Water Systems for a Gadolinium-Loaded WATCHMAN Detector

Mark Vagins

UC Irvine

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From a water system standpoint, to make a Gd-loaded WATCHMAN work we will have to:

Dissolve gadolinium sulfate ($Gd_2(SO_4)_3$) in water

→ Easy and fast (pH control/use octahydrate)

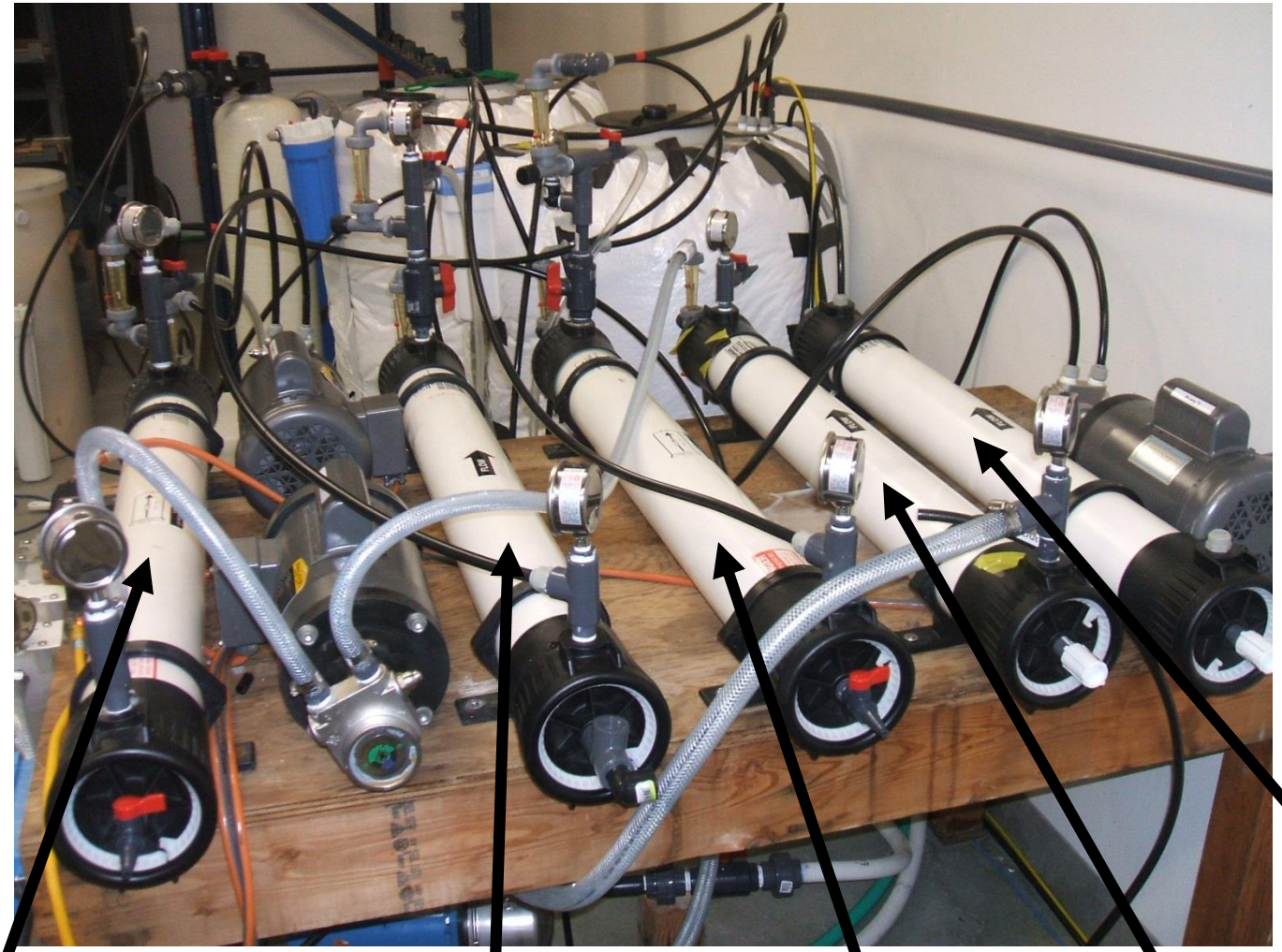
Remove the gadolinium efficiently and completely when desired

→ Also easy and fast (pH control/DI resin)

Keep pure water pure yet retain gadolinium in solution

→ The tricky part; need a selective Gd filtration system

Prototype Selective Filtration Setup @ UCI



0.9 gpm

Membrane Pre-Flush

Nanofilter #1

Nanofilter #2

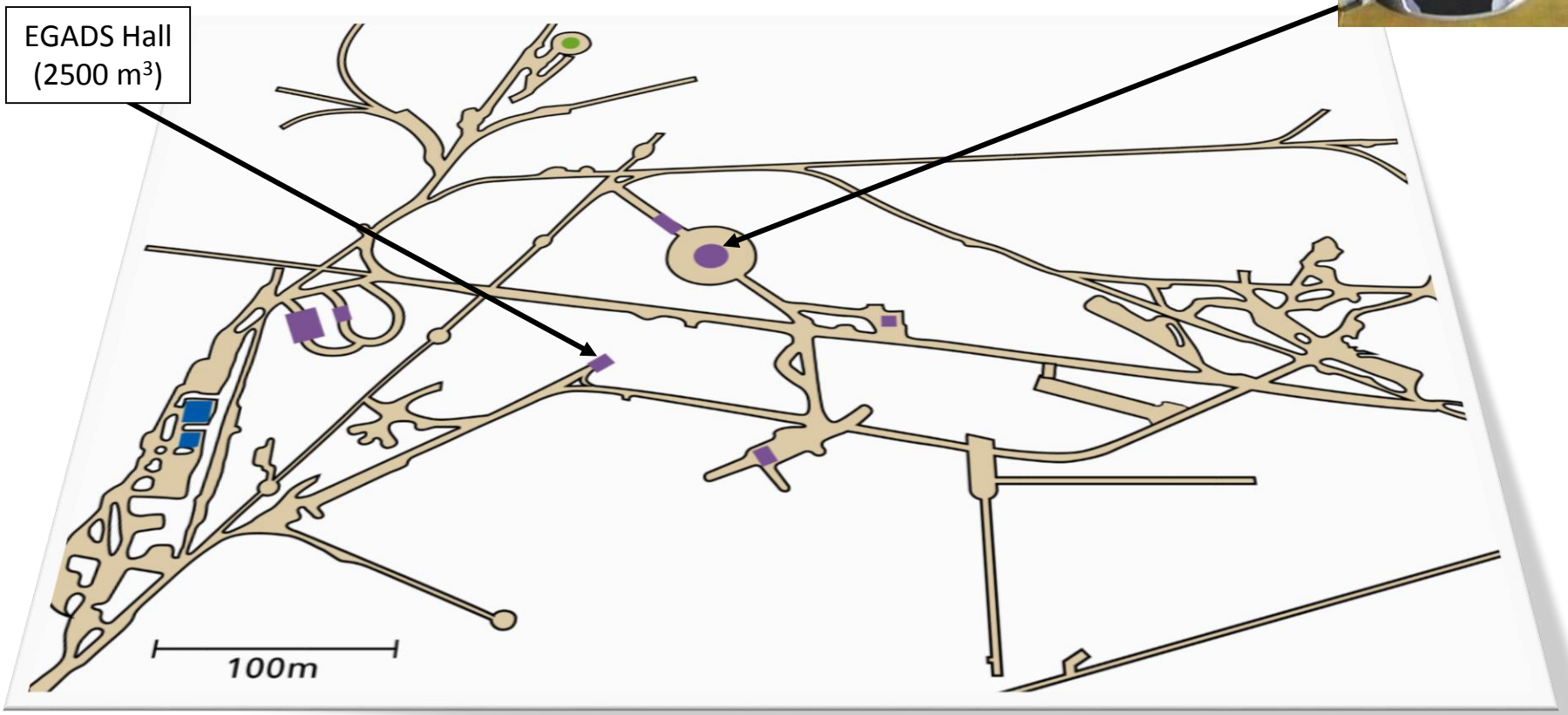
Reverse Osmosis

Ultrafilter

A dedicated Gd test filtration facility was built in the Kamioka mine under UCI's direction.

