OVERVIEW OF ADAPTIVE PHASED MANAGEMENT REPOSITORY DESIGN DEVELOPMENT

S. Russell
Nuclear Waste Management Organization
Toronto, Ontario, Canada

ABSTRACT

The Nuclear Waste Management Organization is implementing Adaptive Phased Management, Canada's plan for long-term management of used nuclear fuel. The organization is proceeding with the process for selecting a site in partnership with an informed and willing host community to safely and securely container and isolate used nuclear fuel in a deep geological repository in a suitable rock formation.

Adaptive Phased Management is the culmination of more than 30 years of research, development and demonstration of repository concepts in Canada. Adaptive Phased Management uses a phased and adaptive step-wise approach to the multi-barrier system which is consistent with the long-term waste management approaches being developed in many other countries with nuclear power programs such as Sweden, Finland, Switzerland, the United Kingdom and France.

The Nuclear Waste Management Organization is examining and developing conceptual designs for a deep geological repository and associated facilities for the placement of used nuclear fuel in long-lived containers. This paper will examine two of these generic conceptual designs which have recently been refined and updated. These conceptual designs will be used to support a pre-project review of repository design and safety by the Canadian Nuclear Safety Commission.

1. INTRODUCTION

The Nuclear Waste Management Organization (NWMO) was created by Canada's nuclear energy generators (Ontario Power Generation, New Brunswick Power and Hydro-Québec) in 2002 as a requirement of the federal *Nuclear Fuel Waste Act*. The Act requires the NWMO to study possible approaches, recommend and then implement a plan for the long-term management of used nuclear fuel in Canada.

In 2002, the NWMO began its work to develop collaboratively with Canadians a management approach for the long-term care of Canada's used nuclear fuel. The NWMO conducted a three-year study involving thousands of citizens, specialists and Aboriginal peoples in every province and territory to develop a long-term management approach that is socially acceptable, technically sound, environmentally responsible and economically feasible. The plan that emerged from that dialogue, Adaptive Phased Management, enables our generation to proceed in a deliberate and collaborative way to establish the foundation for the safe and secure stewardship of Canada's used nuclear fuel for the long term [1].

On June 14, 2007, the Government of Canada selected NWMO's recommendation of Adaptive Phased Management as the best plan for long-term used fuel management in Canada. Following that decision, the NWMO has been collaboratively developing detailed processes and plans for the implementation of Adaptive Phased Management. Development of a deep geological repository is included in those plans.

2. REPOSITORY DESIGN DEVELOPMENT

In Canada, the long-term containment and isolation of used nuclear fuel has been studied since the mid-1970s. Conceptual designs for a deep geological repository have been developed for various used fuel container placement configurations and were presented as part of the Environmental Impact Statement prepared by Atomic Energy of Canada Limited in 1994 [2]. Since 1996, Ontario Power Generation and then since 2009, the Nuclear Waste Management Organization, have been directing and managing the technical program to develop generic conceptual designs for a deep geological repository in potentially suitable host rock formations such as crystalline rock and sedimentary rock [3].

All conceptual repository designs include extended monitoring of the facility and provisions for the retrieval of used fuel containers, if required.

As the NWMO proceeds through the siting process [4], these repository designs will become further optimized and refined to suit the host rock characteristics, hydrogeology and other conditions and features at the particular site. Conceptual repository designs will also be used to support a pre-project review of repository design and safety by the Canadian Nuclear Safety Commission.

3. REFERENCE CONCEPTUAL DESIGNS

3.1 Used Nuclear Fuel

The conceptual repository designs build on a base case inventory of 3.6 million used CANDU®[a] fuel bundles and an alternative case inventory of 7.2 million used CANDU® fuel bundles. The used fuel is assumed to be cooled for a minimum of 30 years out-of-reactor which results in a thermal output of 3.52 watts per bundle. Each fuel bundle has length of about 0.5 m, a diameter of about 0.10 m and a mass of about 24 kg.

A standard CANDU® fuel bundle is illustrated in Figure 1.

Figure 1. CANDU® fuel bundle.

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

3.2 Used Fuel Container Designs

Engineering designs to contain used nuclear fuel in the repository have been developed in Canada and elsewhere for many decades and NWMO continues to study container designs for placement in a deep geological repository. Key features of these designs include corrosion resistance, mechanical strength, geometry, capacity and compatibility with surrounding sealing materials such as bentonite clay.

