

Canister Conditioning & Stabilization (Dry Packaging) Technologies For Spent Fuels (CANDU SC108 & PWR SC-21 CASKS) Possibility For TRISO Spent Fuels (HTGR)



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Pakistan Atomic Energy Commission

**IAEA Technical Meeting Management of Spent Fuels (Pebbles, Compacts) From
High Temperature Reactors**

7 ~ 11 July 2025, Vienna, Austria.

OUTLINES

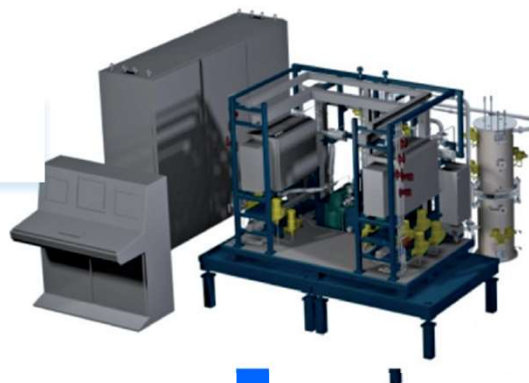
1. Spent Nuclear Fuel Cycle All Types (Generalize Flow)
2. Spent Fuels All Types & Worldwide Dry Storage Systems
3. Regulatory Requirements & Objectives (Dry Packaging)
4. Spent Fuel & Interim Dry Storage Facilities (Pakistan)
5. CANDU, PWR Canister Dry Packaging (Worldwide, Pak)
7. HTGR (Pebbles) Canister Internal Conditioning
8. Comparative Aspects Canister Conditioning Technologies (CANDU CASK SC108 & PWR CASK SC21) & Option for Canister of TRISO Spherical Pebbles of HTGR
9. Summary, Conclusion



**NUCLEAR POWER
PLANT**

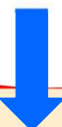


1- WET STORAGE



2- DRY PACKAGING

Canister Conditioning
Stabilization
ASTM-1553, 2021
NUREG-1536



3- DRY STORAGE



4A-Final Disposal



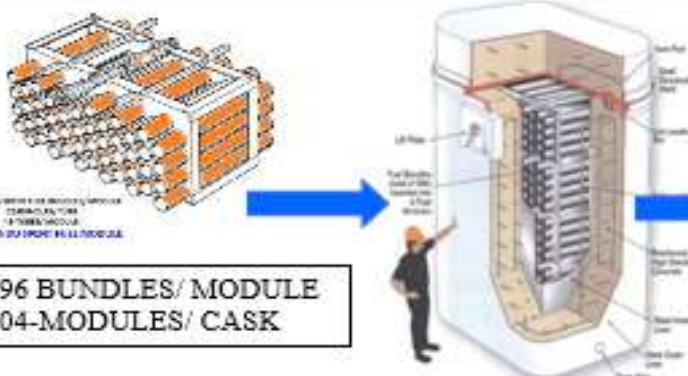
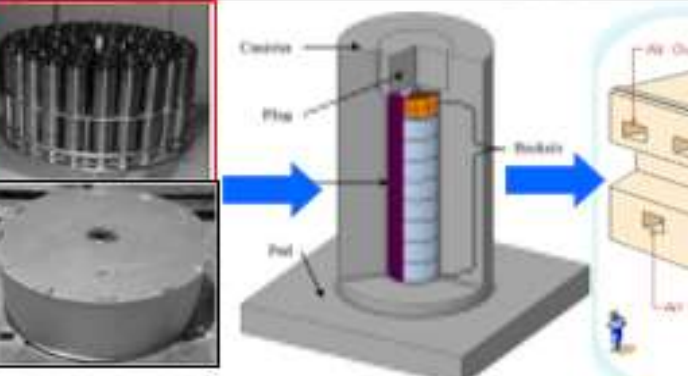
4B-Reprocessing

MOF FUELS

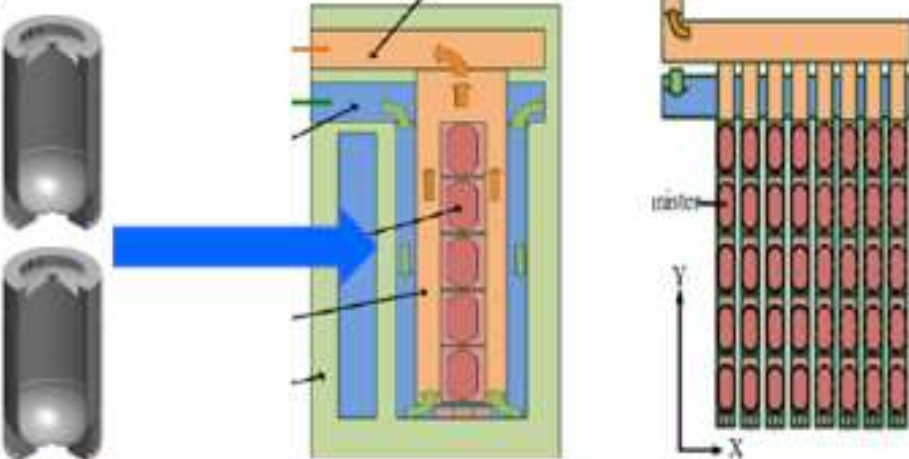


**SPENT
NUCLEAR FUEL
CYCLE**

Spent Fuels & Worldwide Dry Storage Systems

FUEL TYPE	STORAGE SYSTEM	DRY STORAGE (PACKAGING)	
<u>CANDU</u>	<u>DSC CASK</u> SPENT FUEL in BUNDLES in MODULES in CASK	 96 BUNDLES/MODULE 04-MODULES/ CASK	
	<u>MACSTOR</u> SPENT FUEL in BASKETS in CYLINDERS SILOS		
<u>PWR</u>	<u>CASK</u> SPENT FUEL in CANISTERS in CASK	PWR Dry Storage & Transfer Cask, Fuel  Fuel Storage Cask (See Fig. 10.10) MW = 1700 Tons Fuel Transfer Cask (See Fig. 10.11) MW = 1700 Tons Fuel Canister (See Fig. 10.12) MW = 24 Tons	

Spent Fuel & Dry Storage Systems (Worldwide)

FUEL TYPE	STORAGE SYSTEM	DRY STORAGE SEQUENCES
<u>TRISO FUEL</u>	<u>CANISTERS</u> SPENT FUEL in CANISTERS in STORAGE WELL	 The diagram illustrates the process of moving spent TRISO fuel from a storage well into a dry storage cask. On the left, two TRISO fuel pebbles are shown. A large blue arrow points from these pebbles into a central vertical storage well. The well is shown in cross-section, revealing a central column of fuel pebbles surrounded by a moderator and reflector. To the right, a dry storage cask is shown in cross-section, with a vertical column of fuel pebbles being inserted. A coordinate system with X and Y axes is shown next to the cask.
<u>SPHERICAL PEBBLES</u>	<u>CANISTERS</u> SPENT FUEL in CANISTERS in WET POOL/ CASK	 The photograph shows a large number of yellow cylindrical canisters arranged in rows on a green floor. A blue arrow points from a canister in the foreground towards the background, indicating the sequence of storage. The canisters are arranged in a grid-like pattern, with some canisters having white caps.

