GENTILLY 2 NGS RECENT FUEL EXPERIENCE

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ABSTRACT

In the CANDU 6 Gentilly 2 reactor, the 37-element fuel has provided a good record of safe, economic and reliable plant operation for almost 18 years. The fuelling cost is among the lowest in the world due to high neutron economy, simple fuel design, and judicial fuelling scheme. The reliability of fuel is high; only 22 of the 75 760 bundles irradiated at Gentilly 2 at the end of 2000 were confirmed defective and during a five-years period from March 1992 to February 1997 saw no defect at Gentilly-2. Also, thanks to the on-power refuelling capability and an effective defect detection and removal system, the primary coolant loops are kept clean (very low activity level) benefiting both maintenance and safety.

The post-irradiation examinations and the findings from our ongoing R&D program suggest that the fuel behavior in reactor are basically as originally anticipated, despite an evolutionary 3% increase in bundle uranium mass in the 1980's. For operating conditions, the fuel performance parameters were found to be within the expected range.

1. INTRODUCTION

Gentilly 2 NGS is a single unit CANDU 6 PHW[1] type station located on the south shore of the St-Lawrence River, at about 15 km southeast of the city of Trois-Rivières (Québec). The Gentilly 2 station was built, commissioned and operated since in service by Hydro-Québec. Hydro-Québec operates only one nuclear power station, i.e. Gentilly 2.

Since in service (October 1983), Gentilly 2 NGS have provided a solid overall performance. The life gross capacity factor of the station is around 80% to 82%. It should be mentioned that in the early four years of operation, Gentilly 2 station was not allowed to produce at full power because of grid surplus situation.

The motivation of this paper is to update a general assessment of fuel performance with focus on normal operation. The presentation will begin with a short review of fuel performance. This will be followed by relevant data about post-irradiation examinations, current operating practices and fuel operation flexibility. The presentation ends with some informations about Gentilly 2 diversification (Cobalt 60 irradiation) CANFLEX fuel and spent fuel dry storage.

[1] CANDU - CANada Deuterium Uranium; PHW - Pressurized Heavy Water

2. FUEL CONDITION

2.1 Performance

Excellent fuel performance at Gentilly 2 NGS confirmed the enviable record of safe, reliable and economic operation of CANDU 6 reactors. The fuel defect rate in the reactor have been low: from a total of 75 760 bundles irradiated at the end of December 2000, only 22 bundles were found defective obtaining a defect rate of 0.029% on bundle basis or 0.00078% on element basis. Most of these defects (11 or 50%) occurred in the first two years of operation (Reference 1). In a five-year period (March 1992 - February 1997), Gentilly 2 NGS was operating defect free (Figures 1 and 2).

The known defects have been attributed to manufacturing faults (15), on debris fretting (3) and four defects had unknown causes. There have not been any defect attibuable to sheath stress-corrosion-cracking (SCC) associated with power ramp.

The annual average bundle exit burnup since 1986 was kept between 175 and 190 MWh/kgU (Table 1). This was achieved through upgrading of heavy water, decrease of excess reactivity, increase in uranium content in fuel, and appropriate fuelling scheme.

The excellent fuel performance has been made possible by a combination of sound design, quality fabrication, strong R&D support, prudent reactor operation and rapid response from industry to prevent problem escalation.

Uranium Mass Bundle

The average uranium mass of Gentilly 2 fuel after 1988 gradually increased from 19.2 kgU/bundle to around 19.3 kgU/bundle (Figure 2). The highen uranium mass of fuel represents an increase of 3% compared to the lower uranium mass fuel produced in the early 1980 (18.7 kgU/bundle). Our experience shows that the increase in the uranium mass have no adverse effect on the overall fuel performance (References 2 and 3). Indeed, the higher density of pellets around 10.75 Mg/m^3 would result in higher thermal conductivity, lower UO_2 temperature and fission gas releases thus outweighing the minimal adverse effect of minor increase of sheath strain, ridge height and reduced porosity of pellets. Other fuel performance parameters, including CANLUB retention, sheath oxidation and hydriding / deuteriding and pellets cracking showed no dependence on the density; it is mainly the internal clearances that have a dominant effect on sheath strain (Reference 4).

