Water System Status

Patrick de Perio, for the Water Group

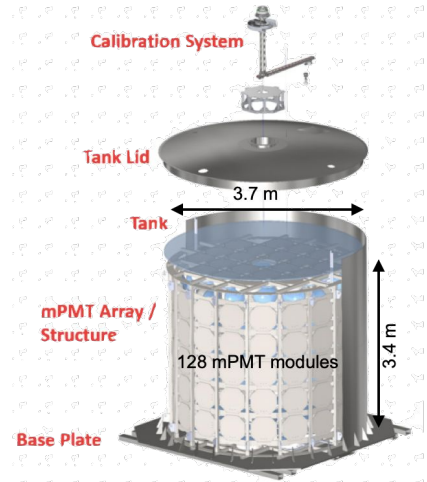
WCTE Collaboration Meeting

November 30, 2021

Introduction

- Aim to develop a minimal (cost & size) water system for WCTE
  - And later for IWCD based on what we learn
- Nakajima-san presented techniques successful for larger Super-K detector
  - Transparency requirements for WCTE not as high

Water Cherenkov Test Experiment (WCTE)



4m tall, 4m diameter

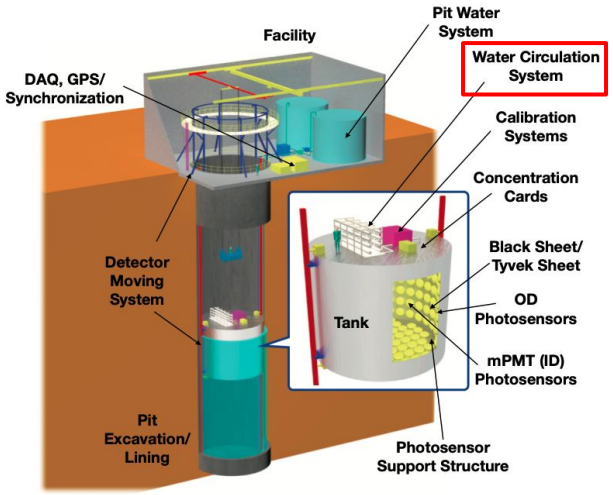
50 tonne (~2 day turnover)

~100 mPMT modules

In CERN particle test beam

Planned operation in 2023

Intermediate Water Cherenkov Detector (IWCD)



10m tall, 9m diameter

650 tonne (~8 day turnover)

~480 mPMT modules

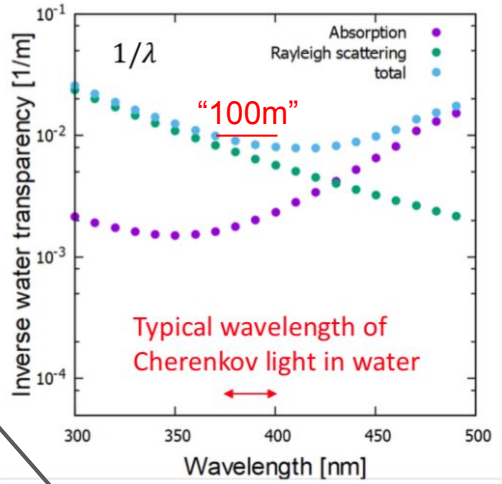
In J-PARC neutrino beam for Hyper-K

Planned operation from 2027

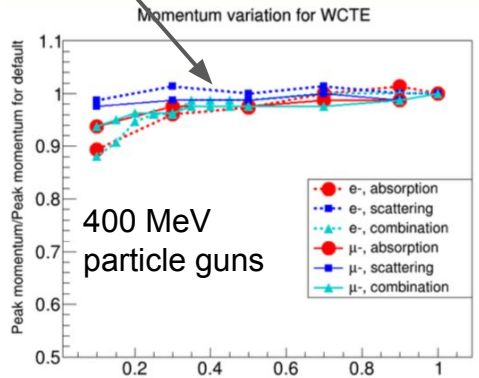
Water Transparency Requirement

- Check effect of increasing light scattering and absorption in detector simulation with e/μ particle gun
  - Super-K “100m” attenuation length model (right) assumed as nominal
  - Scale the curves by factor λ and check effect on e.g. reconstructed momentum
- Indication of performance degradation below “50m” att. length
  - Small, but correlated with all other reconstructed variables (PID, pos, dir)
    - Want to be able to make any impact negligible
  - Momentum can be corrected for *on average*, but water parameters degenerate with other detector parameters like PMT response
    - Want to minimize these degeneracies
- Aim for “50m” attenuation length capable purification system
  - Can always study worse cases by reducing flow
  - However, difficult to predict quantitatively since no well-understood water purification theory and largely dependent on actual materials immersed
- WCTE (IWCD) are 1/10 (1/4) smaller diameter than SK
  - Can probably get away with cheaper, smaller system