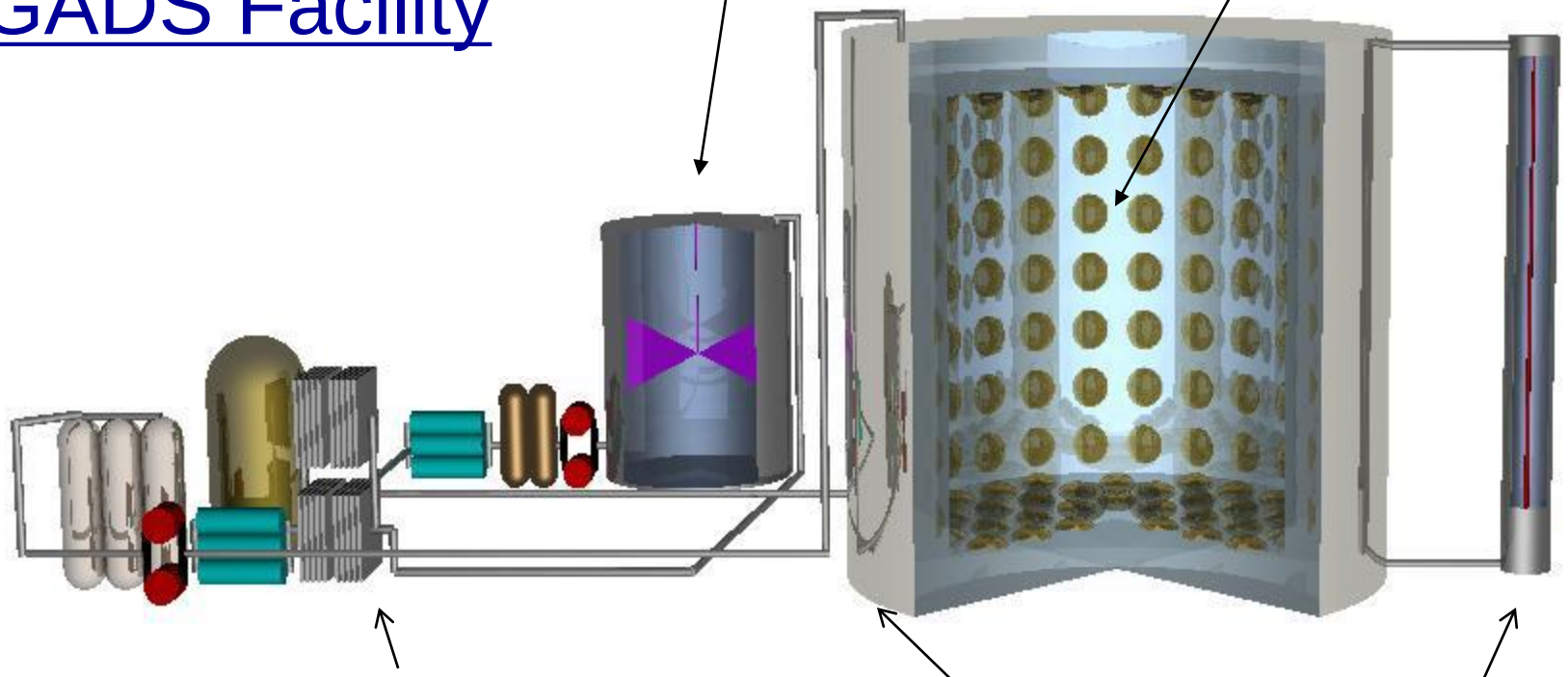
This 200 ton-scale R&D project is called EGADS – Evaluating Gadolinium's Action on Detector Systems.

Super-Kamiokande



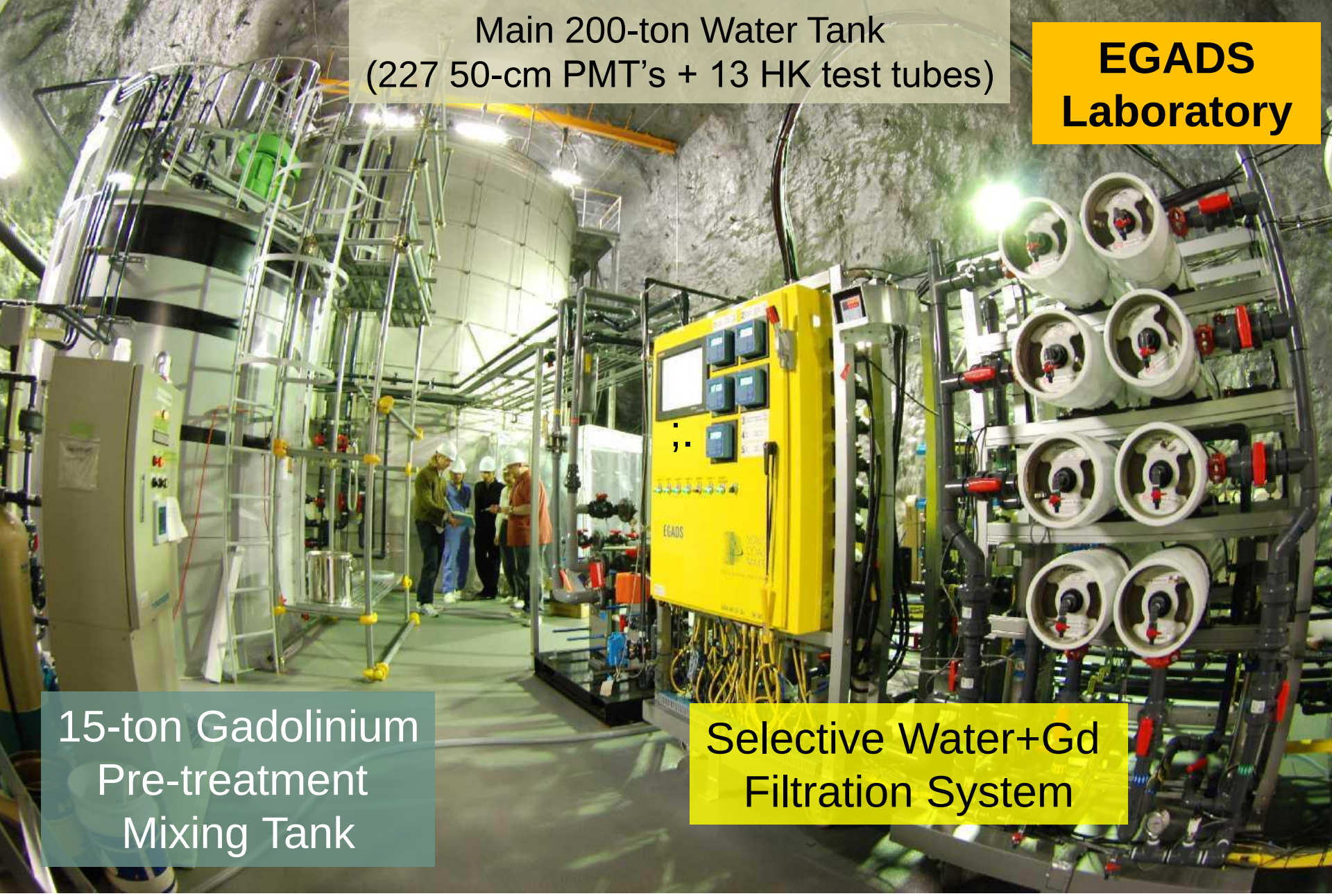
The Kamioka Observatory in the Mozumi Mine