Regulatory Requirements

Spent Fuel Conditioning & Stabilization

Dry Packaging Acceptance Criteria

ASTM-C1553-16, NUREG-1536

- 1> $SVP \leq 4.0 \times 10^{-4} \text{Mpa} \leq 3 \text{Torr (4mBar)} \geq 30 \text{min}$
 - 2> **PDP (Dew Point) $\leq -05.05^{\circ}\text{C}$, EMC $\leq 3.2 \text{gm/m}^3 \geq 30 \text{min}$**
-

Dry Packaging Cover Gas Backfill Criteria

PNL-6365, USNRC DOCKET# 72-1014-06

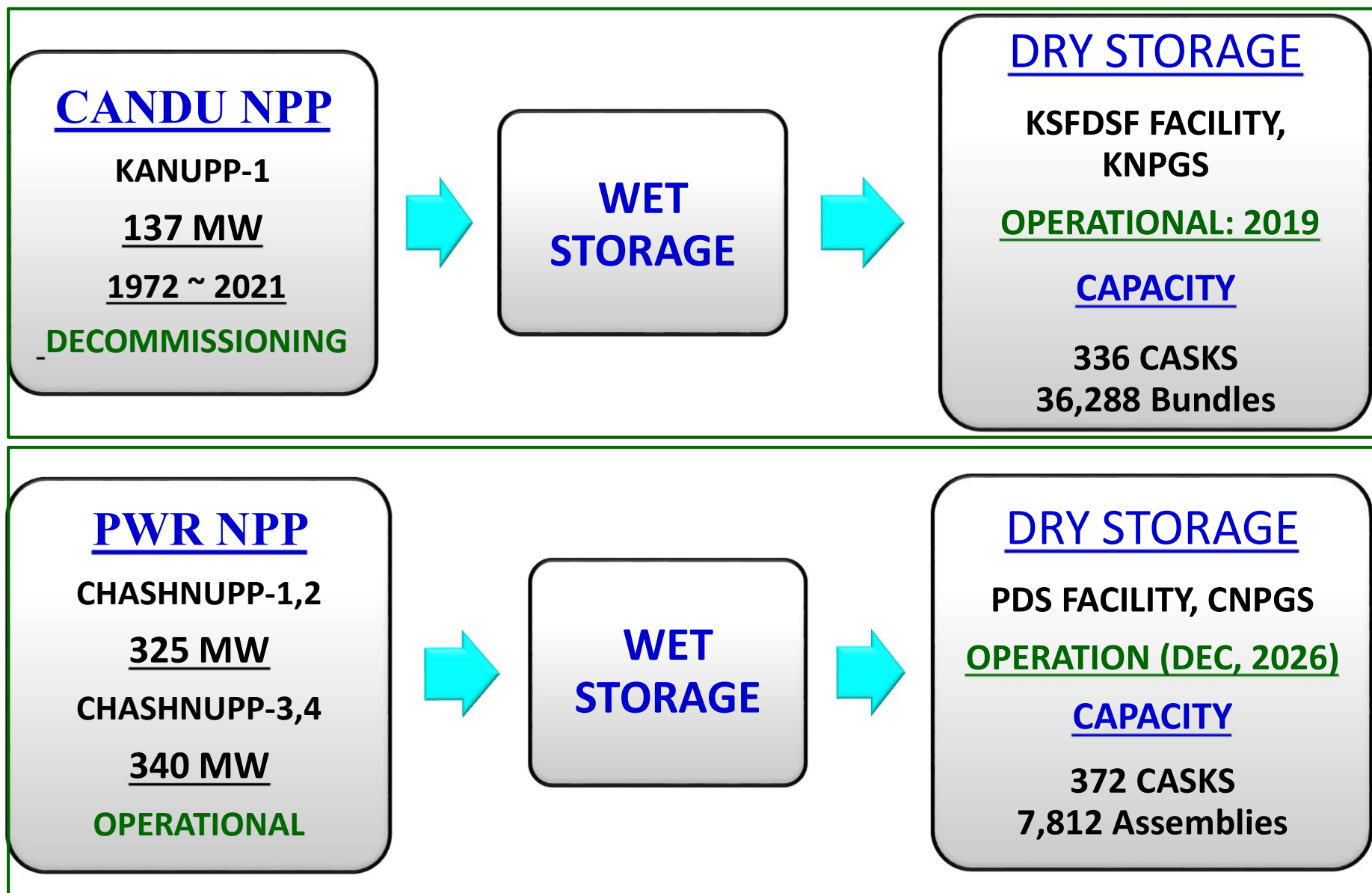
- 1> Gas Purity (Grade) $\geq 99.9995\%$ (N5)
- 2> Backfill Operation = Sub-atmospheric
- *3> Dry Packaged Cover Gas Pressure = 80Kpa ~ 800KPa
- ***BASIS:** Spent Nuclear Fuel (Type, Burnup, Decay Heat, Cooling Time)

OBJECTIVES

Canister Cond., Stabilization (Dry Packaging)

- Ensure Integrity Spent Nuclear Fuel (Reliable Stored)
- Fulfill Regulatory Requirement, Acceptance Criteria/
Rebound Test (ASTM-1553, 2021, NUREG-1356)
- Eliminate Free Trapped Moisture, Gases (Oxy, H₂)
- Prevent Degradation Mechanisms (Embrittlement,
Blistering, Swelling, Rupture etc)
- Provide Non-Corrosive Surrounding Environment
- Make Spent Fuel Retrievable (Transport, Disposal)

Spent Nuclear Fuels & Interim Dry Storage Facilities In Pakistan



CANDU SPENT FUEL CANISTER DRY PACKAGING

**CANDU
REACTOR**

KANUPP-1
Karachi.
9000MWd/MTU

**CANDU SPENT
FUEL
BUNDLES**

19 Pencils/
Bundle

**WET
STORAGE**

10 Years Cooling
Under Water
Transfer

**CASK
SC-108**

2 Baskets/ Cask
54 Bundles/
Basket

SA = 80m²
Void Volume
250L

**DRY PACKAGING
CONDITION
STABILIZE**

Spent Nuclear
Fuel Rinsing &
Bulk Water
Removal

Forced Draft Inert
Gas Hold & Eject
Cyclic Operation

Induced Draft
Inert Gas Hold &
Eject Cyclic
Operation

(UHP) Inert Gas
Backfilling at Sub-
Atmospheric
Conditions

**DRY
STORAGE**

Interim Storage

CANDU Spent Fuel Management (Worldwide)



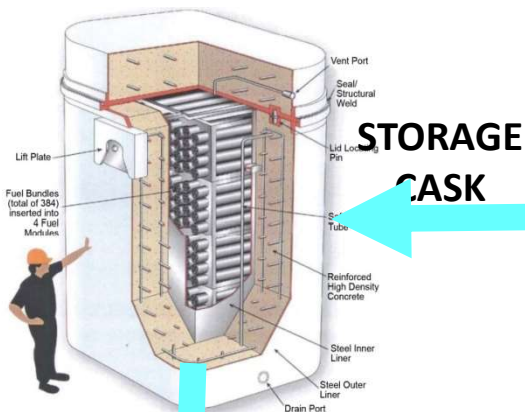
CANDU PHWR REACTOR



CANDU SNF BUNDLES



WET STORAGE POOL



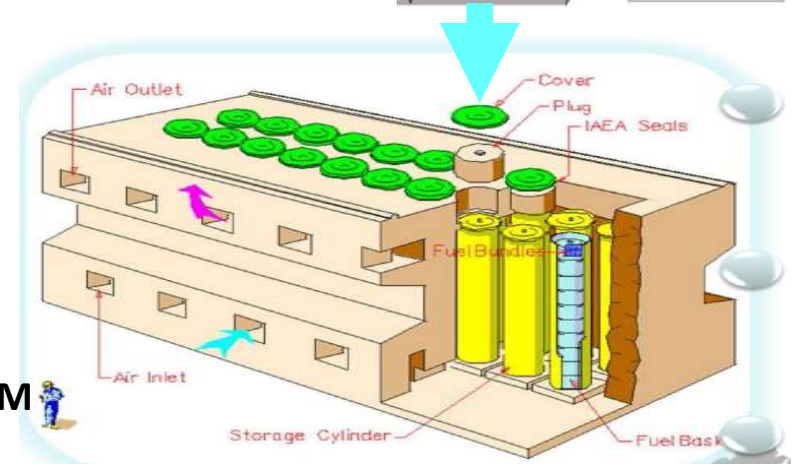
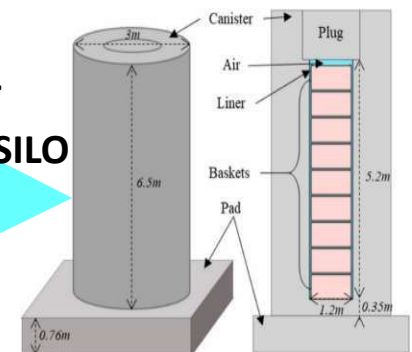
STORAGE CASK