Yamauchi-san (TUS), WCTE



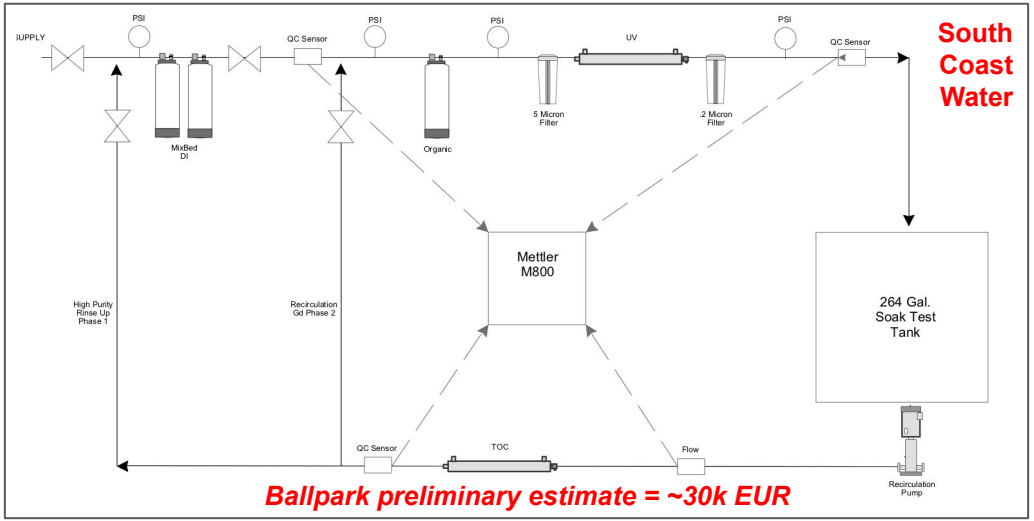
The default settings in WCSim



Scale factor for curves above

Candidate Purification Systems

- Began consultations with two companies so far
  1. Organo system from a “catalog” is still built-to-order, requiring specifications from us
     - Initial discussions stalled; seems they require some commitment and/or consultation fee
  2. South Coast Water designing smaller (~1 tonne) R&D/soak-test system for IPMU/ICRR locally
     - Can probably expand to WCTE based on what we learn
  - T. Ekelof (Uppsala) will begin searching for companies in Europe
    - Start with full system; later potentially build with individually procured components



IPMU/ICRR System Requirements

- **Transparency**: ~50% of Super-K's "100m attenuation length"
- **Volume**: ~1 tonne water
  - ➢ Constrained by available lab space
- **Flow**: Minimum = 3 L/hour, Maximum = 150 L/hour (3.6 tonne/day)
  - ➢ Minimum from expected 8-day turnover of IWCD (also limited by required flow through filters)
  - ➢ Maximum for high-flow testing, ~3 turnover/day (compared to expected 2-day turnover for WCTE)
- **Output temperature**: Variable down to 10°C (higher than ambient not required)
  - ➢ Control bacterial growth; need to be careful about condensation in the lab
- **Gadolinium**: Up to 0.2% gadolinium sulfate octahydrate
  - ➢ Special resins required
- **Test materials**: stainless steel, titanium, anodized aluminum, acrylic, glass, silicone, PVC, Tyvek, other plastics
  - ➢ Perhaps to give an idea how many and/or type of purification components required

IPMU/ICRR System Requirements

- **Monitoring/Logging**: Flow, pressure, temperature, resistivity, etc. at relevant points in the system. Environmental monitoring of temperature/humidity.
  - ➢ “Slow control” for understanding transparency dependence on these parameters
- **Control**: Local touch screen and remote access for valves, flow controllers, pump(s), etc.
  - ➢ Option to avoid manual operation if we want to study many configurations
- **Safety**: Prevent flooding and leaks to municipal drain in room
  - ➢ Drip pan (and/or existing catchment) with level meter and automatic sump to ion exchange resin
    - ■ Also to collect condensation
  - ➢ Sensors to detect leaks / loss of pressure and corresponding automatic fail to safe
  - ➢ Fail to safe in case of power loss
- **Interfaces**:
  - ➢ Inlet & outlet ports for small (~5 mL) sampling (for spectrophotometer)
  - ➢ Inlet & outlet ports for (UDEAL-like) water transparency monitoring system