EGADS Facility



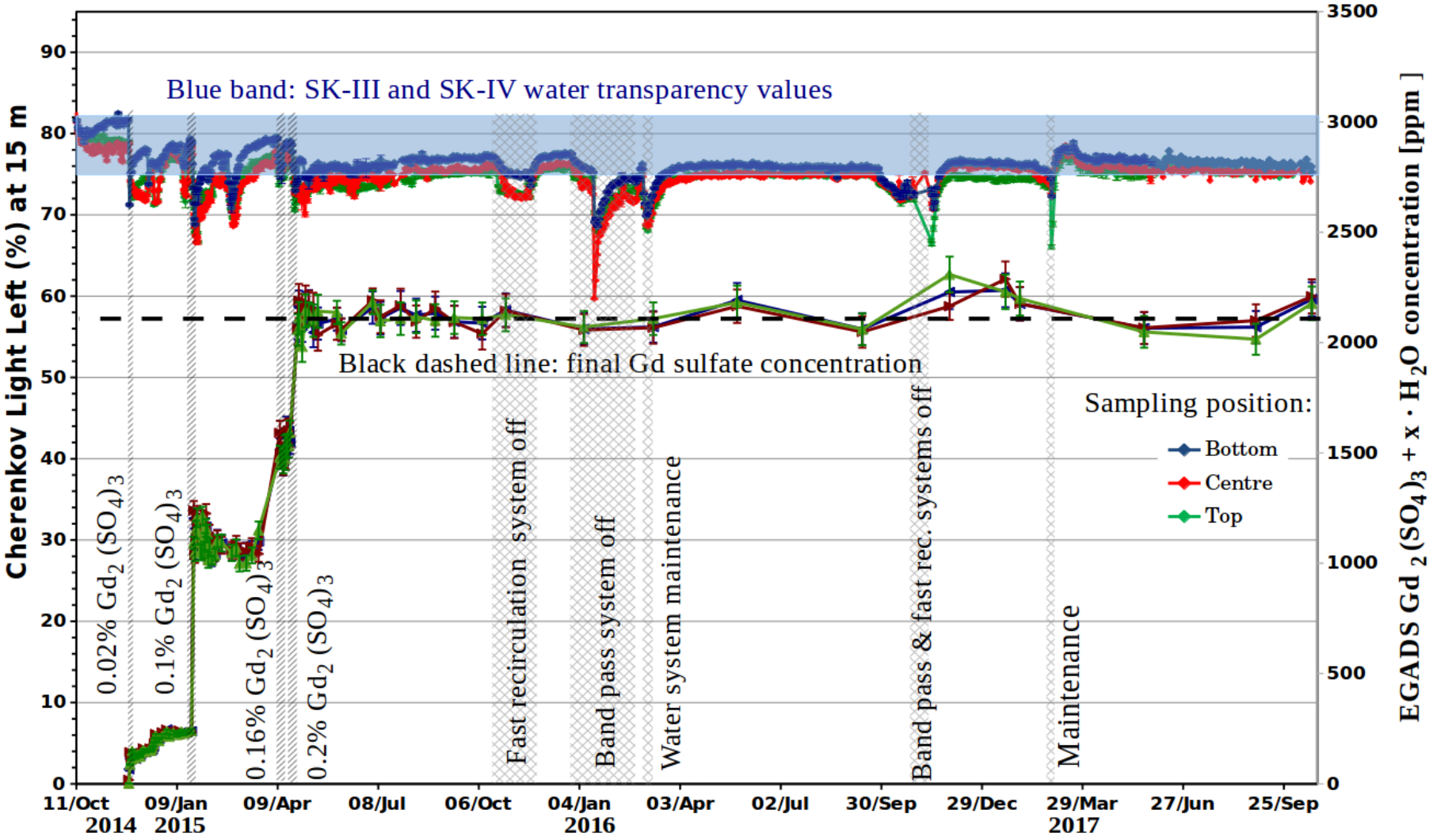
The EGADS water system processes 24 gallons per minute of Gd-loaded water: designed and built by UCI, a direct 27X scale-up of the prototype.

So, another scaling factor of 5 or so is needed for WATCHMAN.



Well over $10,000,000 (1.1B yen) - not counting salaries - has been spent developing and proving the viability of the Gd-in-water concept.

Light @ 15 meters and Gd conc. in the 200-ton EGADS tank



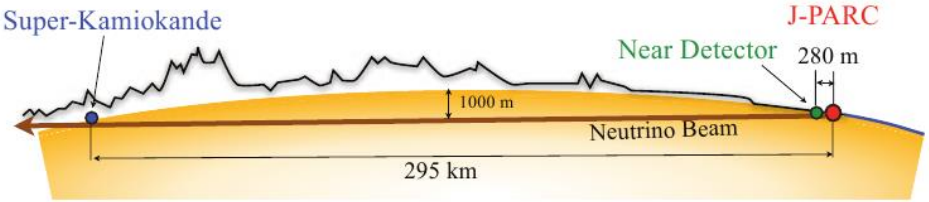
After two and a half years at full Gd loading, during stable operations EGADS water transparency remains within the SK ultrapure range.

→ No detectable loss of Gd after more than 650 complete turnovers. ←

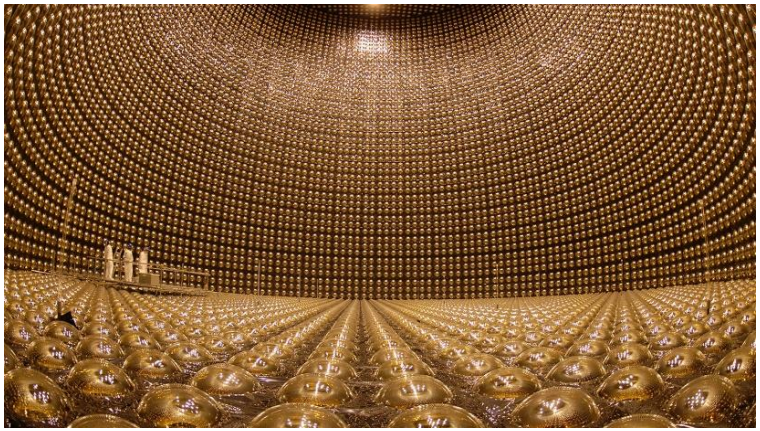
After years of testing and study
– culminating in these powerful EGADS results –
no technical showstoppers have been encountered. And so…

June 27, 2015: The Super-Kamiokande Collaboration approved the addition of gadolinium to the detector, pending discussions with T2K.

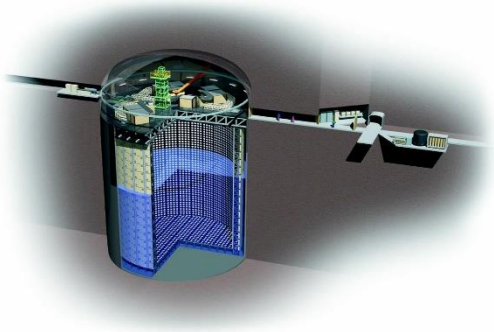
January 30, 2016: The T2K Collaboration approved addition of gadolinium to Super-Kamiokande, with the precise timing to be jointly determined based on the needs of both projects.



July 26, 2017: The official start time of draining the SK tank to prepare for Gd loading is decided to be June 1, 2018.