2.2 Post Irradiation Examination

A review of all available post-irradiation examination (PIE) data obtained over the past 20 years indicates that the 37-element fuel's sheath strain and fission gas releases were generally mild and small under operating condition applicable to CANDU 6 reactors (Reference 5). For typical Gentilly 2 conditions, the average tensile sheath strains on the outer elements remained at about 0.09% while the intermediate and inner elements saw small compressive strains only. The higher strains in the data bank were always associated with higher power rating and/or higher burnup that were beyond the normal range. The distribution of fission gas release averaged from 0.2% (for inner and intermediate elements) to 2.7% (for the outer elements). There is no large sheath strains or severe inter-element spacer wear that would lead to significant coolant subchannel area reduction and element bowing. Thus CHF should not have been affected to any great extent. The absence of end plate cracking and severe fretting wear also confirms the belief that resonant acoustic vibration do not exist at the Gentilly 2 station, the channels being acoustically inactive.

A more recent PIE data for two bundles Gentilly 2 bundles discharged in 1997 are consistent with the data obtained previously (Reference 3). The condition of the endplates, bearing and spacer-pads were examined in response to the 1994 AECB Generic Action Item on "Fuel Condition". Little or no evidence of wear was observed on these components. The end plates exhibited no evidence of cracking due to fatigue of DHC, such as that observed in some Darlington and Bruce reactors. The results also show that element residing in both the top and bottom of the channel exhibited similar, normal performance. This implies that any flow increase over the top of the bundle due to pressure tube creep up to 2.5% has a negligible effect on fuel performance. The bundle-bow measurements show that bow direction and magnitude is predominantly determined by bundle orientation in the channel.

2.3 Fuel Failure Detection

Equipped with and effective system to detect, locate and remove fuel defects, Gentilly 2 operators are able to remove defective fuel as early as optimally possible. The fuel status of the core is continuously monitored by the failed fuel detection system, commonly referred to as the Gaseous Fission Product (GFP) system. It provides the first indication of defect. Coolant samples are analyzed at the chemistry laboratory daily. The failed fuel location system, referred to as Delayed Neutron (DN) system, helps pin down which channels contains the defect by measuring the delayed neutrons emitted from sample lines attached to the outlet feeder of each channel. The Gentilly-2 experience suggests that Xe-133 is the most reliable indicator for onset of a defect, Kr-88 for indicating deterioration of sheath, I-134 for uranium release, I-131 as monitor for public safety, and Xe-135 for information about iodine release when the purification system is operational.

To keep the loop activity low for operational safety and for accidents such as iodine spiking, Gentilly 2 has kept activity levels for many years well below the targets. Figure 3 shows the average activity levels of the main fission products in the HTS in 2000. From coolant activity viewpoint, this is a clean heat transport system for both operation and maintenance. The Average Critical Public Group Doses has been maintained below 1% of the limits of 5 mSv per year stipulated in the Canadian standard (Table 2).

3. SAFETY CONSIDERATIONS

In any postulated accident, evolution of the event and hence the consequence will start from the initial condition of the fuel in the reactor. In practical terms, this initial condition is reflected by the sheath and UO_2 temperatures and deformations, fission gas release, UO_2 stoichiometry, radionuclide distribution in the element, and whether there is any defected fuel already in existence; all these combine to impact on the source term. The ability to detect and remove defective fuel helps to ensure that coolant fission product inventories are low, and that the consequence of defective fuel in accidents is minimal. Based on the excellent performance of the fuel in normal operation in terms of the number of defects and the PIE results on sheath strain and fission gas release, there is no evidence to suggest that the initial condition is not equal or better than that originally anticipated. The strict enforcement of restrictions on bundle and channel powers, further supports our view in this regard.