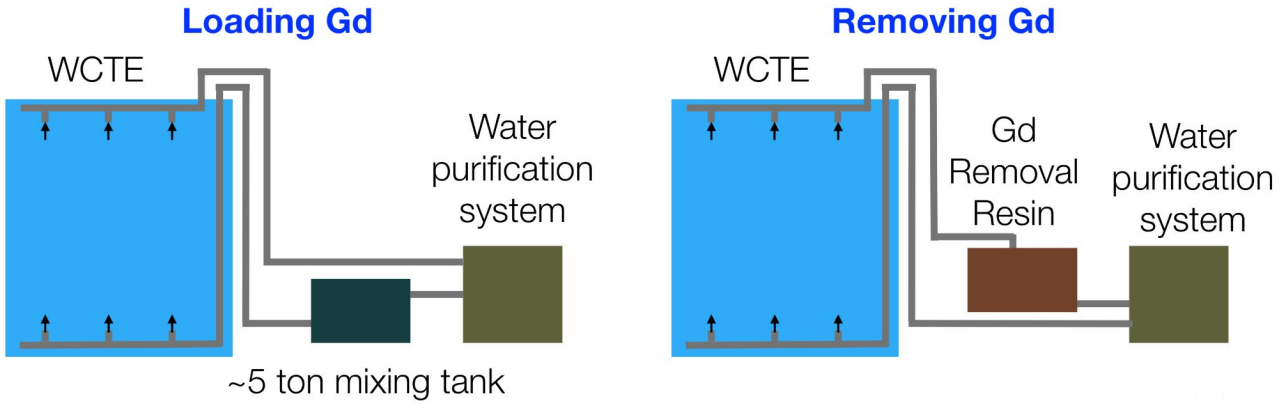
Gadolinium Loading/Removal

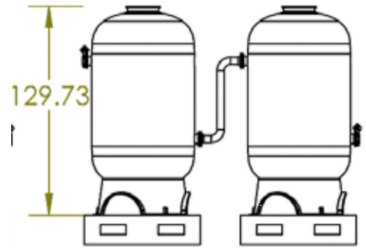
- Gd loading and and removal based on EGADS/Super-K experience
- Need technical design for WCTE

M. Hartz

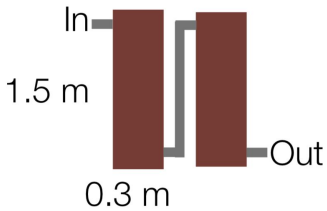
WCTE Water System - Gd Loading Phase

- Will add ~100 kg of $Gd_2(SO_4)_3$ to the water
  - During loading phase, mixing tank is added to dissolve $Gd_2(SO_4)_3$
- Ion exchange resin in water system will be removed or replaced with special resin
- Resin is used to remove $Gd_2(SO_4)_3$ when Gd loading phase is complete
  - Gd concentration measurement system will be used to monitor Gd level





One unit from the Super-K Gd removal system



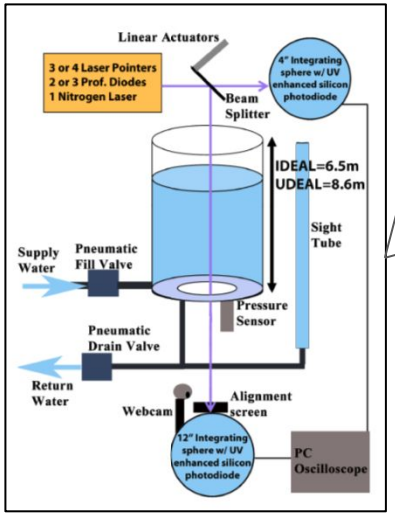
Possible WCTE configuration - 1 m^3 of resin

A. Konaka

Water Quality Monitoring

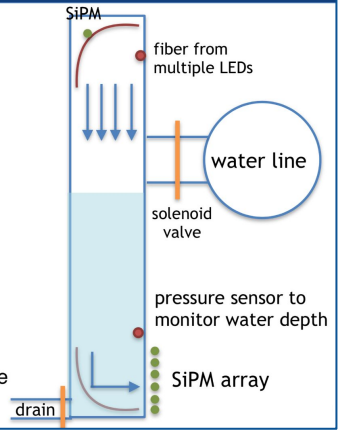
- Light injectors inside detector for monitoring (UK, proposed)
- Gadolinium concentration monitoring (Warwick, planned)

- In addition, build UDEAL/EGADS-like system for precise attenuation & scattering measurements (commitment TBD)



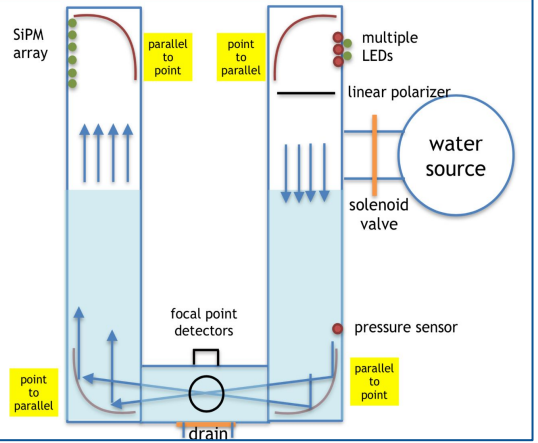
Design concept of a water quality monitoring system

- Similar water column as Irvine but
  - multiple pulsed LED instead of laser
  - 90 deg. off-axis parabolic mirror
    - point to parallel focus from LED
    - parallel (angle) to point focus to SiPM
- Operation
  - open water line, flush and fill the pipe
  - change the water level by draining and measure
    - monitor SiPM gives normalization
    - SiPM array gives scattering angle measurement
  - nsec LED pulse width provides
    - high SiPM dark rate negligible
    - fluorescence life time measurement
- Place air instead of water and change the pressure
  → Fabrice's smoke (air pollution) detector