CASKS INTERIM DRY STORAGE

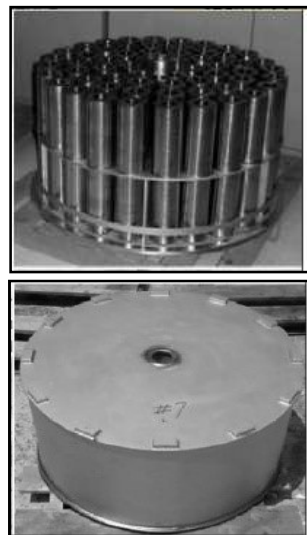
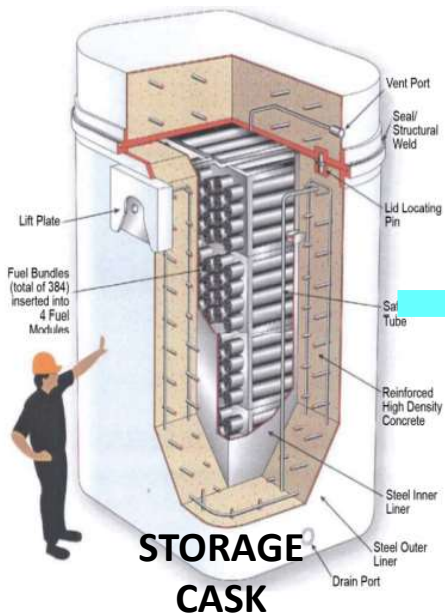
**DRY PACKAGING
CONDITIONING
STABILIZATION
ASTM-1553
NUREG-1536-Rev1**

BASKET CYLINDER, SILO



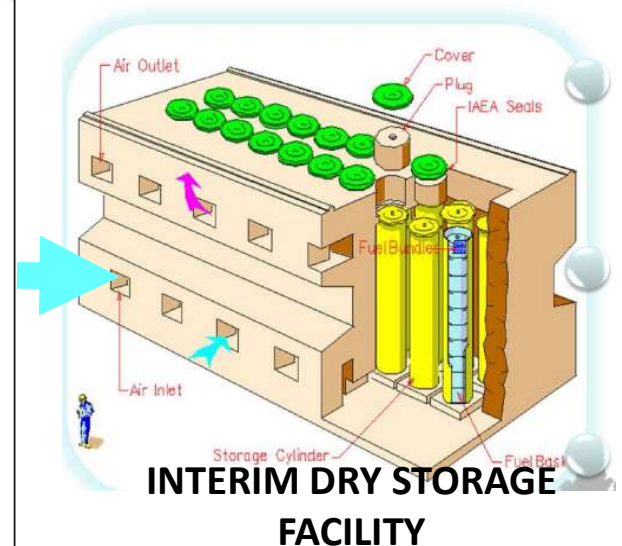
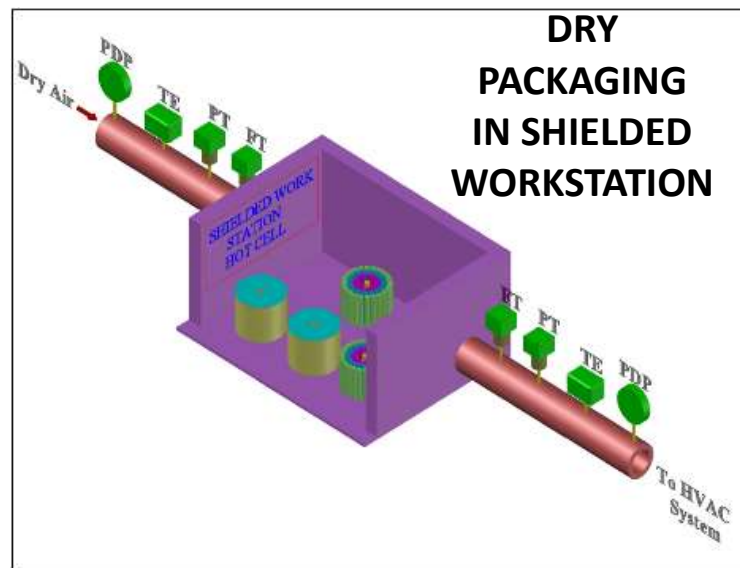
MACSTOR INTERIM DRY STORAGE

CANDU Spent Fuel Dry Packaging Pakistan



CANDU BUNDLE

BSKET



CANDU Spent Fuel Dry Packaging System (Pakistan)

Acceptance Criteria (Dry Packaging)

ASTM-C1553, NUREG-1536 (Rebound Test)

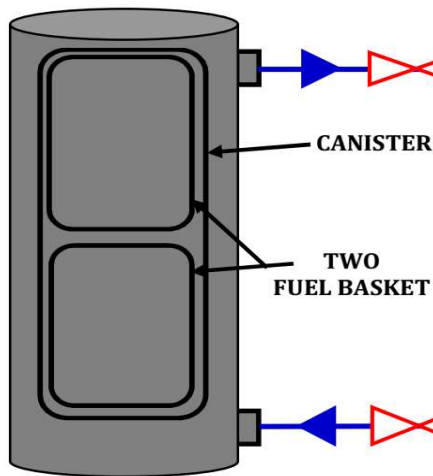
1. $SVP \leq 4.0 \times 10^{-4} \text{ Mpa} \leq 4 \text{ mBar} \leq 3 \text{ Torr} \geq 30 \text{ min}$
2. $PDP \leq -05.05^\circ\text{C}$, $EMC \leq 3.2 \text{ gm/m}^3 \geq 30 \text{ min}$

DRY PACKAGING WORKSTATION

Comp. Dry Air (CDA), Inst. Air (IA),
Power (KW), Deionized Water (DIW)
Inert Gas Manifold

ACTIVE
VENT

SC-108 CASK



BATTERY LIMITS

CANDU RINSE, BULK WATER REMOVAL

Void Volume= 250 L
 $T = 50 \sim 50^\circ\text{C}$, $P = 5 \sim 30 \text{ psig}$
Operation $\geq 45 \text{ min}$

FUNCTION

- To Displace Radiated H₂O
- To Wash CANDU Bundles

ULTRA-HIGH PURE INERT BACKFILL SUBATMOSPHERIC

Cover Gas Media= Helium
Grade= 99.995% (N5)
 $DP \leq -82^\circ\text{C}$, $P = 90 \text{ kPa}$

FUNCTION

- Provide Inert Atmosphere
- Dissipate Heat Uniformly

FORCED DRAFT INERT GAS STEPPED CYCLE SYSTEM

$T \leq 80^\circ\text{C}$, $P = 05 \sim 30 \text{ psig}$
CDA (Dew Point) $\geq -60^\circ\text{C}$

FUNCTION

- To Trap Moisture Dead Ends
- To Trap Intercepted Oxy Gas

INDUCED DRAFT STEPP CYCLES VACUUM SYSTEM

Void Volume = 250L
 $T = 70^\circ\text{C}$, Base Pressure $\leq 1 \text{ Pa}$
Target Pressure = $4 \times 10^{-4} \text{ MPa}$

FUNCTION

- Assure Removal of Moisture
- Assure Removal Oxy, D₂O etc

Conditioning & Stabilization System (DESIGN BASIS)