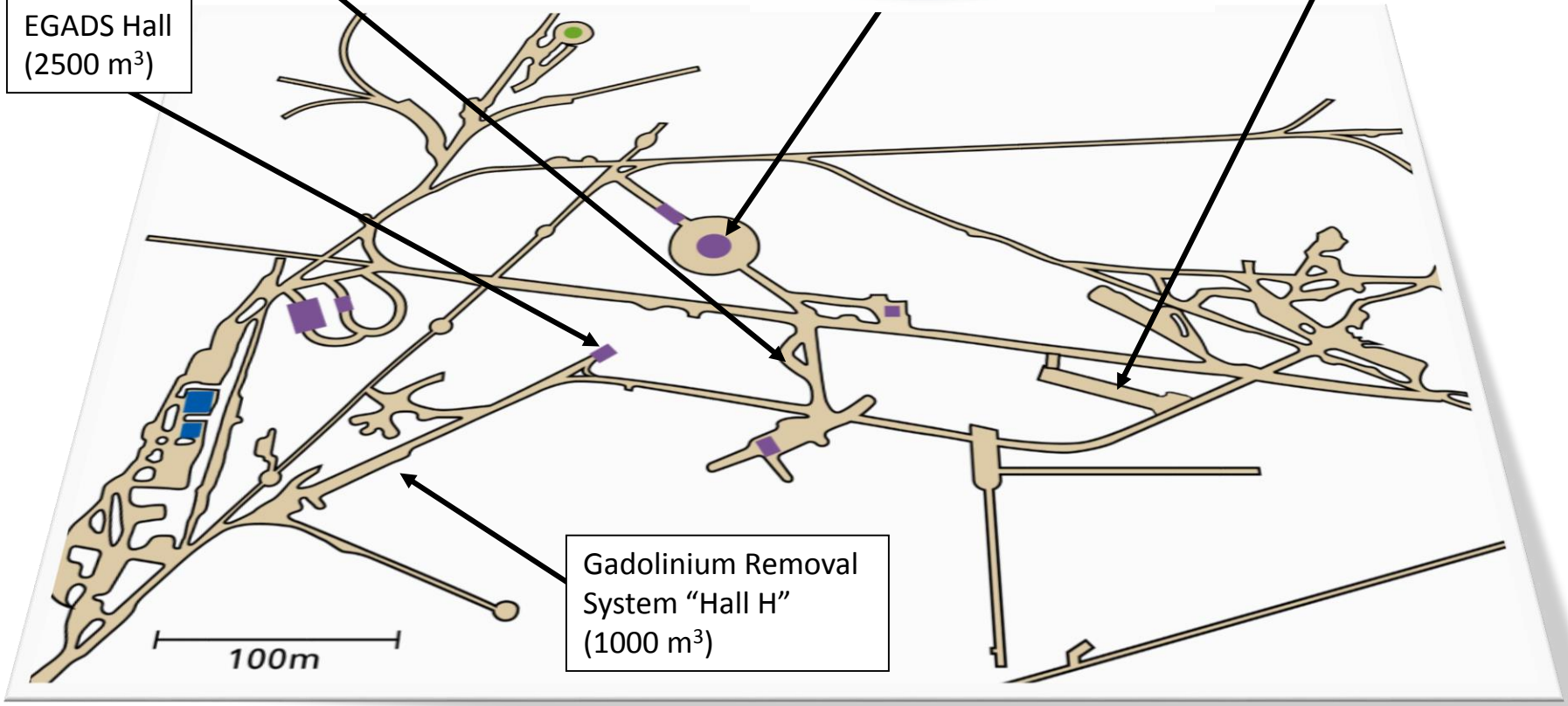
Super-Kamiokande



Original Super-K Water System

New Gadolinium Water System “Hall G” (4000 m^3)

EGADS Hall (2500 m^3)

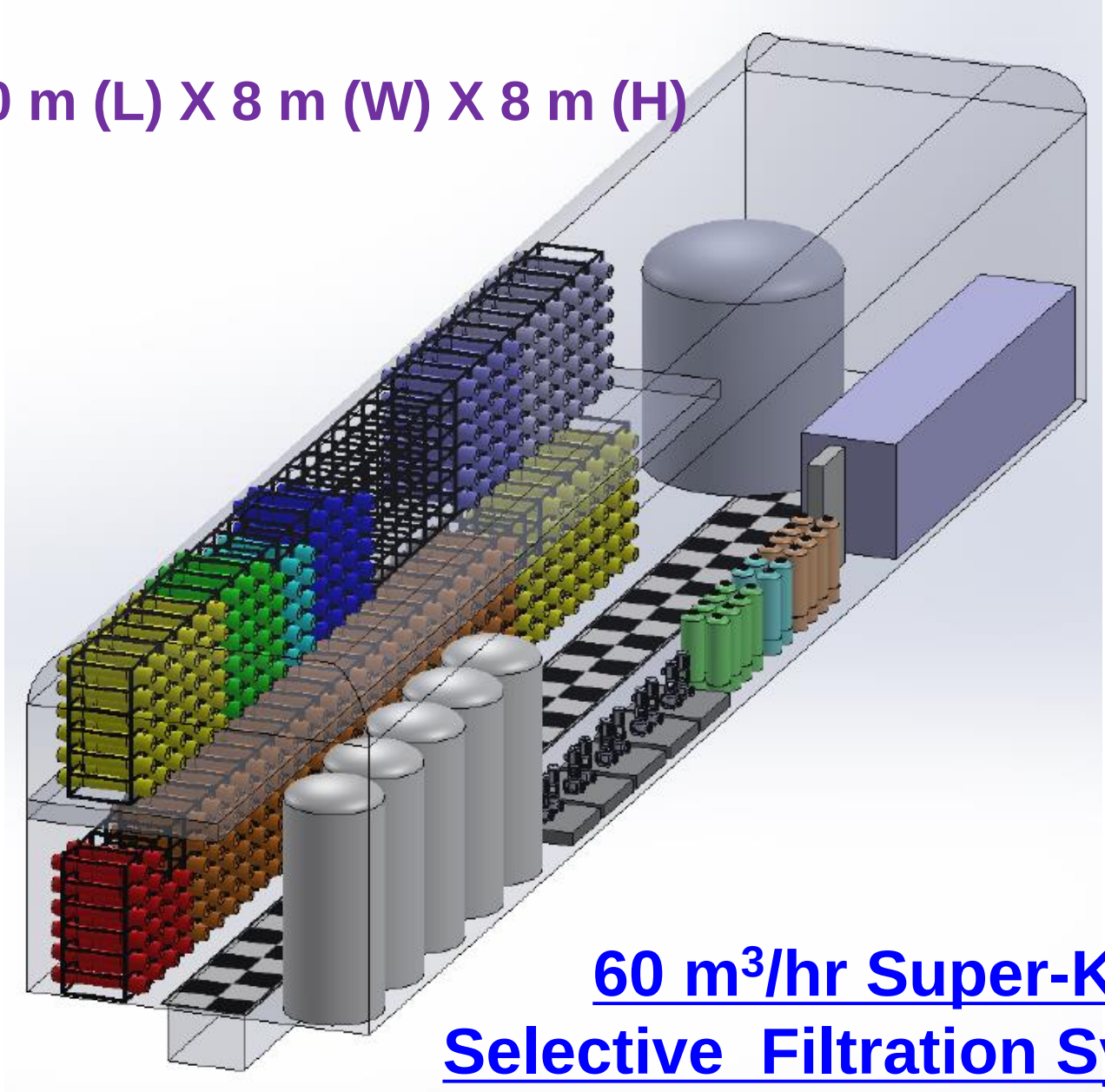


Gadolinium Removal System “Hall H” (1000 m^3)

The Kamioka Observatory in the Mozumi Mine

New Super-K gadolinium water system

50 m (L) X 8 m (W) X 8 m (H)