The initial conditions for CANDU 6 safety analyses have been based on maximum bundle power of 935 kW and maximum channel power of 7.3 MW. Since 1996, to account for uncertainties involved in the calculation of reactor power, Gentilly 2 introduced stricter operating limits of 891 kW (for maximum bundle power) and 7.01 MW (for high power channels),. The record for the previous years showed that the limit for maximum bundle power was met, while the maximum channel power was exceeded three times, each time the result was an imposed reduction of reactor power to ensure compliance with the operationnal limit These statistics demonstrate that the fuel has been operated strictly within their analyzed limits.

4. OPERATION FLEXIBILITY

Low Power Operation

During the first four years of operation (1983 to 1987), an over-capacity existed in Hydro-Québec's power system and Gentilly-2 was operated at only 50% of its rated capacity over long periods of time. Mainly through prudently managing power rise from low power, Gentilly 2 went through several high-low-high cycles without any fuel failure (Reference 3).

Shim Mode

One unique CANDU feature which deserves credit is "shim" operation (Reference 6). Shim capability permits continued reactor operation near full power or at reduced power, depending on the duration of the fuelling machine unavailability. The process involves using the adjusters to add or remove small amounts of reactivity. The local power perturbations caused by adjuster's withdrawal must not cause fuel failures. Shim operation was necessary on two occasions at Gentilly. The first lasted about ten days in late 1989, with reactor power down to 87%. The second lasted four months starting in February 1990. During this period, reactor operation continued at various power levels, including a five bank shim operation for two months at 50% power. In view of the relatively high burnup of the fuel in the core, some consideration was given to the rate of power rise when Gentilly 2 was returned to full capacity following the sustained shim operation. No fuel defects occurred during adjuster removal or during the return to full power.

5. CANFLEX[2] FUEL

Pressure tubes ageing (creep) allows some coolant to by-pass the fuel bundles along the top of the channel. When the by-pass flow becomes significant, it reduces the **C**ritical **C**hannel **P**ower (CCP). This reduction in heat removal efficiency from the bundles erodes operating margin, thus leading to a loss of operating flexibility and eventually foreing reactor power derating.

The CANFLEX bundle could compensate for some of the ageing effects. In addition to the normal spacer and bearing pads, CANFLEX bundles have CHF (**C**ritical **H**eat **F**lux) enhancement "buttons". These small appendages combined with a slightly smaller cross-sectional area act to improve the CHF and CCP of CANFLEX fuel ratings.

The CANFLEX fuel is the product of a joint projct between AECL (**A**tomic **E**nergy of **C**anada **L**td) and KAERI (**K**orean **A**tomic **E**nergy **R**esearch **I**nstitute). The CANFLEX bundle contains 43 elements and uses 2 elements diameters (15.2 mm near the center and 11.5 mm in the outer 2 rings). The bundle is compatible with the fuelling machine for 37 elements bundle.

Presently, Hydro-Québec is studying in conjunction with the life extension project, the possibility to use the CANFLEX fuel at Gentilly 2 NGS.

6. COBALT IRRADIATION

Besides generation of nuclear power, the Gentilly 2 NGS produces Cobalt-60 for use in medicine and industry. Under a new contract with MDS-Nordion, the production of Cobalt-60 resumed in 1997. Since then, Gentilly 2 produced Cobalt-60 having an average of about 3.7 millions curies each year.

7. SPENT FUEL DRY STORAGE EXPERIENCE

In order to provide the needed interim storage facility for the spent fuel, Hydro-Quebec chose the dry storage CANSTOR module developed by the Atomic Energy of Canada Ltd (Figure 4). The decision was made based upon the technical feasibility, public and environmental protection criteria, operational flexibility, economic and space saving advantages (Reference 7). Before the commissioning of the spent fuel dry storage facility, the project received all the required approvals. A joint provincial - federal public hearings was held in summer of 1994 in order to assess the project in term of its impact on the environment.