The current reference designs for a used fuel container employ either high-purity copper or carbon steel as the primary corrosion barrier material. These particular container designs hold 360 used fuel bundles distributed in six layers of 60 bundles per layer in three steel baskets (with two bundle layers per basket) [5]. The container's thermal output is 1,268 watts. The copper container has an inner steel vessel designed to withstand the mechanical stresses in a repository.

The current reference used fuel container designs are illustrated in Figure 2. Details on these particular container designs are summarized in Table 1.

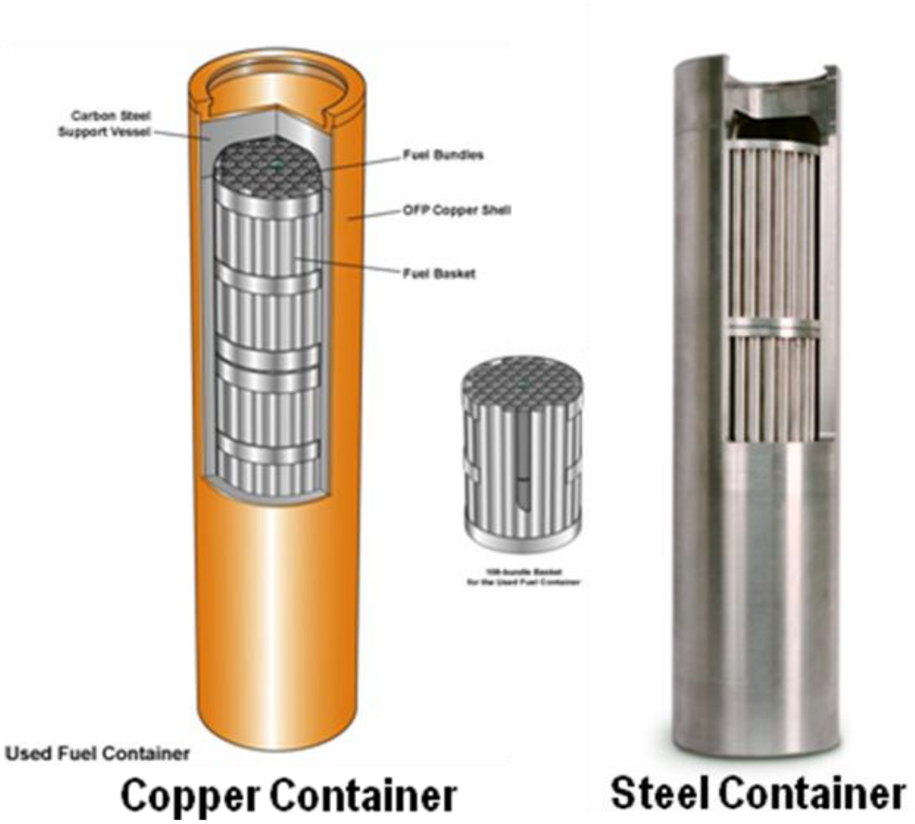

Figure 2. Conceptual designs for a used fuel container.

For the based case used fuel inventory of 3.6 million bundles, 10,000 used fuel containers would be required for placement in the deep geological repository over a 30-year operating period.

Over the next several years, NWMO will be conducting further studies on used fuel container design options, corrosion barrier materials, fabrication methods and demonstrations of container technology prior to selection of a preferred site currently planned by 2018.

Table 1. Example conceptual designs for copper and steel used fuel containers.

Feature	Copper Container	Steel Container
Corrosion Barrier:	Copper	Carbon steel
Length:	3.84 m	3.88 m
Diameter:	1.25 m	1.20 m
Capacity:	360 CANDU® bundles	360 CANDU® bundles
Thermal Output (container):	1,268 watts	1,268 watts
Number of Fuel Layers:	6	6
Number of Bundles per Layer:	60	60
Number of Fuel Baskets:	3	3
Mass of 3 Fuel Baskets:	1,240 kg	1,240 kg
Copper Shell Thickness:	25 mm	N/A
Copper Shell Mass:	4,170 kg	N/A
Steel Vessel Thickness:	102 mm	102 mm
Steel Vessel Mass:	12,650 kg	13,145 kg
Fuel Mass:	8,640 kg	8,640 kg
Total Container Mass (approx.):	27,000 kg	23,000 kg

3.3 Adaptive Phased Management - Common Surface Facilities

The generic, reference designs for the Adaptive Phased Management facility consist of various surface handling facilities which are generally common to repository designs in both crystalline rock and sedimentary rock. The surface facilities include a Used Fuel Packaging Plant which receives used fuel transported from the interim storage locations and re-packages the fuel into long-lived containers for placement in the repository [5]. The surface facilities will also include a Sealing Material Compaction Plant, laboratories, shaft complexes administrative offices and other facilities related to repository operation, monitoring, safeguards and security.