Design concept: two column version

- Two water columns
  - point→parallel→point →parallel→point
  - height is half
  - LED and sensors are above the water
  - magnifiation at the sensor is adjusted by focal length
- Bottom focal point detectors
  - 90 degree monitors
    - Rayleigh scattering suppression in polarization direction
  - λ>300nm optical filter → sensitive to fluorescence
- Drain at the bottom to flush the tube and mirror

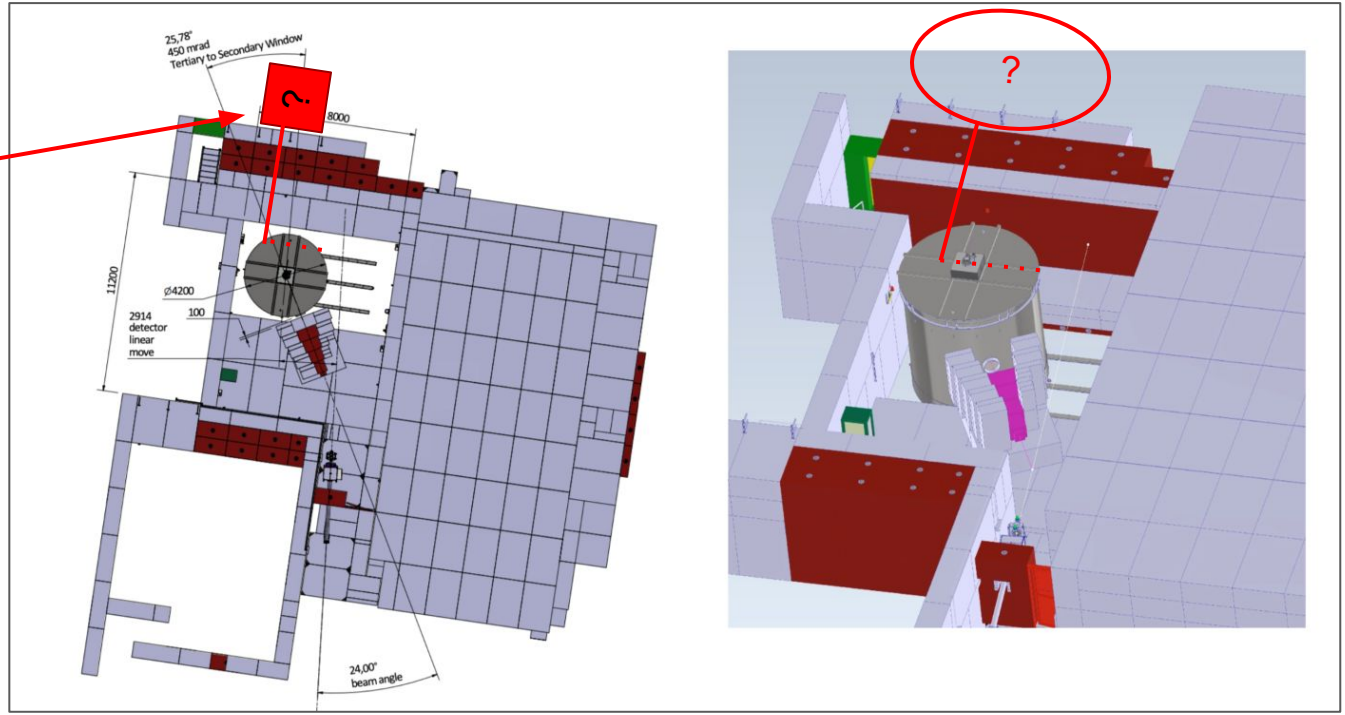


Placement

- Limited space in the experimental area, neighbouring space available?
  - Plumbing through channel in shielding

- Approximate estimated footprint: 3m x 2.5m
  - Can ~5m tall monitoring station be accommodated?