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[2] CANFLEX – CANDU FLEXible fuelling.

In September 1995 took place the first transfer of spent fuel from the station bay to the dry storage facility and since then 42 000 bundles were transferred in four CANSTOR modules built on the station site located within the protected area of the Gentilly-2 station. To date, the expected performance of the dry storage units and equipment have been met.

One CANSTOR module can accommodate 12000 fuel bundles stored in 200 sealed stainless steel baskets kept in 20 storage cylinders (10 baskets per cylinder). The cylinders are enclosed in a single vault-like cavity. The minimum required cooling period of fuel before the dry storage is 6 to 7 years.

Shielding and Safety Features

The walls of 0.96 m. thick and the top slab 1.07 m. thick provide the required shielding of the CANSTOR module. The design dose rate on contact (at module concrete wall) is maximum 25 μSv/h and at the storage site fence maximum 2.5 μSv/h.

CANSTOR modules, have two physical barriers enclosing the spent fuel: **a) the spent fuel basket** (a stainless steel seal-welded cylinder containing 60 fuel bundles); **b) the storage cylinder** (a steel container that is seal-welded to its permanent cover). The integrity of the two barriers are monitored by an air sampling system that monitors the captive air for possible leaks from the exterior or from the baskets.

Preparation and Transfer Operation

The team in charge of the preparation and transfer of the irradiated fuel from the station bay to the dry storage site is composed of for or to five persons: two operators (at the bay), one welder and one or two other operators (for transfer operation including CANSTOR loading). On average, three baskets (180 irradiated bundles) are processed from the bay to CANSTOR module in one day of 12 hours operation.

CANSTOR Module Cost

The total cost (in 1999) of a CANSTOR module (including the 200 stainless steel storage baskets and 20 storage cylinders) is around 2,5 millions Can$ or 10,8 Can$/kgU stored (7,20 US$/kgU stored). Site preparation cost as well as the cost for the equipment required are not included.

8. CONCLUSION

Overall, the fuel performance at Gentilly 2 NGS was excellent. The current uranium mass around 19,3 kgU of fuel had shown no adverse effect. Fuel defect rate has been low, heat transport system is clean. The Average Critical Public Doses are below 1% of the allowable dose limit. Fuel design has proved to be robust and resilient to operational transients.

CANDU 6 fuel has maintained a high degree of dimensional stability, partly due to absence of pulsating flow in the heat transport system and partly due to support of fuel string by shield plugs. As a result, the interaction with pressure tube and the effect on CHF strain or wear are held to a minimum.

The excellent CANDU 6 fuel performance should be attributed to the combination of sound design, quality fabrication, strong COG R&D support, and prudent reactor operation.

In order to reduce some of the ageing effects of the station, Hydro-Québec is studying the possibility to use CANFLEX fuel.

The Cobalt-60 irradiation resumed in 1997 with about 3,7 millions Curies produced annually. No adverse effect was observer on station operation.

To date, the overall performance of the interim dry storage of irradiated fuel at Gentilly 2 NGS was good and all the expected performance have been met. At the end of 2000, a total of 42 000 irradiated bundles were transferred from the station bay to the AECL type CANSTOR modules.