The conceptual designs include three shafts: a Main Shaft, a Service Shaft and a Ventilation Shaft. The Main Shaft has a diameter of 7 m and will convey the used fuel containers within a shielded transfer cask. The Main Shaft has a friction hoist and has a payload of 63.5 tonnes. The Service Shaft has a diameter of 6.5 m and will convey personnel, equipment, waste rock, muck and sealing materials such as bentonite clay. The Service Shaft has a drum hoist and has a payload of 10 tonnes and can carry up to 50 people. The Ventilation Shaft has a diameter of 6.5 m, handles the majority of the repository exhaust to surface and is able to support mine rescue or evacuation efforts, if required during operations. The Ventilation Shaft has a drum hoist and has a payload of 1.6 tonnes. These shafts, and the general overall design of the deep geological repository in crystalline rock, are illustrated in Figure 3.

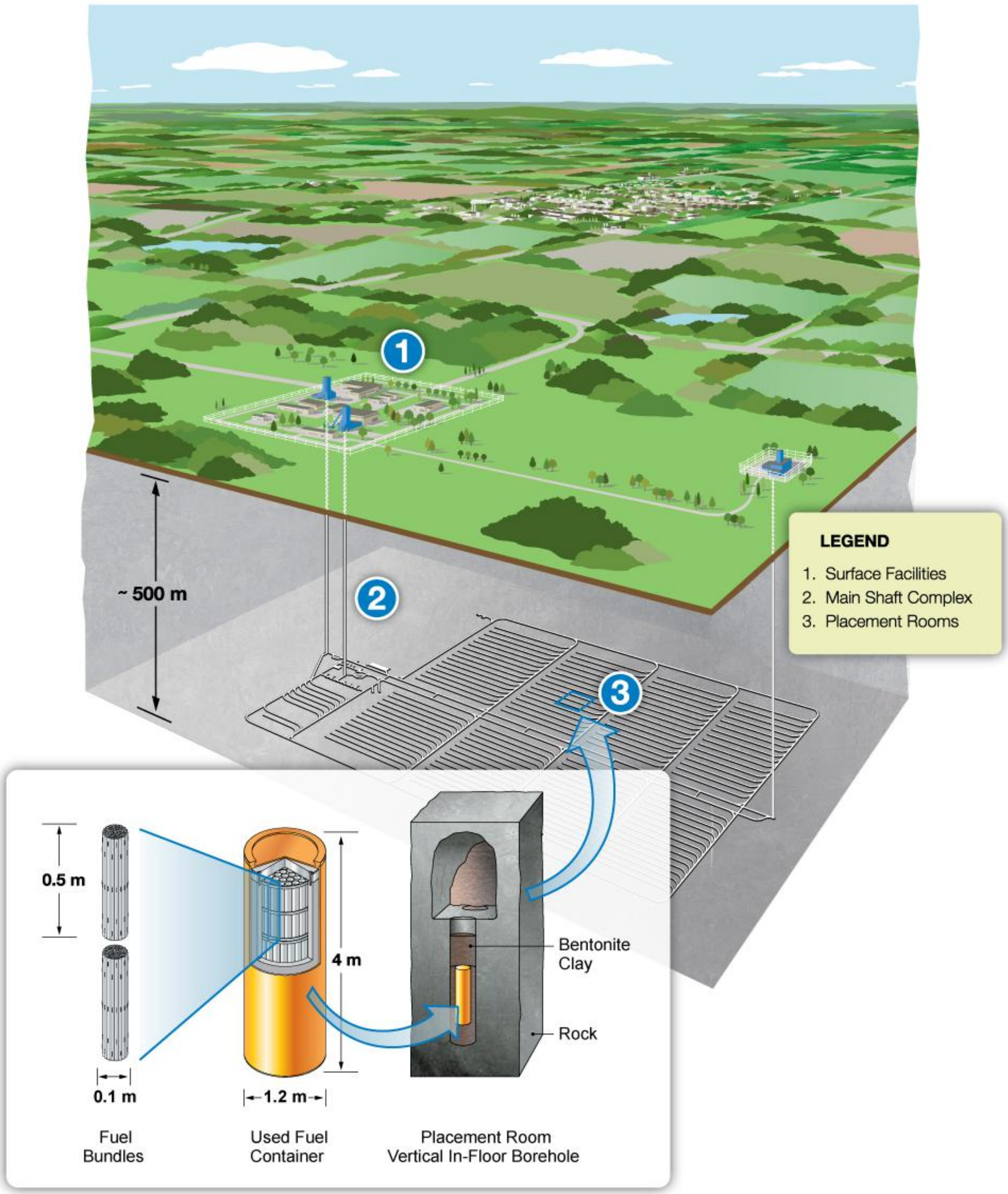

Figure 3. Illustration of a deep geological repository in crystalline rock with in-floor borehole placement of used fuel containers.

3.4 Repository Design in Crystalline Rock

The generic, reference conceptual design for a deep geological repository in crystalline rock is based on the in-floor borehole placement method for used fuel containers [5], as illustrated in Figure 3. This approach for container placement is consistent with reference repository designs in crystalline rock developed by SKB in Sweden [6] and Posiva in Finland [7].

The reference geosphere for the generic repository design has properties typical of granitic gneiss which is moderately to sparsely fractured and typical of the Canadian Shield. Rock excavation is primarily done via the drill & blast method. The repository is assumed to be constructed at a single elevation at a depth of about 500 m below ground surface. (Actual depth of the repository will depend on the specific conditions and features at the preferred site).

The 124 placement rooms for the 10,000 used fuel containers are 5.5 m high and have a length of about 400 m and a centre-to-centre room spacing of 40 m. Within a placement room, the in-floor boreholes have a centre-to-centre spacing of 4.2 m (see Figure 4). The placement room spacing and used fuel container spacing were designed to ensure the repository meets thermal-mechanical design requirements (e.g., 250 mm of buffer around container below 100 °C).