Average Fuel Burnup: 9000 MWD/ MTU, Fuel Type: CANDU

Decay Heat (Accumulative)/ Cask: 400W

Cooling Years (Min) Wet Pool: 10-Years, CASK: Design

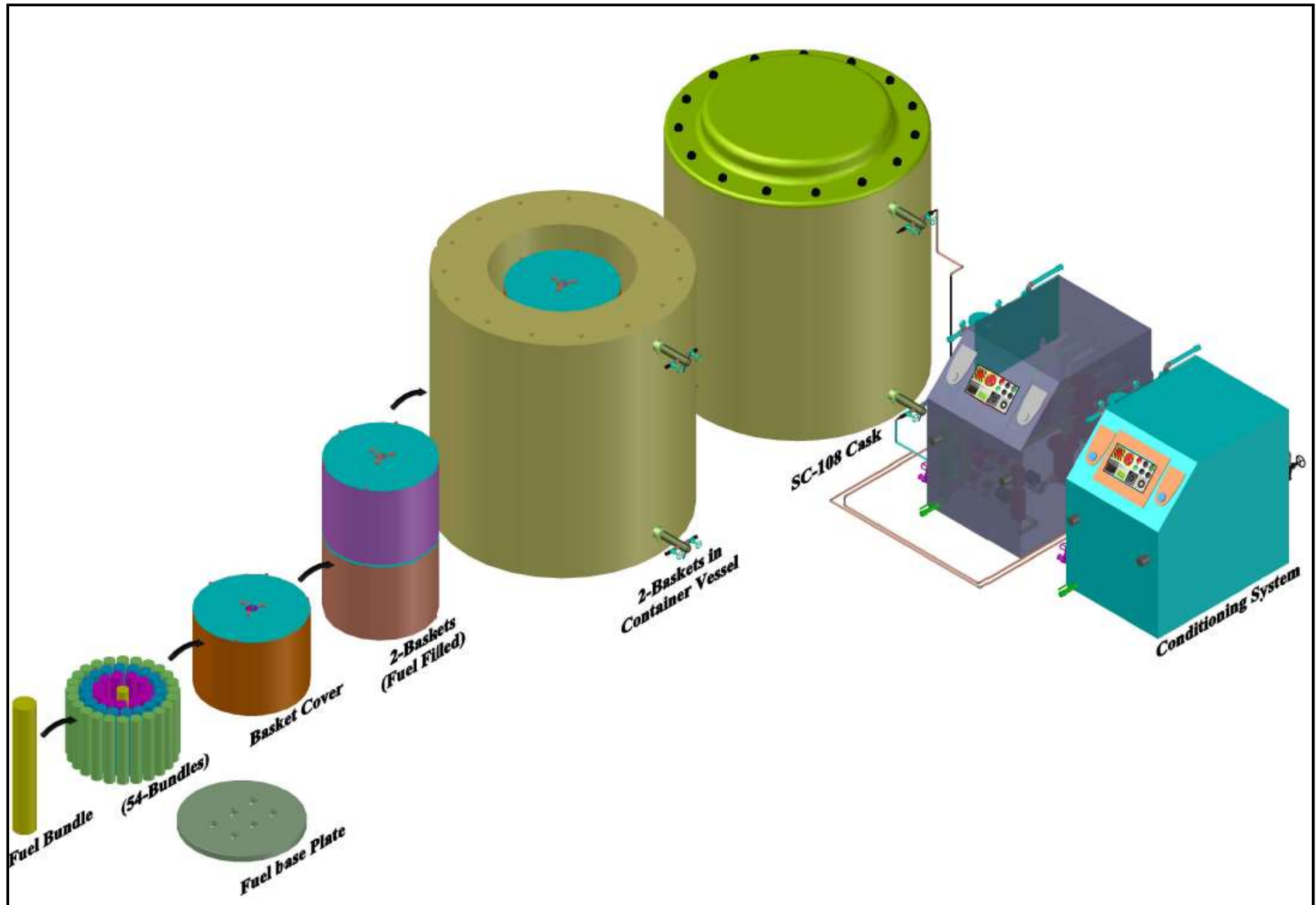
Fuel Physical State: Healthy (ASTM-1553-21)

Void Volume (Canister Vol. – Fuel Bundle Vol.): 250L

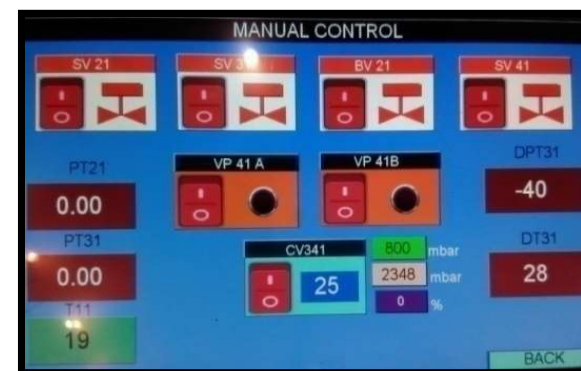
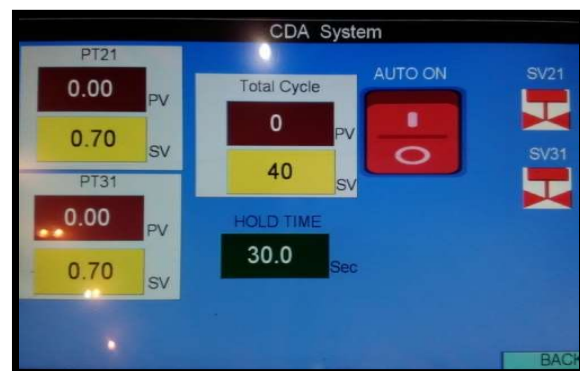
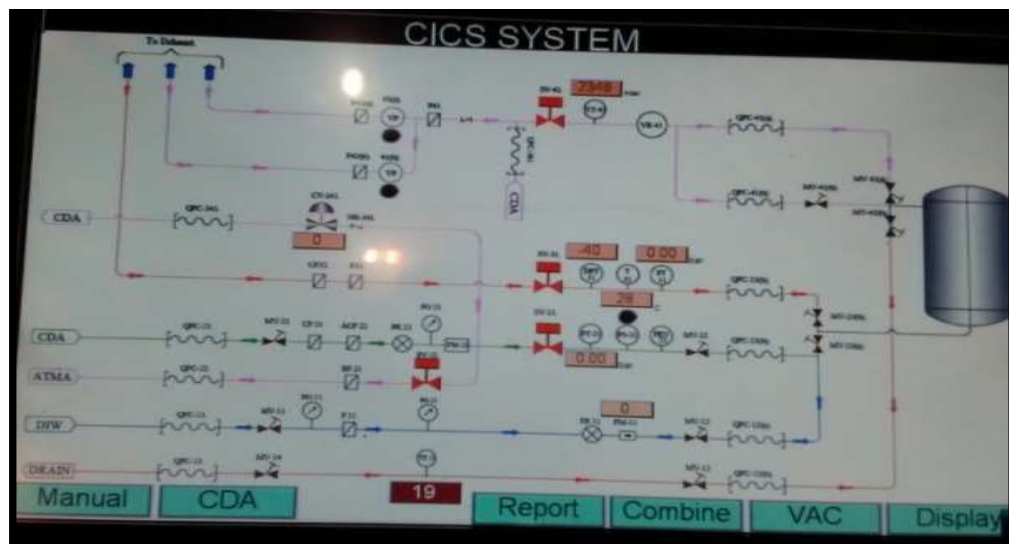
Surface Area (Interiors): 100m². Inlet/ Outlet Ports: Top & Bottom

Active
Drain

SC108 Cask Dry Storage System



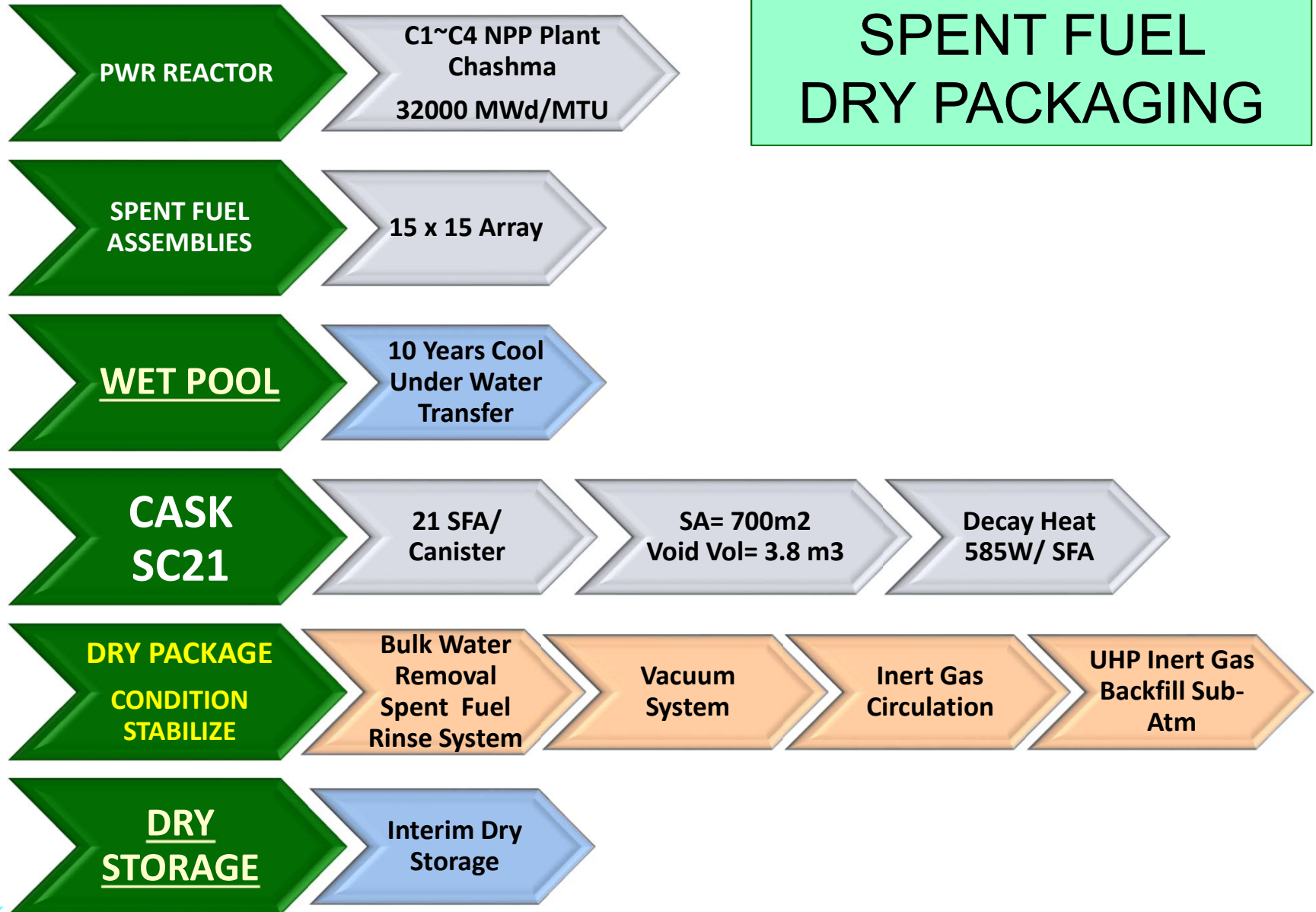
Conditioning System (Sequential Operations)