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TABLE 1
GENTILY-2 DISCHARGE IRRADIATION AND FUELING DATA
(decenber 31, 2000)

DATE	BUNDLES DISCHARGED		EFPD	DISCHARGE AVERAGE BURNUT MWH/KCU		FUELING DATE (bundles/ EFPD) FOR THE YEAR
	SINCE IN SERVICE (cumulative)	FOR THE YEAR	(cumulative)	SINCE IN SERVICE (cumulative)	FOR THE YEAR	
Decembre 31, 1984	4770	3770	362,1	131,9	141,5	16,5
Decembre 31, 1985	8082	3312	576,0	147,2	168,8	15,5
Decembre 31, 1986	11934	3852	832,0	157,4	179,5	15,0
Decembre 31, 1987	16506	4572	1140,1	165,3	186,1	14,8
Decembre 31, 1988	21466	4960	1485,7	170,8	188,9	14,4
Decembre 31, 1989	26106	4640	1804,1	173,7	187,1	14,6
Decembre 31, 1990	30328	4222	2074,9	175,1	183,7	15,6
Decembre 31, 1991	34296	3968	2334,1	174,8	172,6	15,3
Decembre 31, 1992	39008	4712	2641,6	174,9	175,6	15,3
Decembre 31, 1993	43780	4772	2960,0	175,5	180,7	15,0
Decembre 31, 1994	49084	5304	3315,6	176,0	180,5	14,9
Decembre 31, 1995	53644	4560	3614,0	176,5	180,7	15,3
Decembre 31, 1996	58788	5144	3956,9	176,7	178,9	15,0
Decembre 31, 1997	63112	4324	4324,3	176,5	174,7	15,6
Decembre 31, 1998	67012	3900	4487,4	176,5	176,4	15,4
Decembre 31, 1999	70876	3864	4738,2	176,6	177,3	15,4
Decembre 31, 2000	75756	4880	5061,2	176,6	177,6	15,1
				SINCE IN SERVICE:		14,97

A13D6

TABLE 2

Average Critical Public Group Doses From Gentilly-2 NGS

1983	0,0045 mSv
1984	0,0022 mSv
1985	0,0105 mSv
1986	0,0061 mSv
1987	0,0067 mSv
1988	0,0073 mSv
1989	0,0069 mSv
1990	0,0077 mSv
1991	0,0095 mSv
1992	0,0185 mSv
1993	0,0171 mSv
1994	0,0128 mSv
1995	0,0175 mSv
1996	0,0172 mSv
1997	0,0073 mSv
1998	0,0059 mSv
1999	0,0054 mSv
2000	0,0080 mSv