- Probably have two discrete plumbing configurations for detector movement

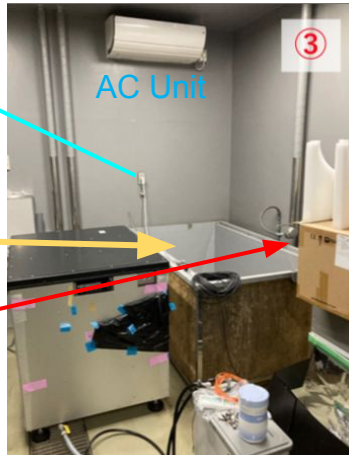


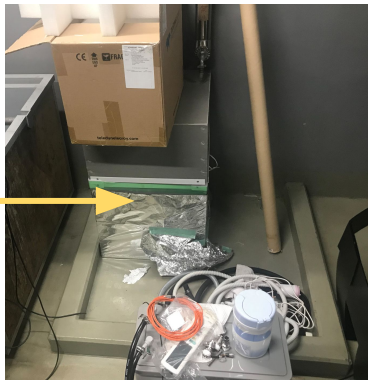
Summary

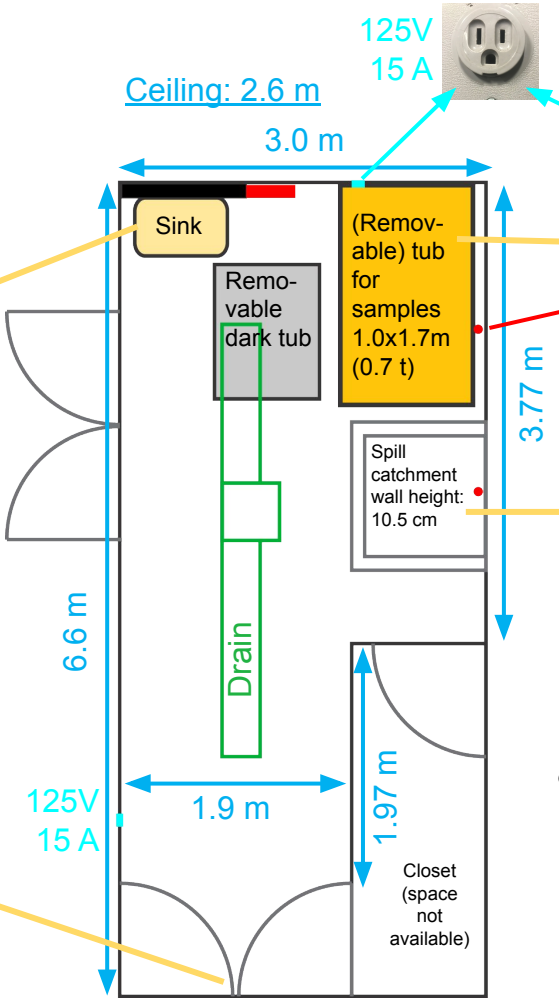
- WCTE (and IWCD) may be able to perform with scaled down (smaller & cheaper) water system than Super-K
  - Local system initiated at IPMU/ICRR to help answer this question
- Cost/effort sharing of major components:
  - Purification (Gd compatible)
    - Chiller
  - Gd loading/removal
  - Water quality monitoring
  - Plumbing
- Status: full budget not yet secured (30k EUR for 0.15 t/hr may scale to 175k EUR for 1-2 t/hr...)
  - Sweden (T. Ekelof) has ~20k EUR available now
  - Japan Kakenhi grant (Lead PI: Masaki Ishitsuka) ~2.7M¥ (~20k EUR) budget request result expected in March 2022
  - Canada planning R&D for water quality monitoring system
    - However, need other funding for production for WCTE

Appendix

Available Lab





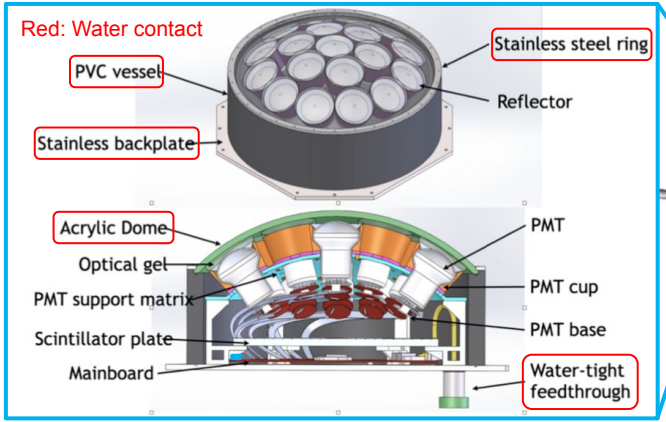


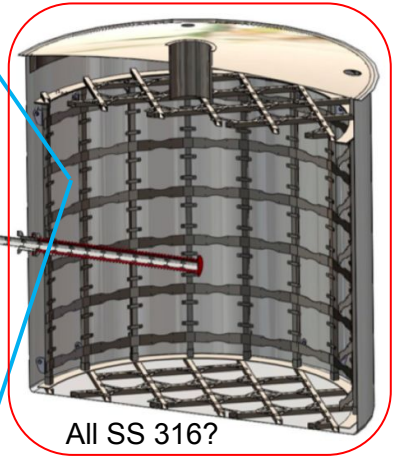
All objects and positioning are drawn to scale

- Existing tub may be used for sample volume
  - Inlet on side near bottom & outlet drain bottom corner
- Existing (tap) water source
- Need to build around the catchment if we want to use this space
  - Can be integrated as part of spill prevention
- Dark tub can be removed if space required
  - Prefer to keep in room to fill with pure water for other tests