Conditioning System (Results Achieved)

Parameter	Acceptance Criteria	Results Achieved
PDP (Dew Point)	$\leq -05.05^{\circ}\text{C} \geq 30\text{min}$	$\leq -60.0^{\circ}\text{C} \geq 60\text{min}$
SVP (Sat. Vap. Pressure)	$\leq 4.0 \times 10^{-4} \text{Mpa} \geq 30\text{min}$	$\geq 6.0 \times 10^{-4} \text{Mpa} \geq 30\text{min}$
EMC (Moisture Cont.)	$\leq 03.02 \text{gm/m}^3$	$\approx 0.031 \text{gm/m}^3$

PWR SPENT FUEL DRY PACKAGING

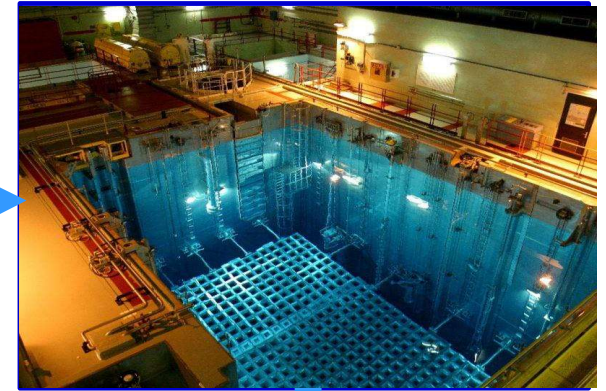
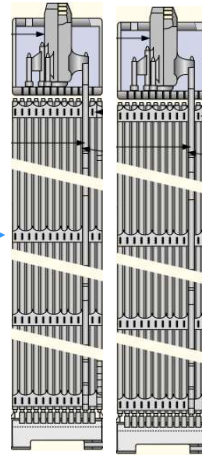


PWR Spent Fuel Management (Worldwide)



PWR REACTOR

PWR
ASSEMBLY



WET STORAGE

DRY PACKAGING
CONDITIONING
STABILIZATION
ASTM-1553
NUREG-1536-Rev1

INTERIM DRY STORAGE FACILITY



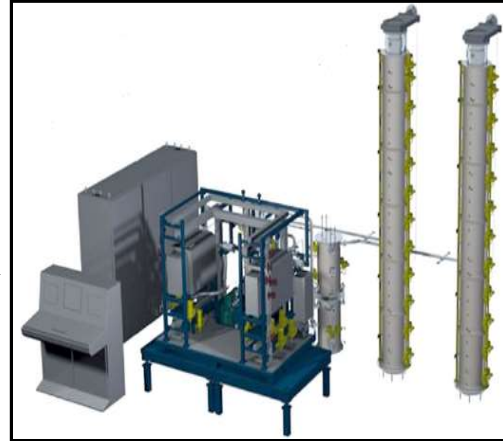
DRY STORAGE CASK



PWR Spent Fuel DRY PACKAGING Pakistan



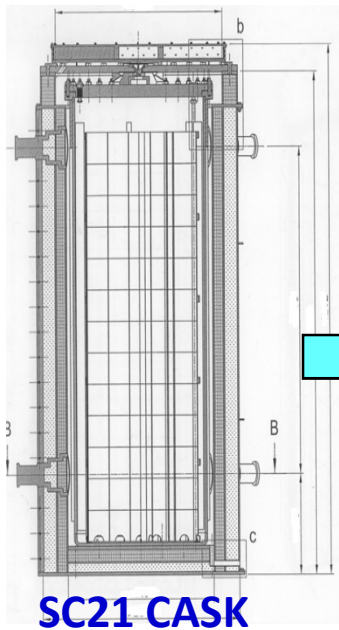
DRY STORAGE CASK



**DRY PACKAGING
(CONDITIONING)**



INTERIM DRY STORAGE



SC21 CASK

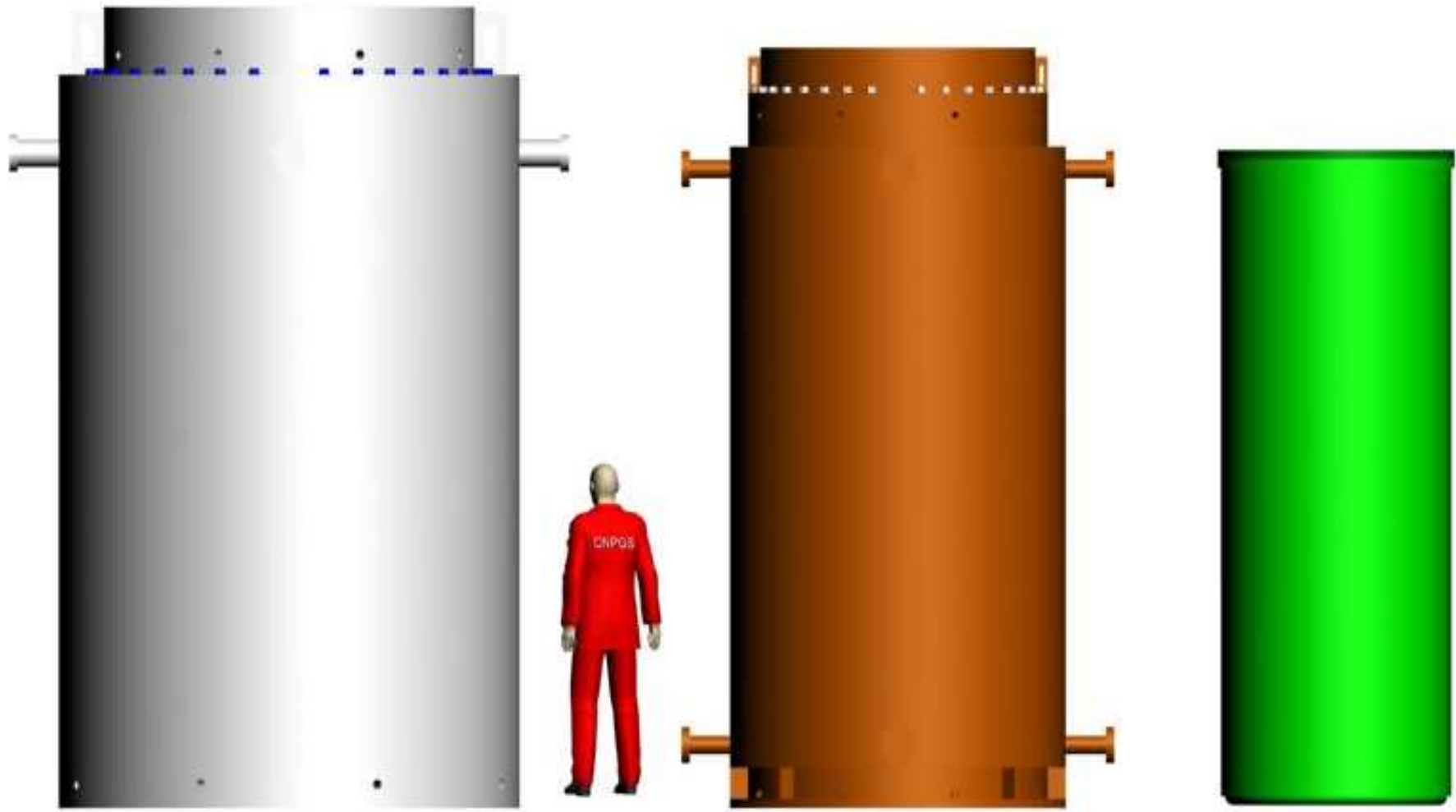


**DRY PACKAGING
(CONDITIONING)**



INTERIM DRY STORAGE

PWR Casks (SC21, TC21) & Canister (Pakistan)