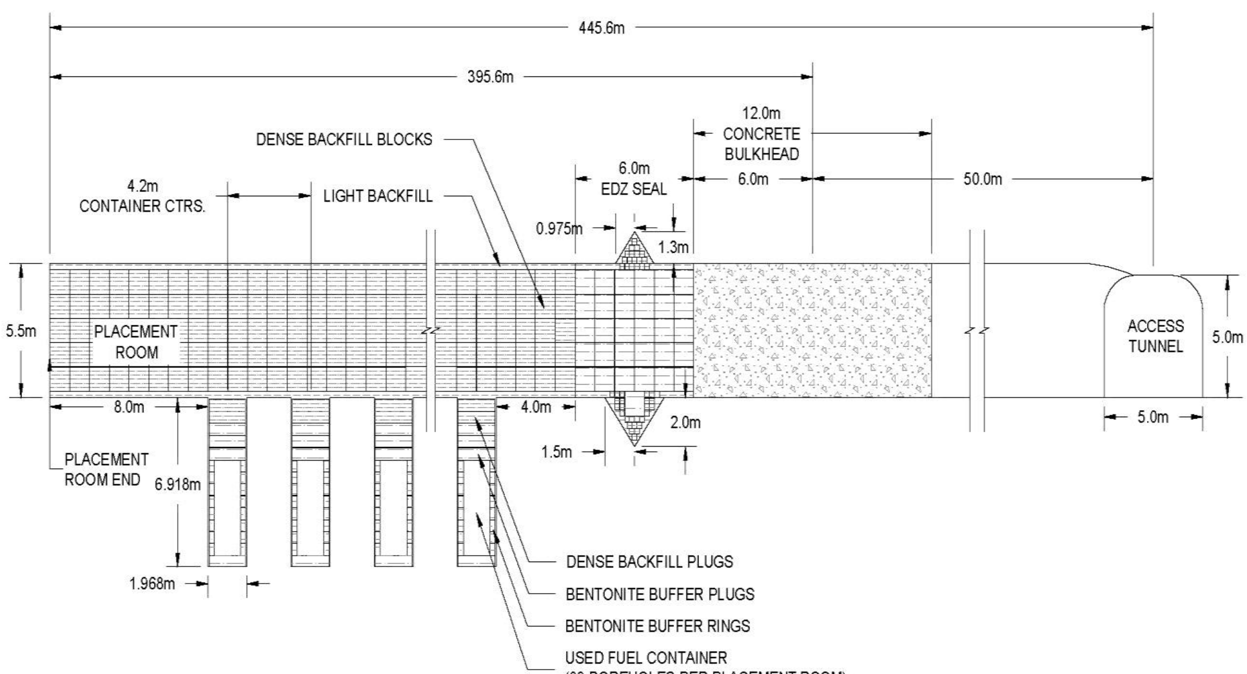

Figure 4. Room layout for in-floor borehole placement of used fuel containers.

Each borehole in the floor along the placement room centerline has a used fuel container surrounded by highly-compacted bentonite buffer disks, rings and gap-fill pellets. The placement room above the boreholes is filled with backfill materials such as a bentonite / sand mixture and other sealing materials. For the 3.6 million bundle scenario, the underground footprint of a deep geological repository in crystalline rock has a length of about 2.6 km and a width of about 1.6 km (see Figure 5).