Materials in Water

- Care about rate of impurities dissolving (elution) in water from all materials



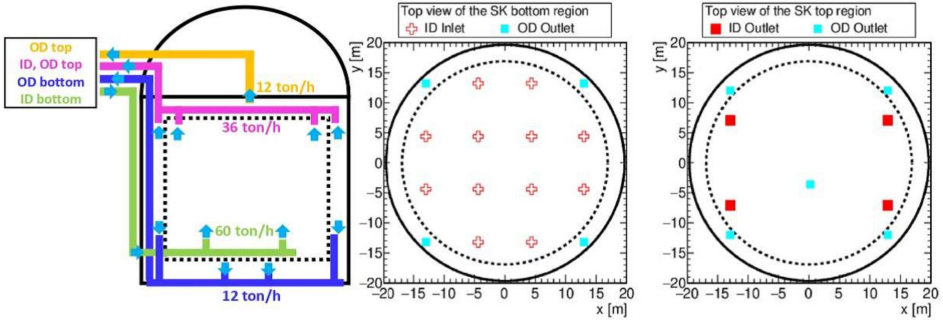


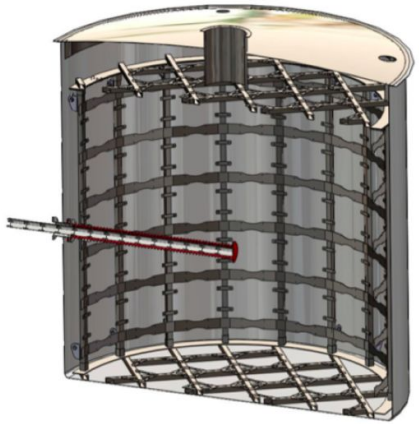
- Surface area estimates:
  - Tank = 64m^2 = 23m^2 (endcaps) + 41m^2 (barrel)
  - Support structure = ?
  - 106 mPMTs = 74m^2 = [0.20m^2 (SS) + 0.27m^2 (PVC) + 0.23m^2 (acrylic)] x 106
  - ID Blacksheet = 27m^2

Mechanical Integration

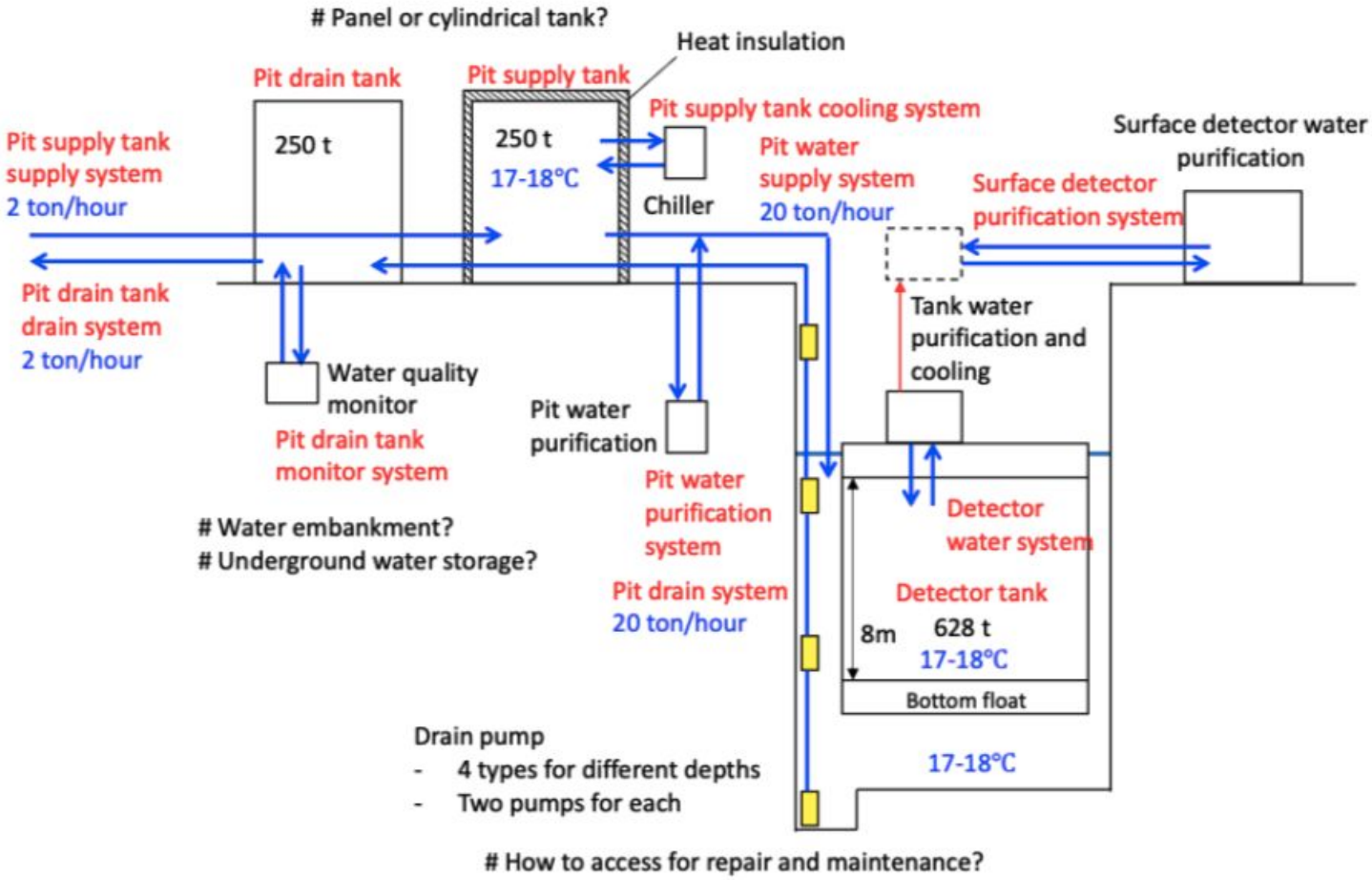
- Need to start considering mechanical integration (some questions from Prof. Garde, VIIT already):
  - We would be interested in knowing the plumbing inside the tank and mounting of valves, etc on the lid because the space inside the tank is very small.
  - We would also like to know if someone from your group would be looking into the effect of water flow (2 tons/hr?) and the buoyancy effect on mPMTs and other components.