Max allowable: 5,00 mSv

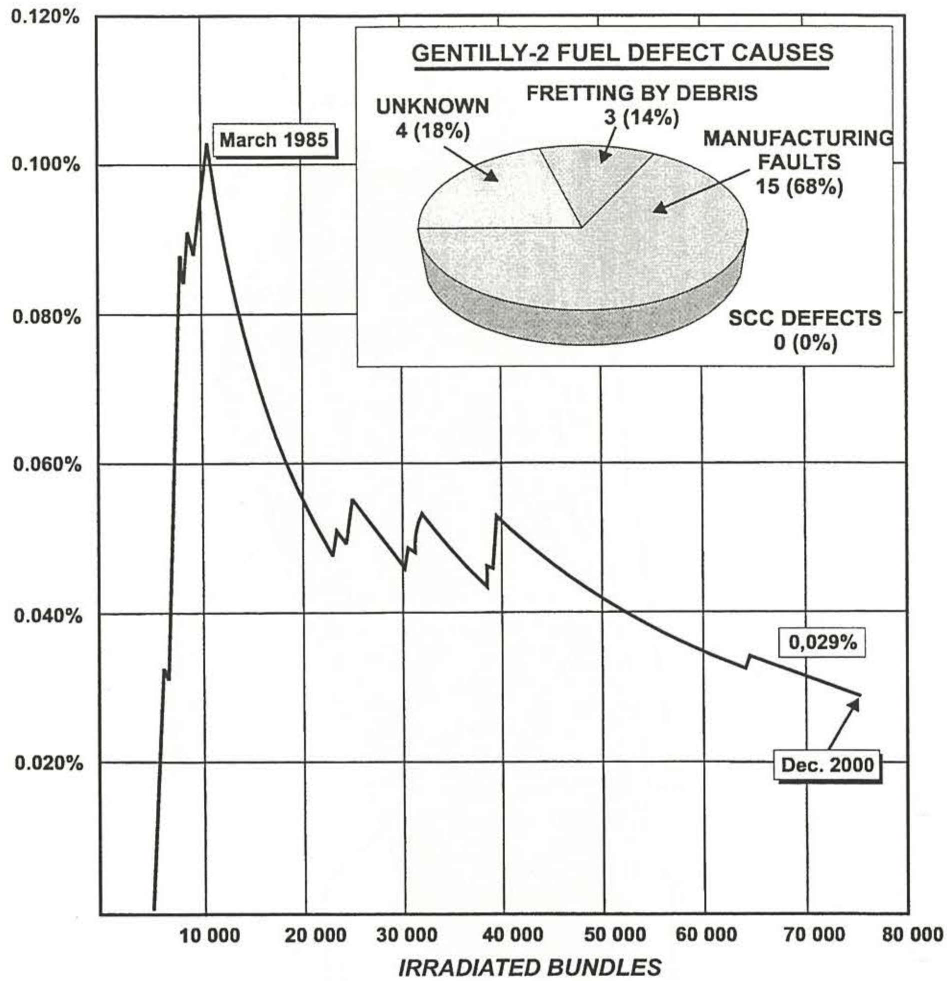


Figure 1 Defect Rate of Fuel at Gentilly-2 NGS

A13D3

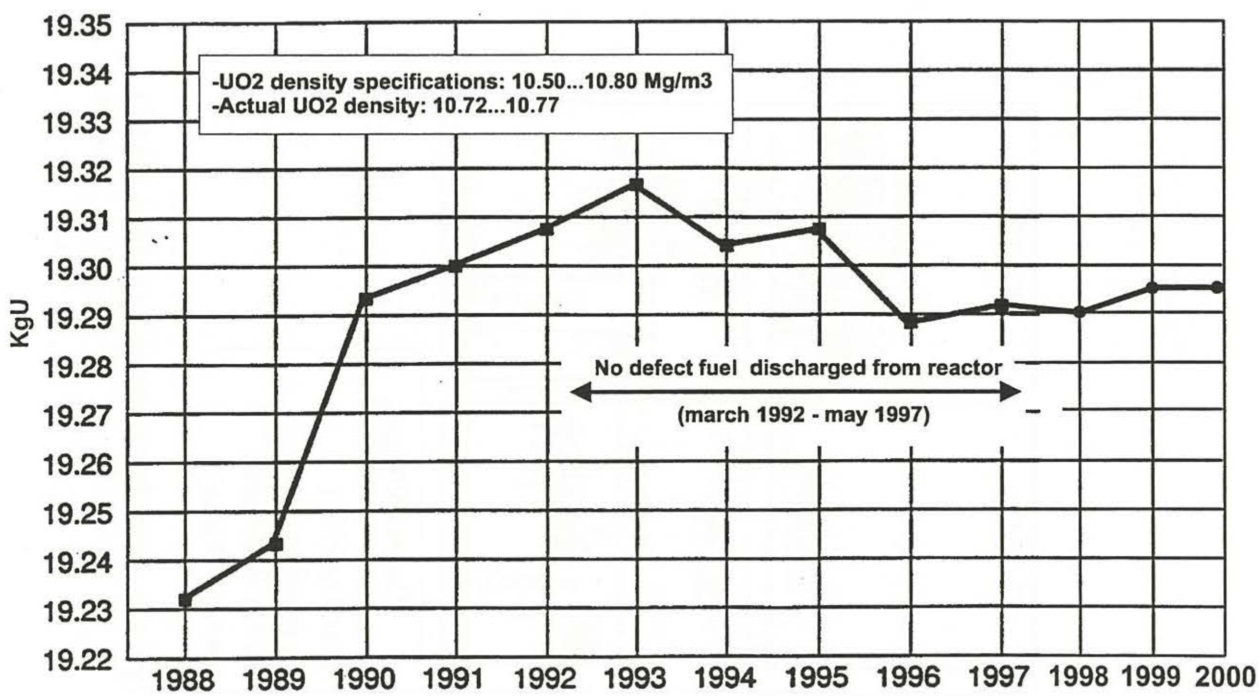
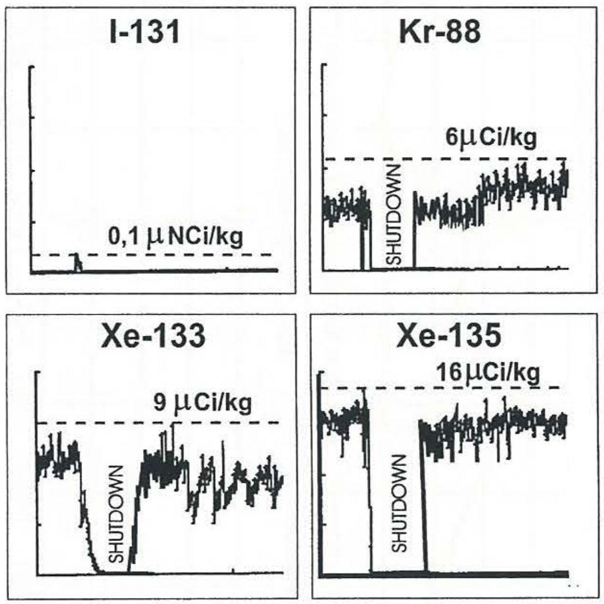