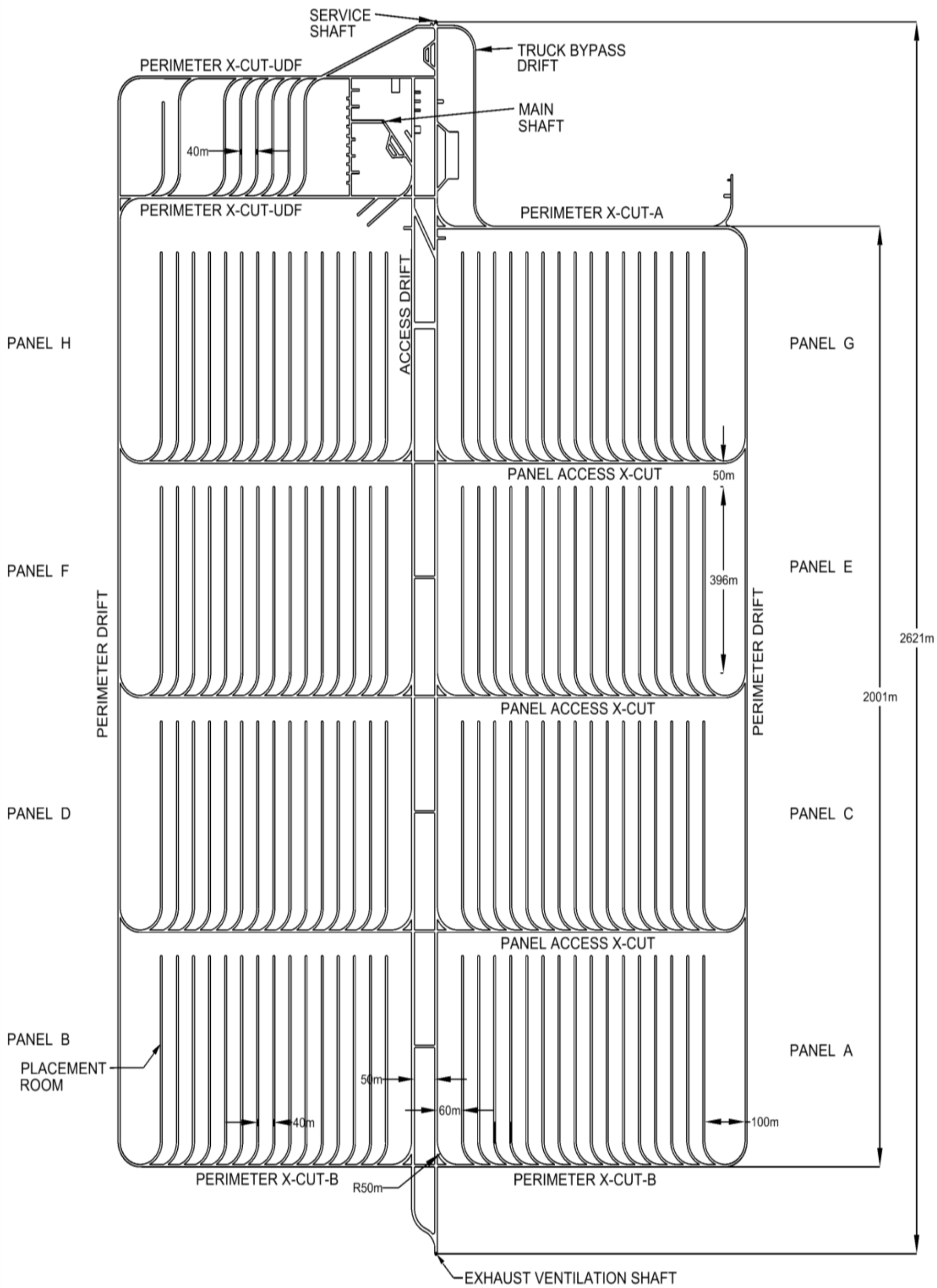

Figure 5. Underground repository layout for the in-floor borehole placement method.

3.5 Repository Design in Sedimentary Rock

The generic, reference conceptual design for a deep geological repository in sedimentary rock is based on the horizontal tunnel placement method for used fuel containers [8]. This approach for container placement is consistent with the reference repository design in sedimentary rock developed by Nagra in Switzerland [9].

The reference geosphere for the generic repository design has properties associated with a good quality, low permeability limestone overlain by a thick layer of low permeability shales which are typical of the large sedimentary basins in Canada. Rock excavation is done via the drill & blast method for the shafts and access tunnels, and via a tunnel boring machine for the placement rooms. The repository is assumed to be constructed at a single elevation at a depth of about 500 m below ground surface. (Actual depth of the repository will depend on the specific conditions and features at the preferred site).