Fuel Storage Cask
(Barite Filled)
Wt : ~100 Ton

Fuel Transfer Cask
(Lead + AlB4C + HDPBr)
Wt : ~70 Ton

Fuel Container
(SS304)
Wt : 16 Ton

PWR Spent Fuel Dry Packaging System Pakistan

Acceptance Criteria (Dry Packaging)

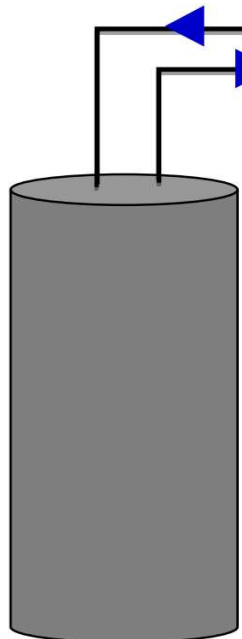
ASTM-C1553, NUREG-1536 (Rebound Test)

1. $SVP \leq 4.0 \times 10^{-4} \text{ Mpa} \leq 4 \text{ mBar} \leq 3 \text{ Torr} \geq 30 \text{ min}$
2. $PDP \leq -05.05^\circ\text{C}$, $EMC \leq 3.2 \text{ gm/m}^3 \geq 30 \text{ min}$

DRY PACKAGING WORKSTATION

Inst. Air (IA), Power (KW), Deionized Water (DIW), Inert Gas Manifold, Helium, Nitrogen Gases etc

ACTIVE VENT



**SC21
PWR CASK**

PWR RINSING BULK WATER REMOVAL

Void Volume= 4000L
 $T = 50 \sim 50^\circ\text{C}$, $P = 5 \sim 30 \text{ psig}$
Operation $\geq 45 \text{ min}$

FUNCTION

- To Displace Radiated H₂O
- To Wash PWR Bundles

ULTRA-HIGH PURE INERT BACKFILL SUBATMOSPHERIC

Cover Gas Media= Helium
Grade= 99.995% (N5)
 $DP \leq -82^\circ\text{C}$, $P = 300 \text{ kPa}$

FUNCTION

- Provide Inert Atmosphere
- Dissipate Heat Uniformly

VACUUM SYSTEM

Void Volume = 4000L

Flow: 350m³/hr

$T = 70^\circ\text{C}$, Base Pressure $\leq 1 \text{ Pa}$

Target Pressure= $4 \times 10^{-4} \text{ MPa}$

FUNCTION

- Remove Moisture, Oxy Gases
- Reduce Drying Times, Cycles

INERT MEDIA RECIRCULATION HEAT DISSIPATE SYSTEM

Inert: Helium, $T \leq 150^\circ\text{C}$,
 $P = 05 \sim 40 \text{ psig}$, $DP \leq -60^\circ\text{C}$

FUNCTION

- Rebound Test, Heat Dissipate
- Efficient Moisture Removal

BATTERY LIMITS

Conditioning & Stabilization System (DESIGN BASIS)

Average Fuel Burnup: 37000MWD/ MTU, Fuel Type: PWR

Decay Heat (Accumulative)/ Cask: 15000W

Cooling Years (Min) Wet Pool: 10-Years, CASK: Design

Fuel Physical State: Healthy (ASTM-1553-21)

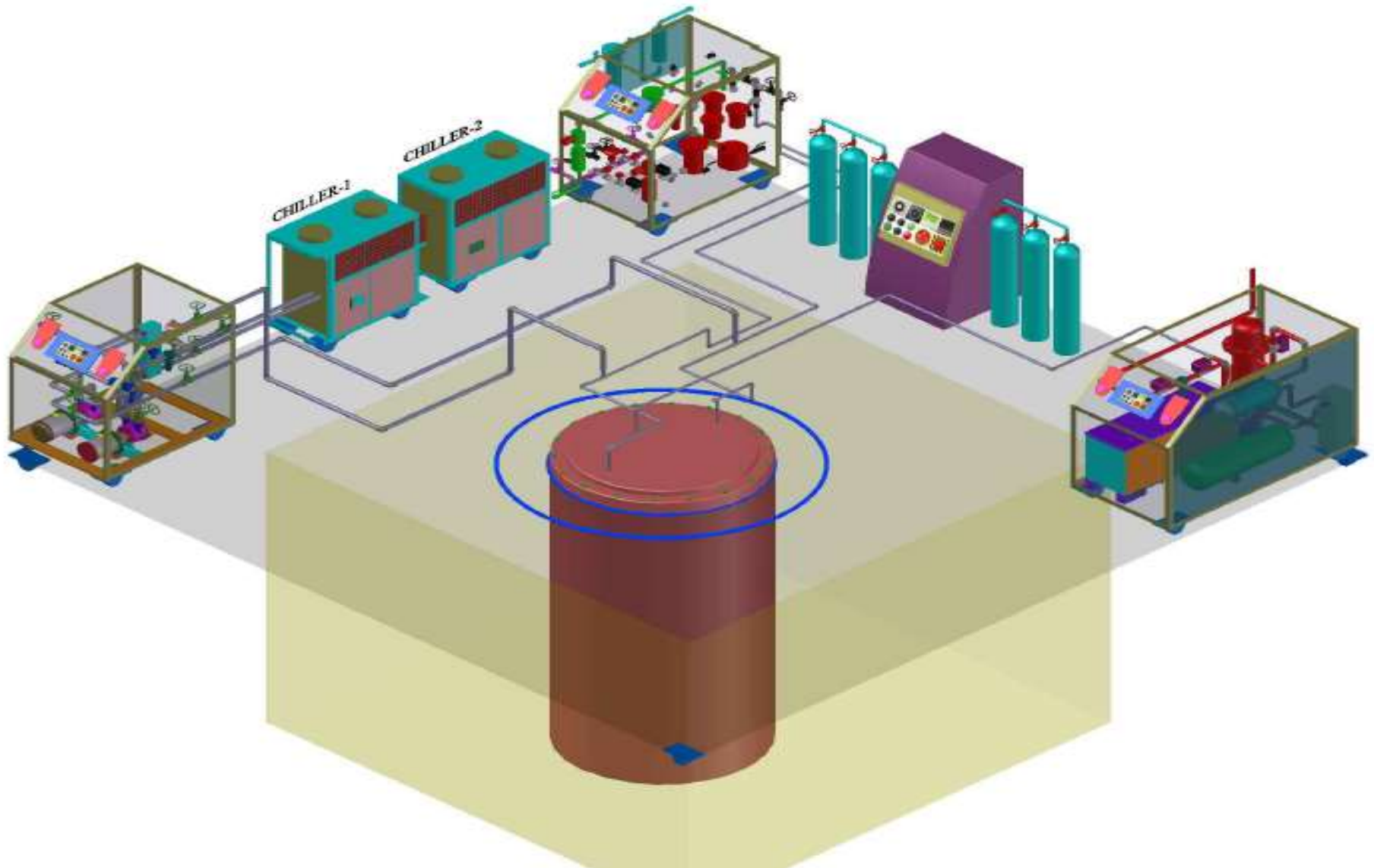
Void Volume (Canister Vol. - Fuel Bundle Vol.): 4000L