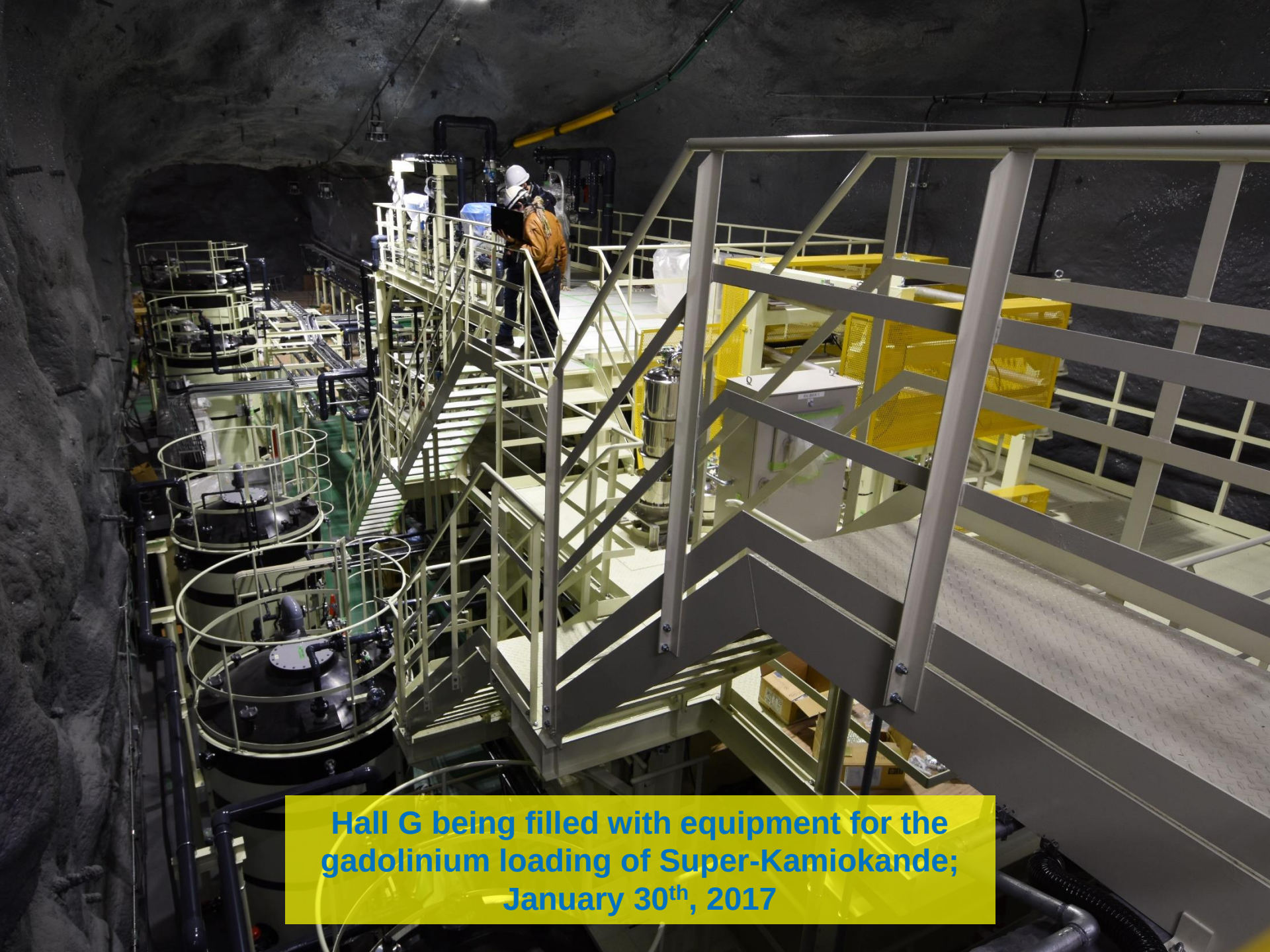
60 m^3/hr Super-K
Selective Filtration System

New gadolinium water system hall (“Hall G”);
September 10st, 2015

New gadolinium water system hall (“Hall G”);
September 10st, 2015

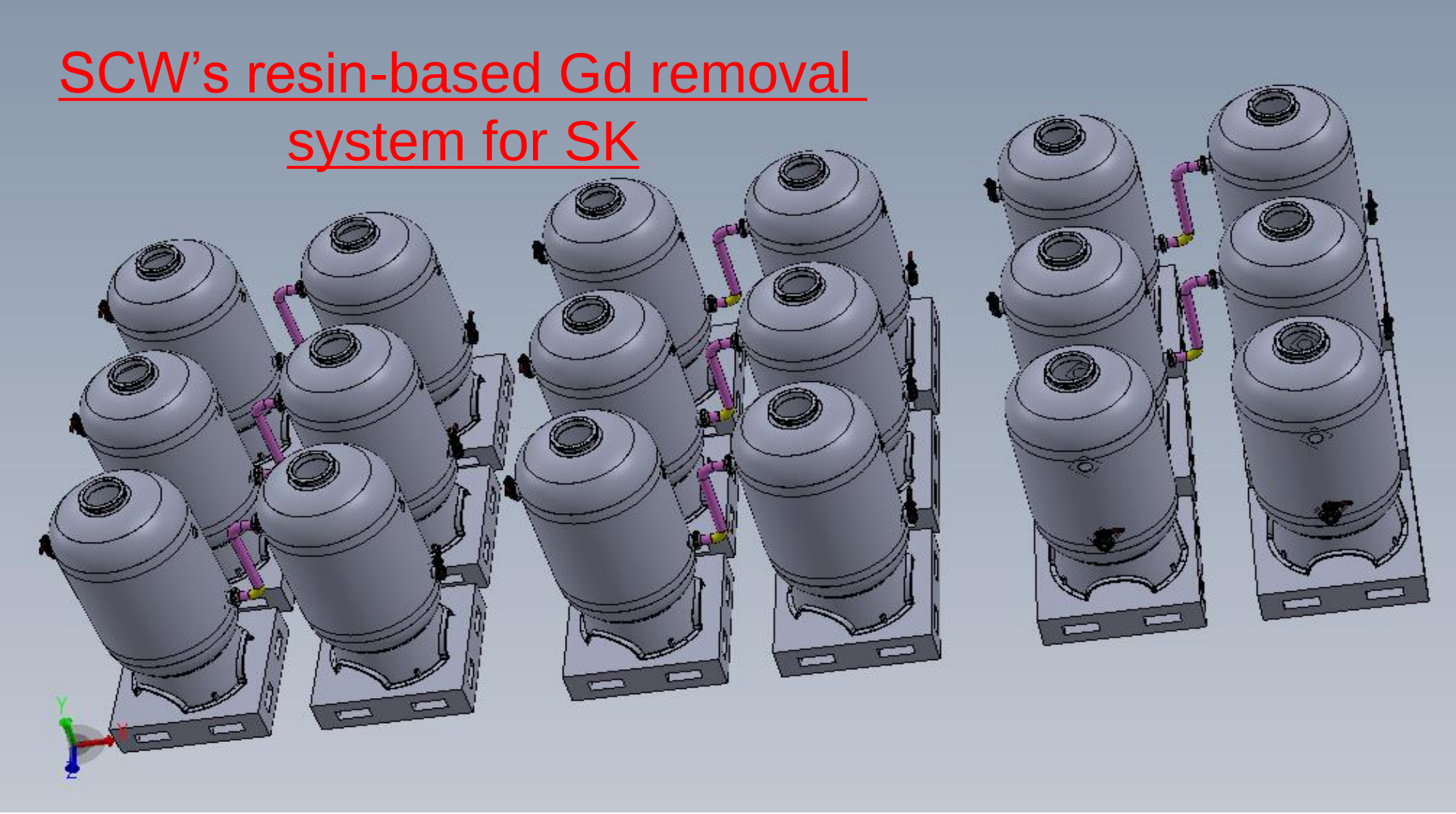
Hall G ready for occupancy;
April 22nd, 2016

Hall G being filled with equipment for the gadolinium loading of Super-Kamiokande; November 10th, 2016



Hall G being filled with equipment for the gadolinium loading of Super-Kamiokande; January 30th, 2017

SCW's resin-based Gd removal system for SK



This system is designed to capture all of the gadolinium in Super-K following T_1 loading (10 tons of $Gd_2(SO_4)_3$) by passing the water through a sodium form cation exchange resin called ResinTech CG8 at 60 tons/hour.