- Super-K example below, for intricate flow control
  - WCTE will be much simpler with no OD and smaller volume to control





First Concept for IWCD



Water Temperature Control

- Water chiller is needed for
  - suppress biological growth
    - most serious purification concern
  - electronics cooling
    - 20W x 500 = 10kW from electronics
  - forced water replacement
    - efficient water replacement
  - lower temperatuire needed for Gd desolving

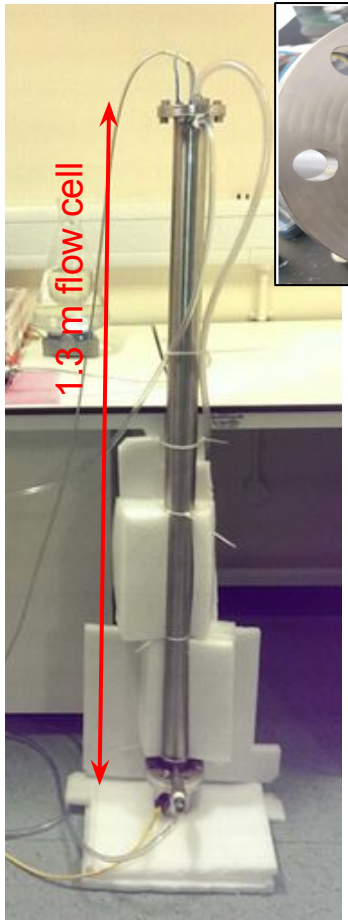
- Commercial chiller is not so expensive
  - used for cooling water for laser cutter
    - high capacity and economical:
      is there a catch?

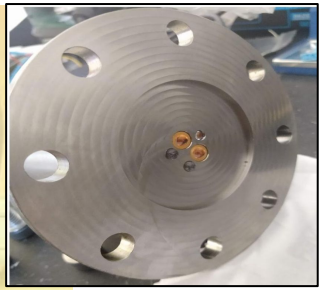
S&A CW-7800FN

Cooling capacity: 19kW
Flow: 67-133L/min (8ton/h)
Size: 155x82x178cm
Consumption: 9.2kW
weight: 380kg
price: $9k

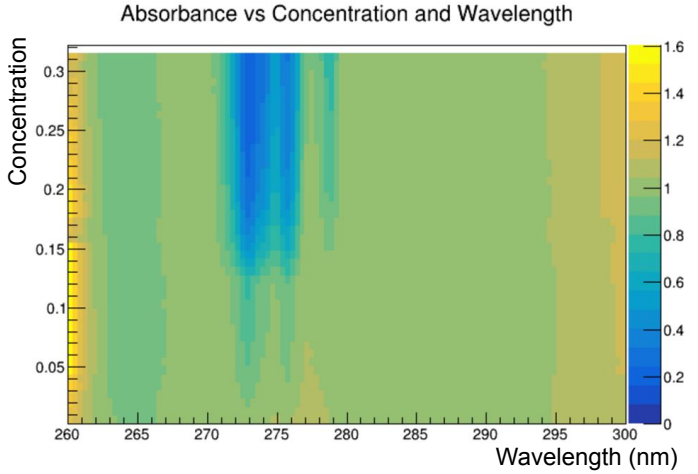
GAD v3.0 Update

(Warwick)