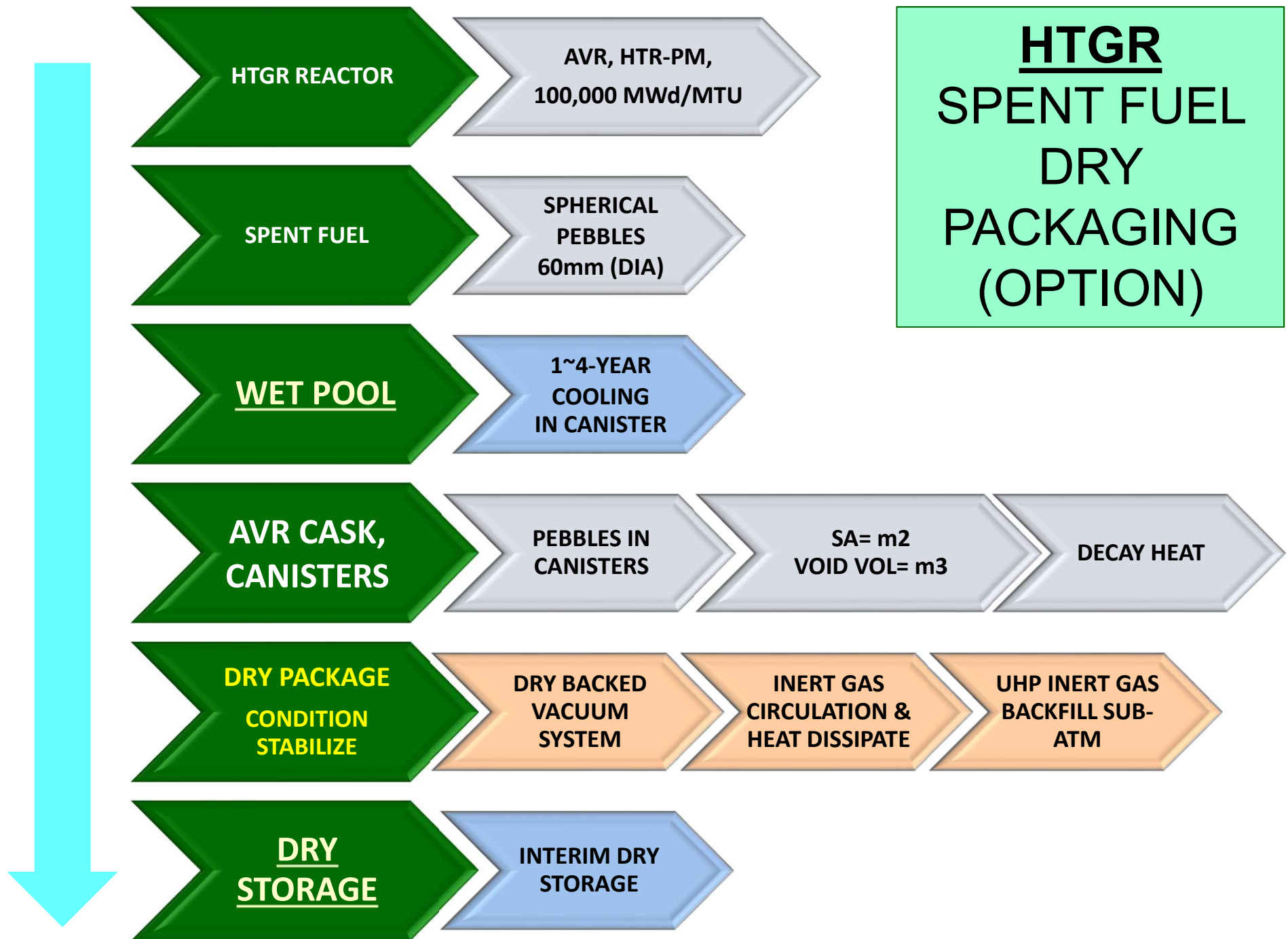
Surface Area (Interiors): 800m². Inlet/ Outlet Ports: Top

ACTIVE DRAIN

SCHEMATIC

Cond & Stabilization (Dry Packaging) PWR Spent Fuels





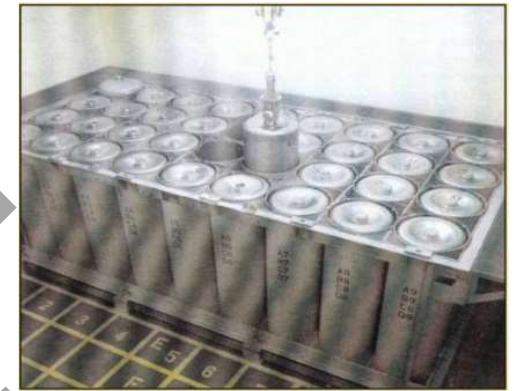
TRISO Spherical Pebble SNF Manage (Worldwide)



HTGR REACTOR



TRISO SPHERICAL PEBBLES

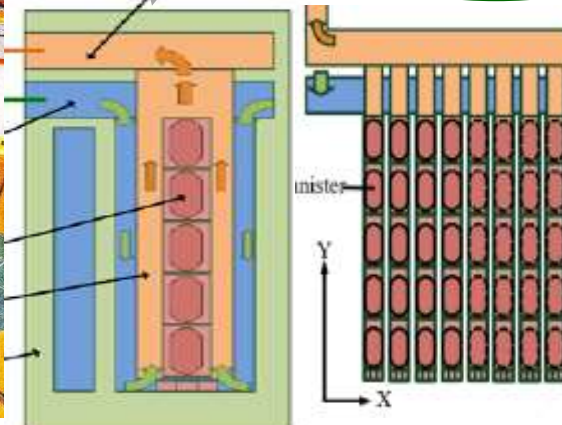


SS304 CANISTERS

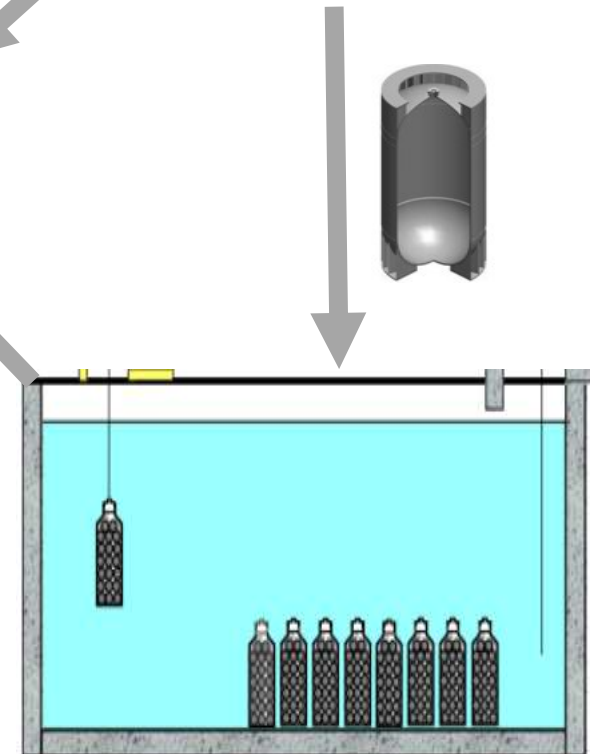
**DRY PACKAGING
CONDIONING
STABILIZATION
ASTM-1553
NUREG-1536-Rev1**