The 120 placement rooms for the 10,000 used fuel containers are 2.5 m in diameter and have a length of about 410 m and a centre-to-centre room spacing of 20 m (see Figure 6). Within a placement room, the used fuel containers are placed horizontally on a bentonite pedestal and then surrounded by pneumatically placed bentonite pellets to fill the void space in the room. The container centre-to-centre spacing is about 8 m. The placement room spacing and used fuel container spacing were designed to ensure the repository meets thermal-mechanical design requirements (e.g., 250 mm of buffer around container below 100 °C).

The overall layout of a deep geological repository in sedimentary rock is illustrated in Figure 7. For the 3.6 million bundle scenario, the underground footprint of a deep geological repository in sedimentary rock has a length of about 2.7 km and a width of about 1.5 km (see Figure 8).

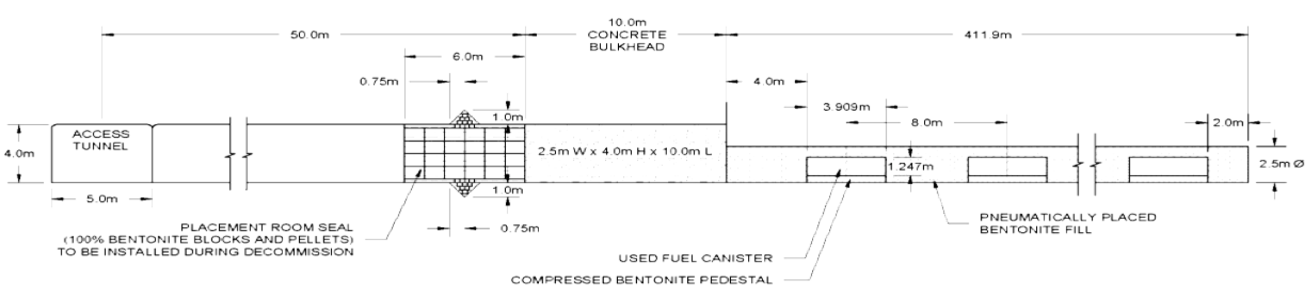

Figure 6. Room layout for horizontal tunnel placement of used fuel containers.