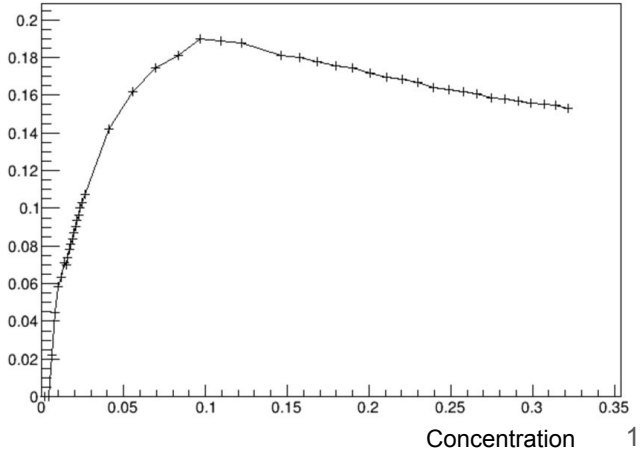




- v3.0 fully constructed
- Multiple optical sources for constant monitoring over entire spectral range 200 – 800 nm



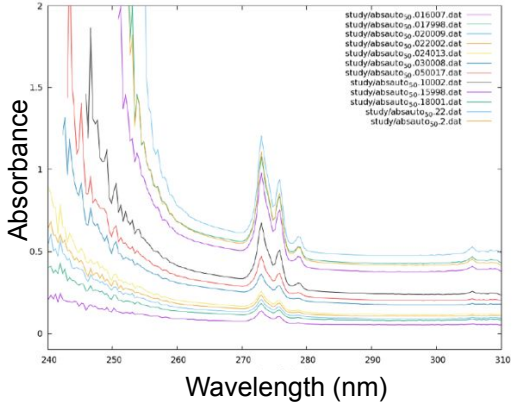
- Performance testing underway
- Developing software and automated analysis/web interface
- Ready to ship to Japan for deployment at EGADS and Super-K when lockdown ends

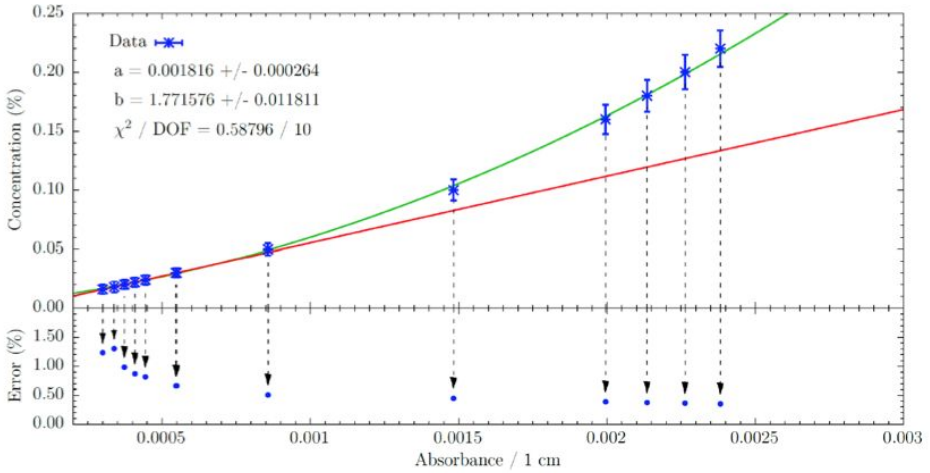


Gadolinium Absorbance Detector (GAD)

(Warwick)

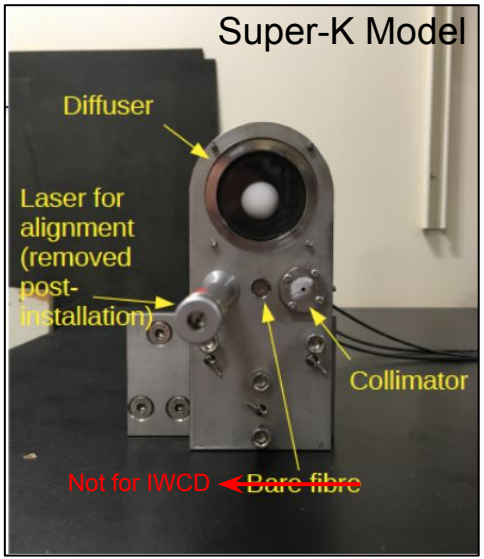
- Automated continuous monitoring of Gd concentration
- Gd has strong absorption lines near 275 nm
  - Absorption directly proportional to Gd concentration
- To be operated at inlet to WCTE/IWCD tank
- v2.0 (1 m flow cell) working very well
  - ~1% error at 0.02% $Gd_2S_3O_{12}$ concentration
  - ~0.5% error at 0.2% $Gd_2S_3O_{12}$ concentration





Light Injectors

- IWCD system consists of 16 injectors:
  - Including diffuser and a collimator to provide different beam characteristics for calibrations and monitoring
    - Optical: Water attenuation, scattering; reflectivity
    - PMT: Timing and gain; wavelength dependence
  - Based on system for Hyper-K and now testing in Super-K
- IWCD ID: 4 columns, 3 heights
  - 32 fibers running through OD to 4 patch panels on lid
- *WCTE to be determined*
  - Not as critical for absorption/scattering
  - However, reflections are still important



Preliminary Concept