Figure 2 Average Uranium Bundle Weight in Reactor Core.

A13D2



Target Values

I 131 < 5 µCi/kg
Kr 88 < 15 µCi/kg
Xe 133 < 50 µCi/kg
Xe 135 < 60 µCi/kg

Figure 3 Activity in Gentilly-2 HTS (2000)
A13D1

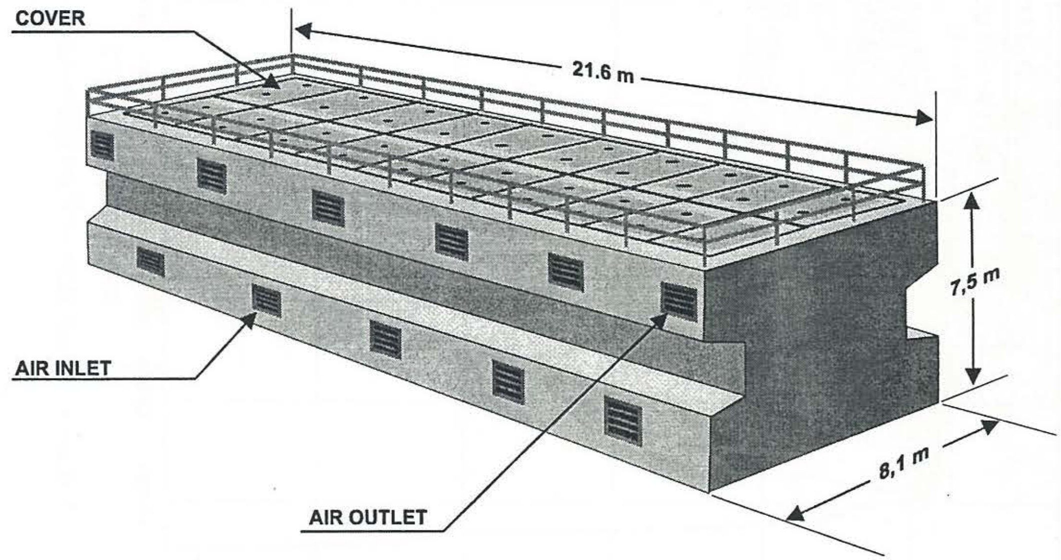


Figure 4 CANSTOR MODULE VIEW
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