A single pass through the resin removes >99.9% of the gadolinium.

This system for SK uses three stages for ~10^9 removal power.

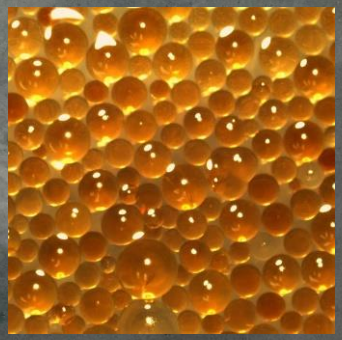

At South Coast Water factory, Santa Ana, CA; Feb. 13th, 2018

At South Coast Water factory, Santa Ana, CA; Feb. 19th, 2018

At South Coast Water factory, Santa Ana, CA; Feb. 19th, 2018

In front of Atotsu entrance to the mine; March 24th, 2018


In Hall H; March 24th, 2018

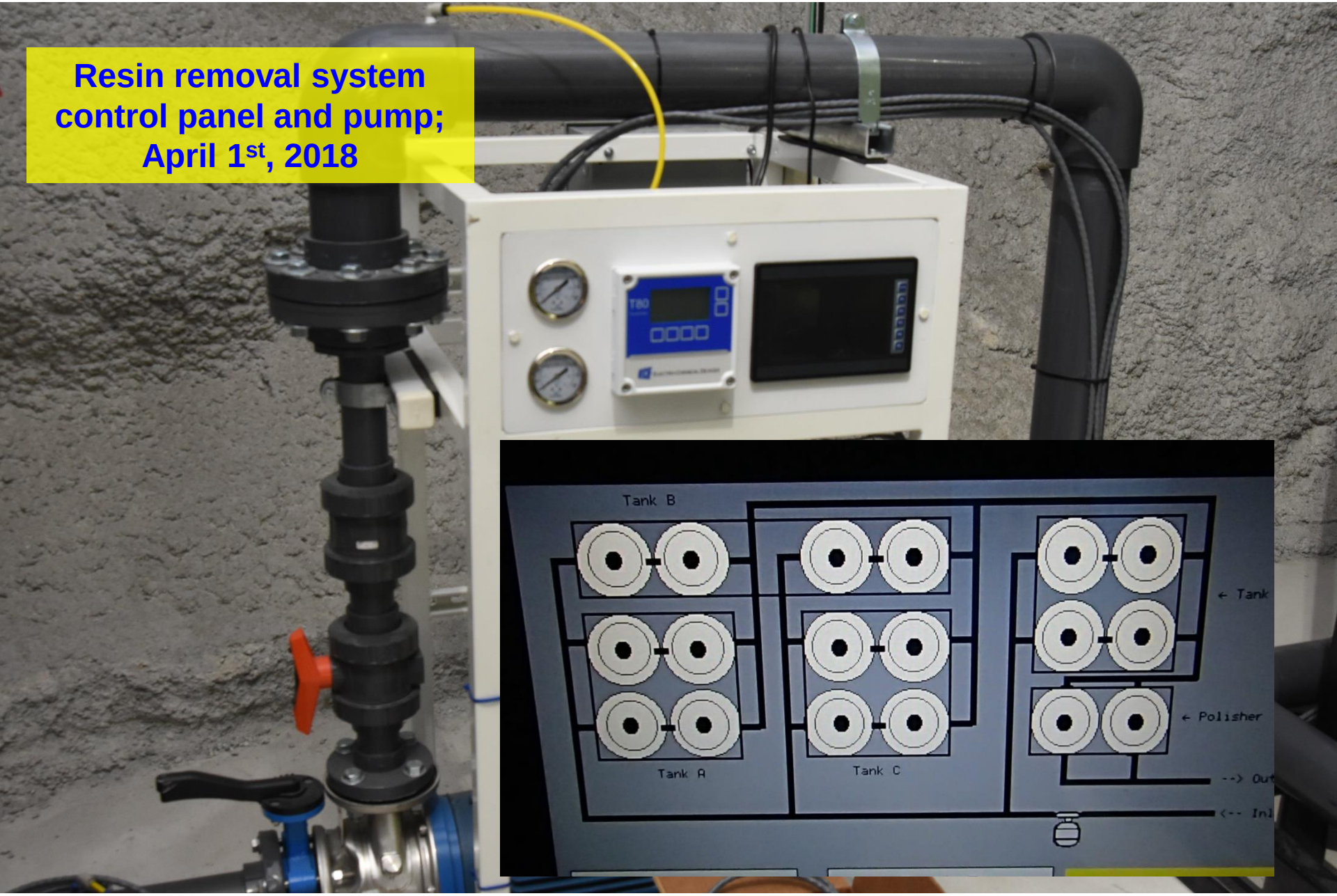


Some of the 2400 bags (62 tons) of cation exchange (ResinTech CG8) resin needed for T_1

