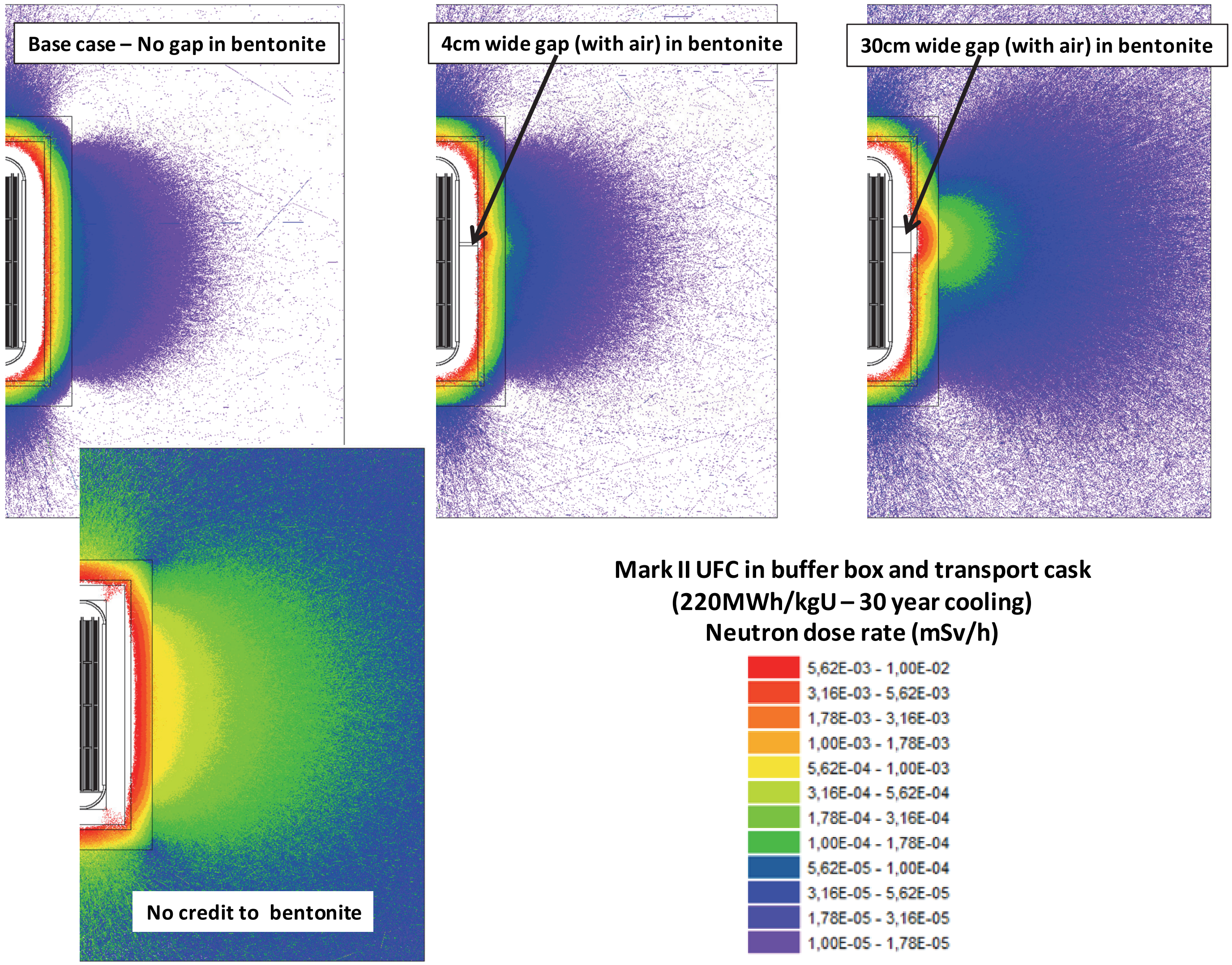

Figure 57: Illustration of the Effect of Streaming on Neutron Dose Rates from a UFC in a Bentonite Buffer Box and a Transfer Cask