CASK DRY STORAGE

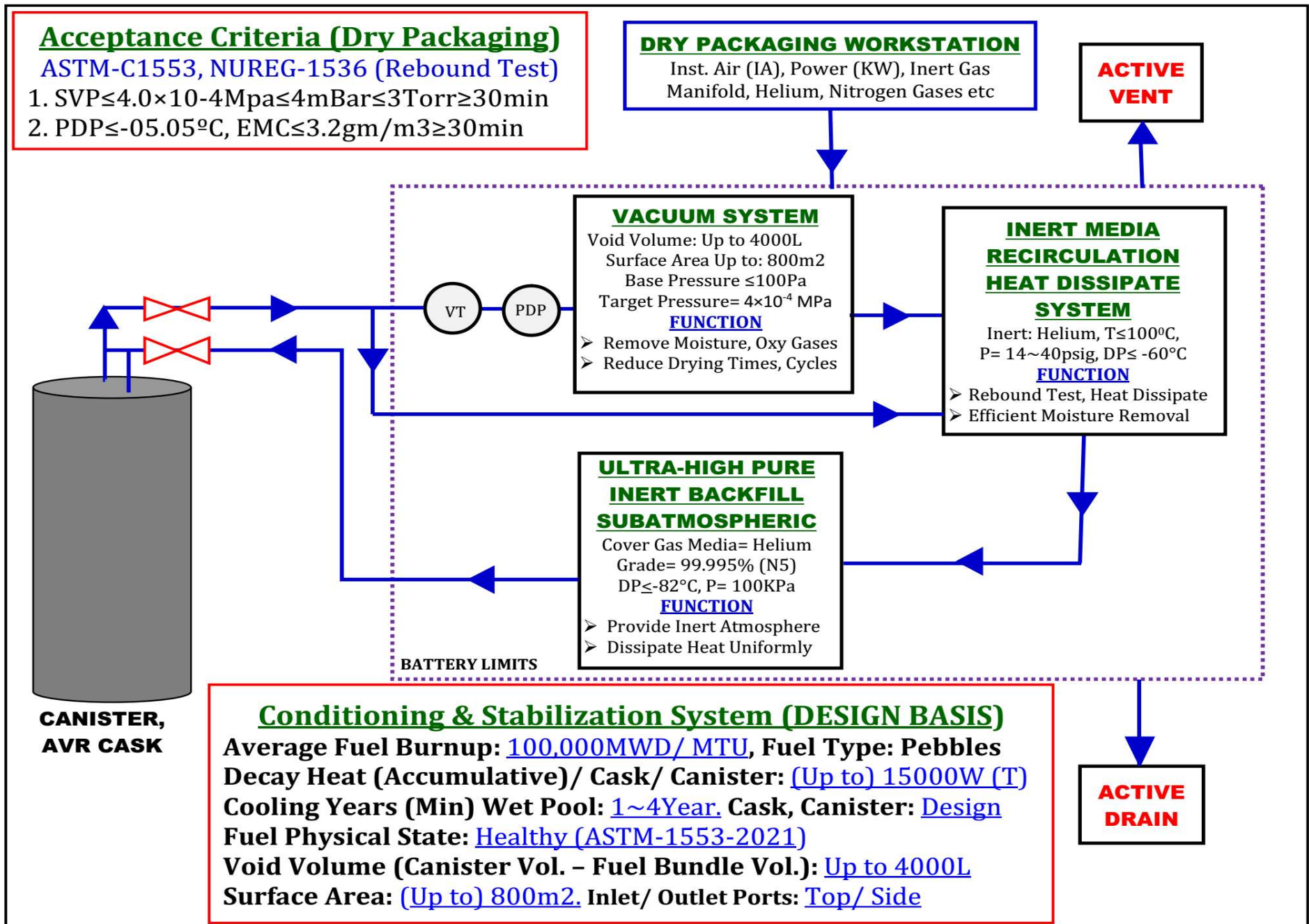


STORAGE WELLS (HTR-PM)



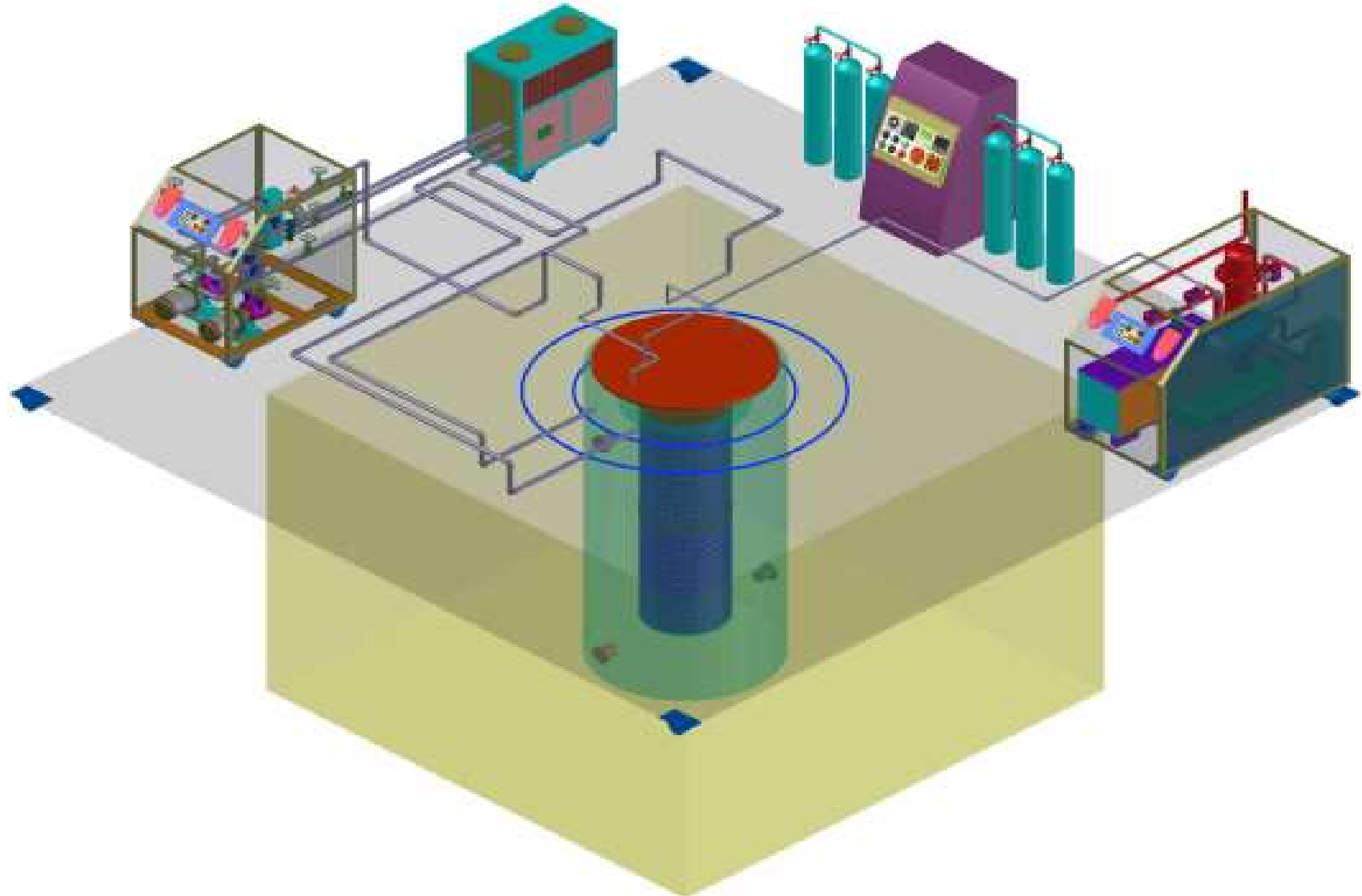
CANISTER WET STORAGE

HTGR Spent Fuel Dry Packaging System (Option)



SCHEMATIC

Canister Conditioning & Dry Packaging Option For TRISO Spent Fuel (Spherical Pebbles) of HTGR



Comparative Aspects

Dry Packaging of (PWR CASK SC21) & (CANDU CASK TC108) & Option For TRISO (HTGR)

Parameter to Consider	CANDU	PWR	HTGR
Fuel Burnup MWD/MTU	9000	37000	≥ *80,000
Decay Heat (W)/ CASK	400	15,000	1.3 ~5W/ Element
Cooling Year Wet Pool (Min)	10	10	1~ 4
Fuel State (ASTM-1553)	Healthy	Healthy	Healthy
Canister Void Volume VV (m3)	0.250	4.0	*
Interior Surface Area SA (m2)	100	800	*
In/ Out Ports (Orientation)	Top/ Bottom	Top	Top/ Side
Fuel Peak Cladding Temp. °C	160	400	400

* Comparison (Summary, Conclusion) Next

Comparison HTGR Spent Fuels (Pebbles) (Canister, Cask, Decay Heat)

Reactor Dry Storage	Spherical Pebbles/ Canister	Decay Heat (KW/ Canister)	Decay Heat (W/ Element)
AVR	*950	7.3	3.8
HTR-PM	40,000	27	1.3
Xe-100	6,000	30	5.0

* AVR CASK (02 Canisters, Total: 1900 Spherical Pebbles)

SUMMARY, CONCLUSION

- * Canister Internal Conditioning & Stabilization System (**Dry Packaging**) of **PWR for SC21 CASK** (PDS Dry Storage Facility, CNPGS Chashma, With Some Modifications) Be Adopted for TRISO Spent Fuel of HTGR **Up To**
 - Canister Interiors & Spent Fuel Surface Area= **800m²**
 - Canister Void Vol.= **4m³**
 - Canister Decay Heat= **15000W**
- Compliance To Regulatory Requirement **ASTM-1553, NUREG-1536** For Dry Packaging of Spent Nuclear Fuels