In Hall H; March 28th, 2018

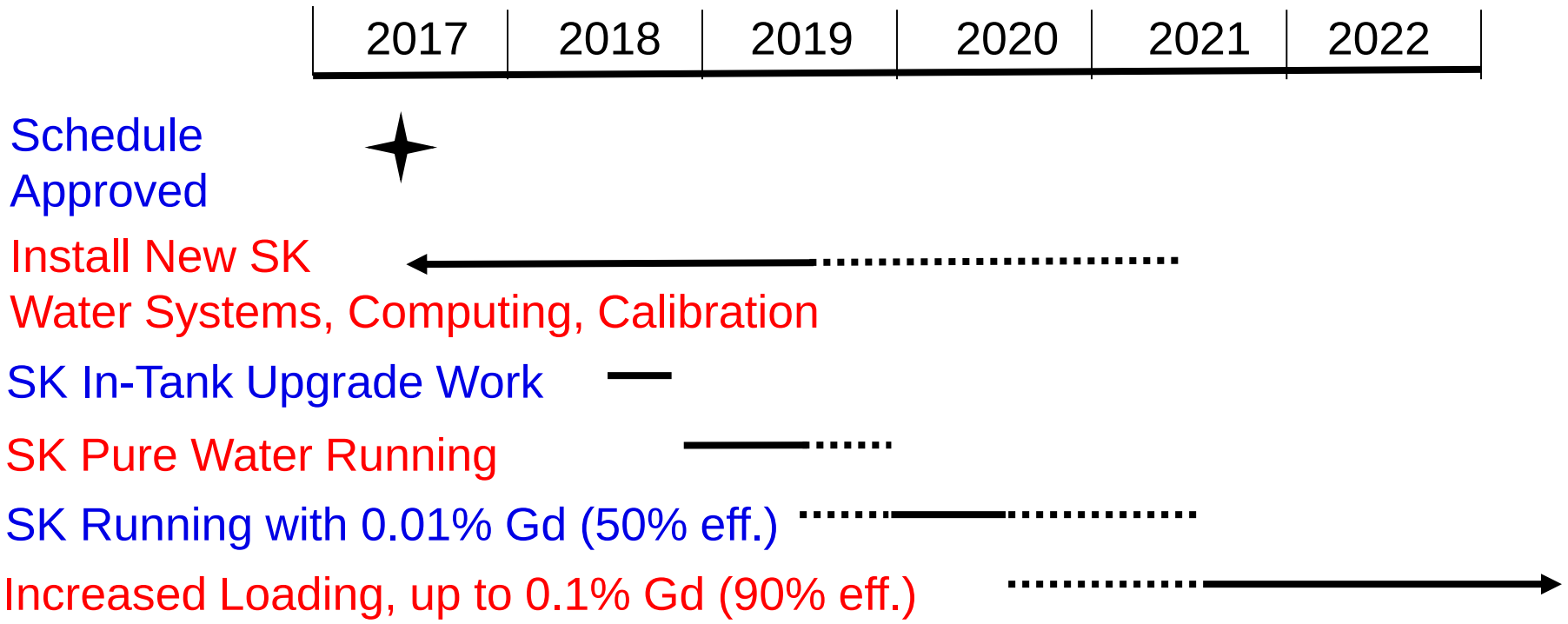
In Hall H; March 30th, 2018


In Hall H; April 1st, 2018

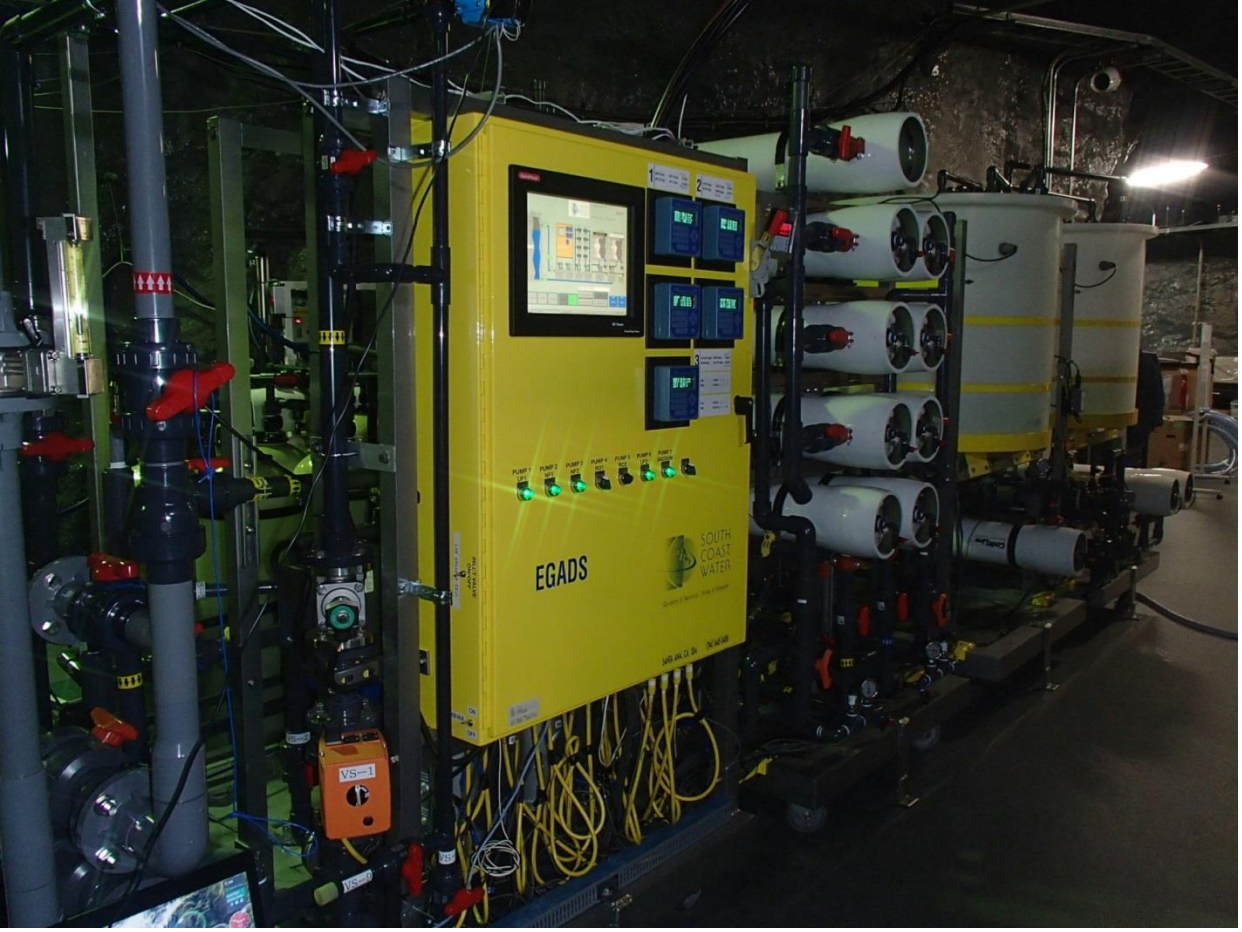


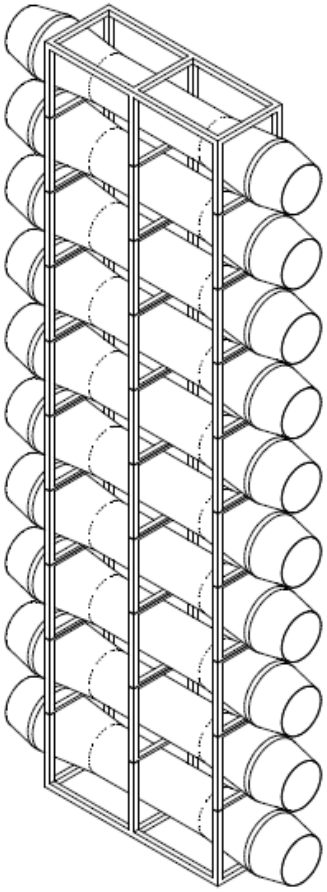
Resin removal system control panel and pump; April 1st, 2018

Expected timeline for SK-Gd



First Gd in SK as early as 2019!