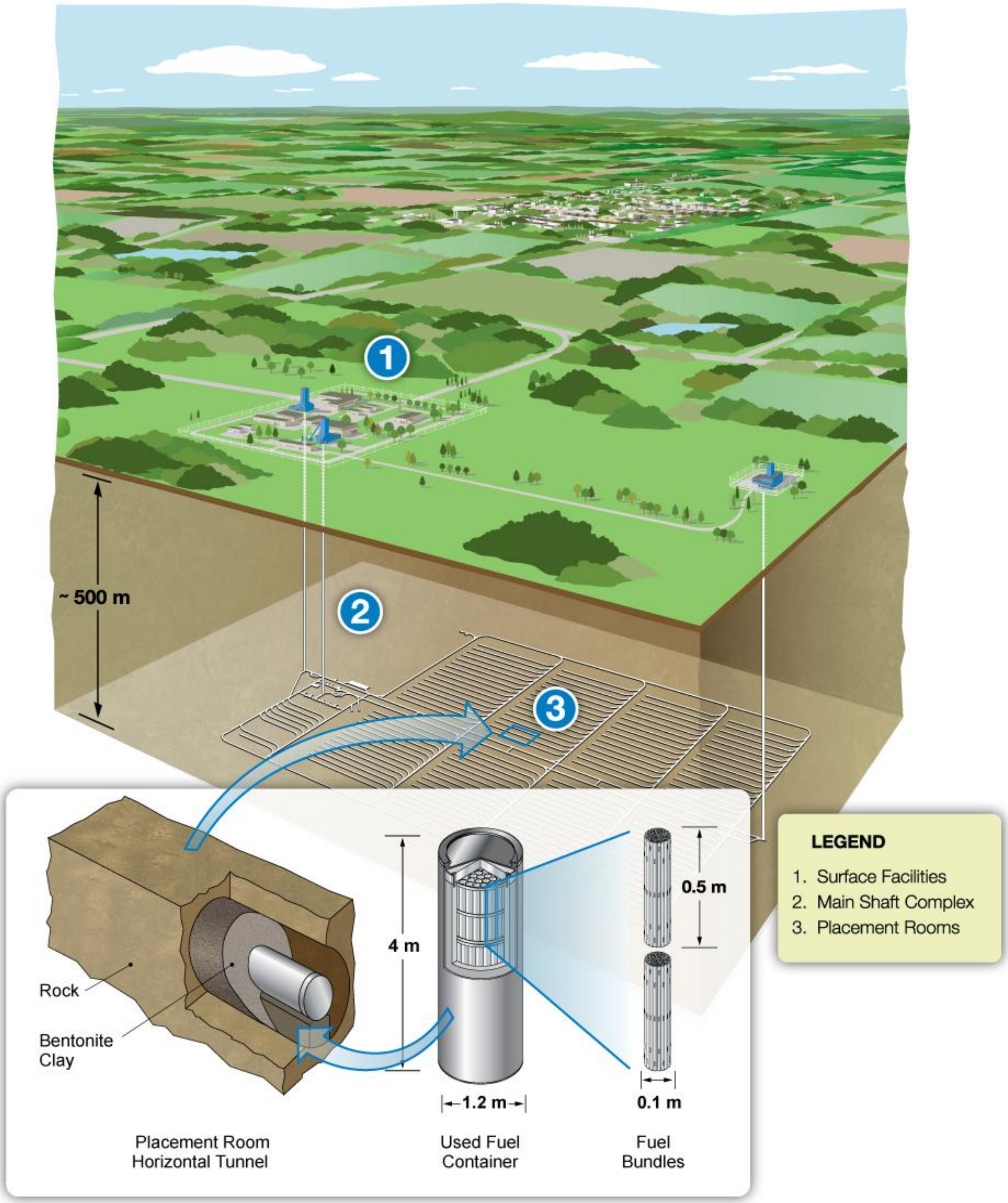

Figure 7. Illustration of a deep geological repository in sedimentary rock with horizontal tunnel placement of used fuel containers.