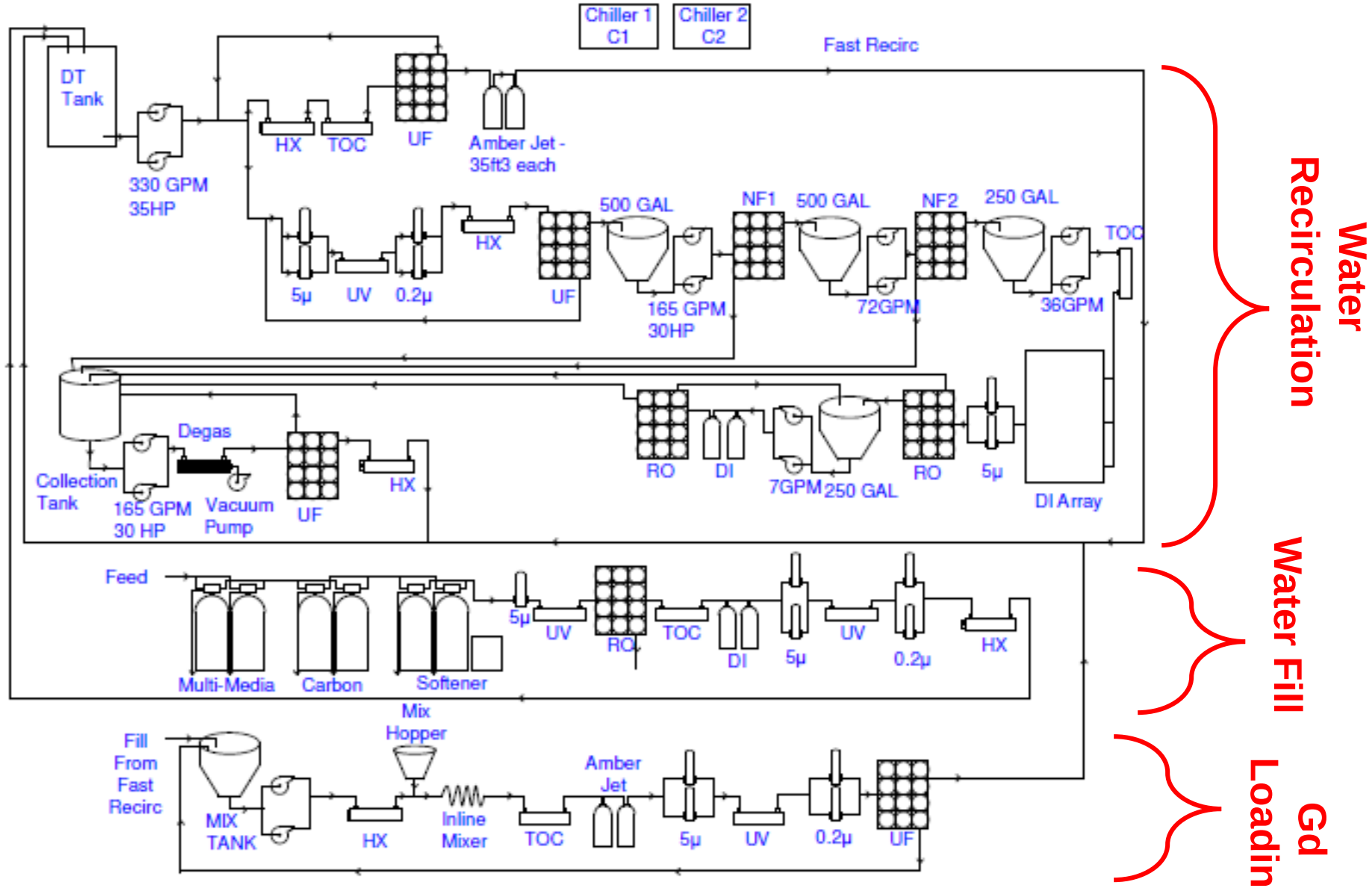




EGADS Selective Filtration System

WATCHMAN Membrane Rack

Based on years of experience with EGADS - and by using modular components - scaling up by the additional order of magnitude needed for WATCHMAN (or scaling down from the SK design) is straightforward.

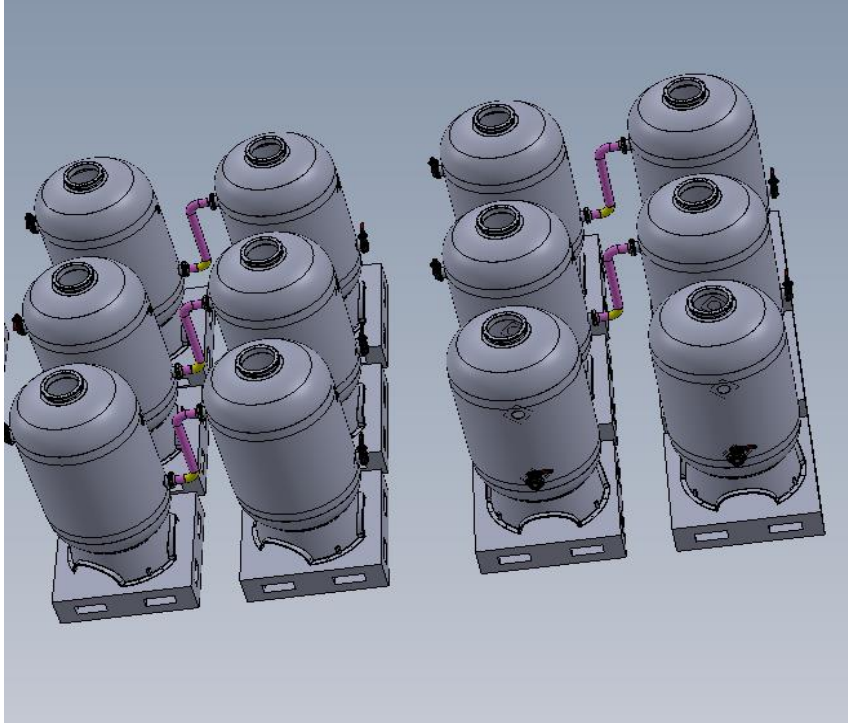


330 gpm total capacity

WATCHMAN FLOW DIAGRAM

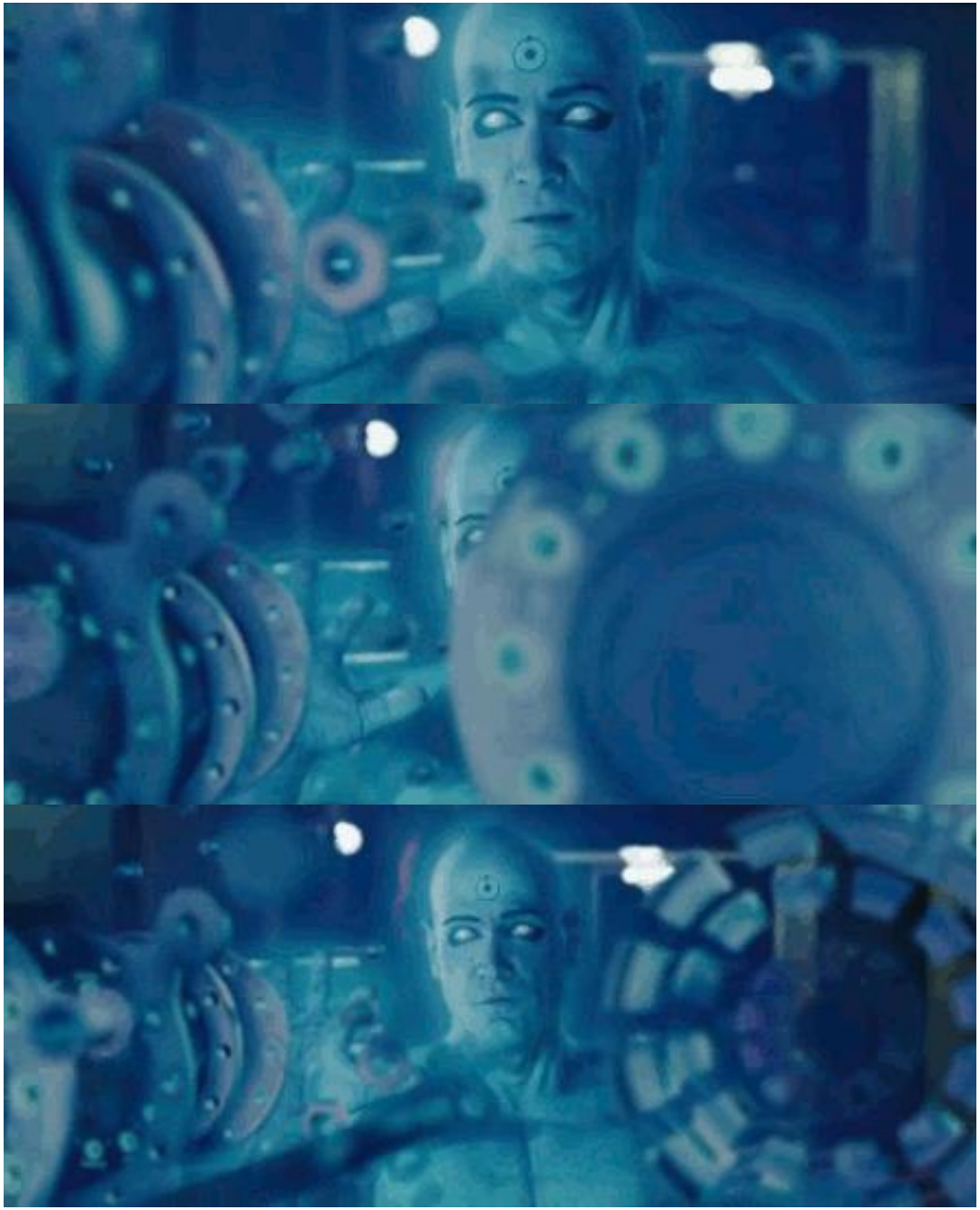
Resin-based Gd removal system for WATCHMAN

The basic unit of this system is a pressurized tank 1.6 meters in diameter and 3.2 meters high, filled with 4 tons of Na^+ exchange resin.
($Gd^{3+} \rightarrow 3\ Na^+$)



If desired for the Boulby deployment, the price for this Gd removal system would be about $600,000, including shipping and installation.

It will collect all of the Gd^{3+} in 3.5 ktons of 0.2% loaded water.



We have built successful Gd-capable water systems several times already.

System parameters (total flow, footprint, etc) can be adjusted.

The time from placing an order to having the water systems for WATCHMAN assembled and installed at Boulby will be approximately twelve months.