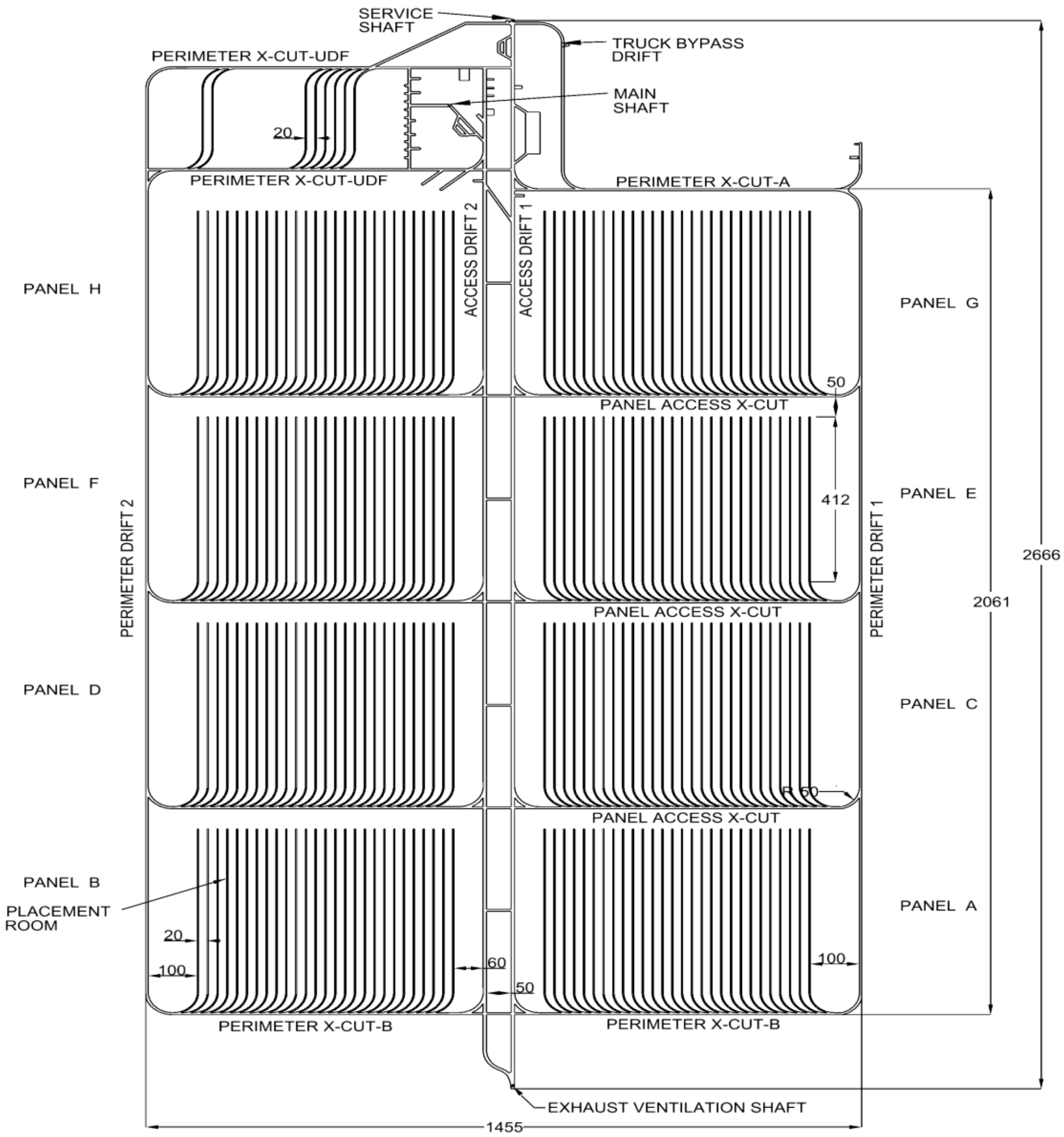

Figure 8. Underground repository layout for the horizontal tunnel placement method.

4. CONCLUSIONS

NWMO is implementing Adaptive Phased Management for long-term management of Canada's used nuclear fuel. Adaptive Phased Management includes the development of a deep geological repository to safely contain and isolate used fuel in a suitable host rock formation.

Conceptual designs for a deep geological repository have been developed for various used fuel container placement configurations and host rock formations since the mid-1970s. Recently, reference conceptual repository designs have been prepared for a facility in crystalline rock and in sedimentary rock. The reference repository design in crystalline rock is based on the in-floor borehole approach for container placement. The reference repository design in sedimentary rock is based on horizontal tunnel approach for container placement. All conceptual repository designs include extended monitoring of the facility and provisions for the retrieval of used fuel containers, if required. These conceptual designs will be used to support a pre-project review of repository design and safety by the Canadian Nuclear Safety Commission.

NWMO is continuing to study and develop designs and options for used fuel container materials, container placement methods, rock excavation techniques, underground layouts and other features of a deep geological repository. Refinement and final selection of these repository designs will be based on further design optimization studies and safety analyses, as well as the characteristics and features of the preferred site selected for Canada's used nuclear fuel.

5. REFERENCES

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