Overview of Applications & Global Projects

Yan-Jie Schnellbach
RWTH Aachen University

schnellbach@nvd.rwth-aachen.de

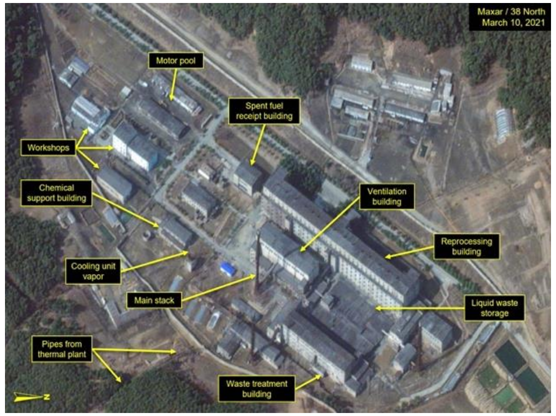
Applied Antineutrino Physics 2024 | Aachen | 28th October 2024

Nuclear Verification and Disarmament | III. Physikalisches Institut B | RWTH AACHEN UNIVERSITY

Introduction: Antineutrino Applications

- Majority of antineutrino applications intertwined with main source:
  - Nuclear facilities & devices

- Cooperative reactor monitoring – safeguards
- Submarine monitoring – verification
- Long-range reactor discovery – surveillance
- Spent fuel monitoring – safeguards, re-verification
- Precision spectral measurements – nuclear data



- Neutrino communication - ???

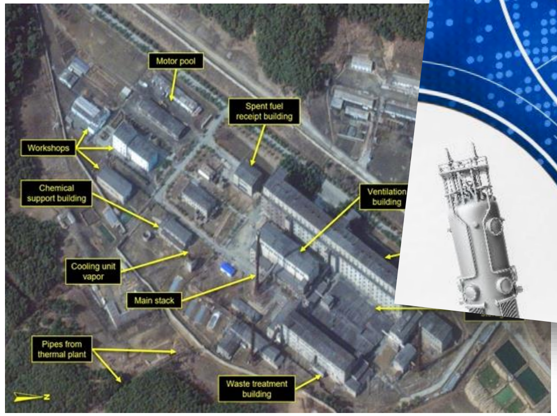
Yan-Jie Schnellbach | schnellbach@nvd.rwth-aachen.de
Nuclear Verification and Disarmament
III. Physikalisches Institut B
RWTH AACHEN UNIVERSITY

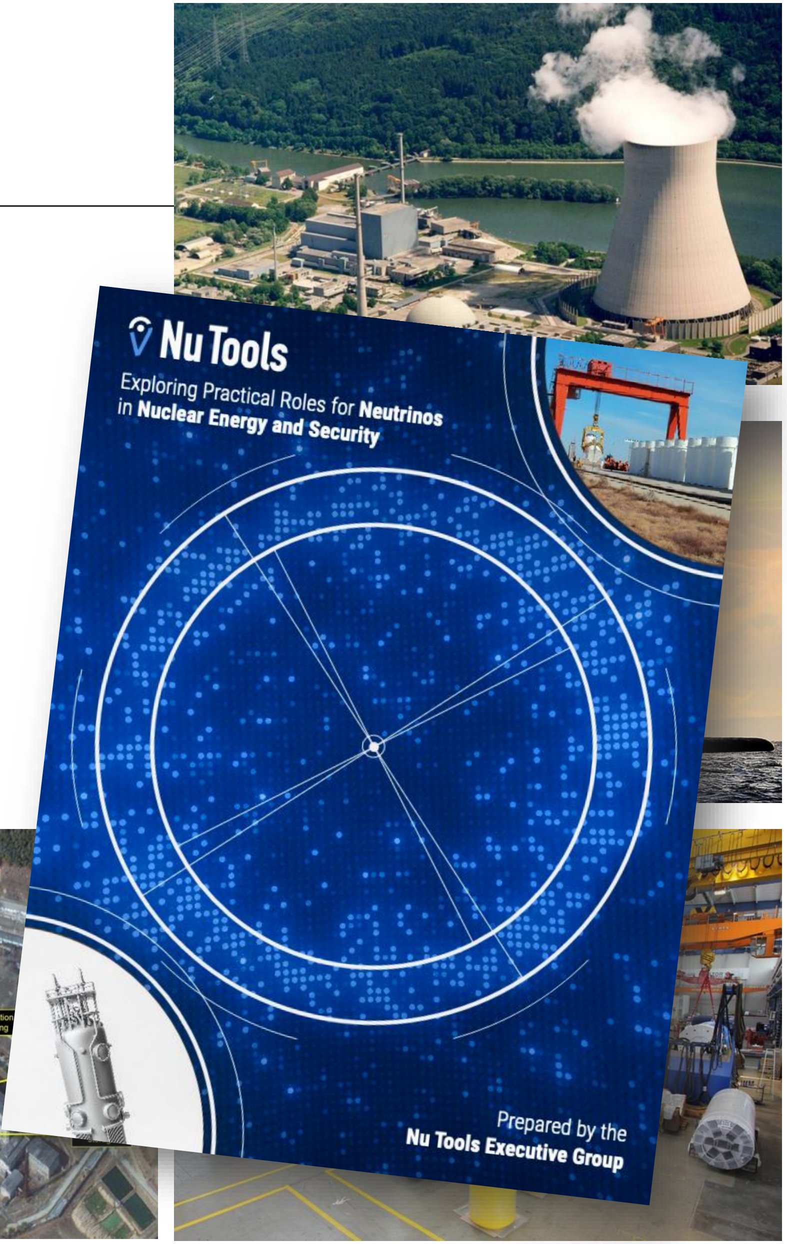
Introduction: Antineutrino Applications

- Majority of antineutrino applications intertwined with main source:
  - Nuclear facilities & devices

- Cooperative reactor monitoring – safeguards
- Submarine monitoring – verification
- Long-range reactor discovery – surveillance
- Spent fuel monitoring – safeguards, re-verification
- Precision spectral measurements – nuclear data

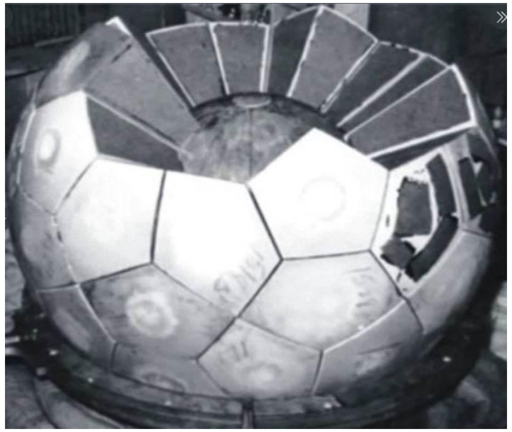
- Neutrino communication - ???



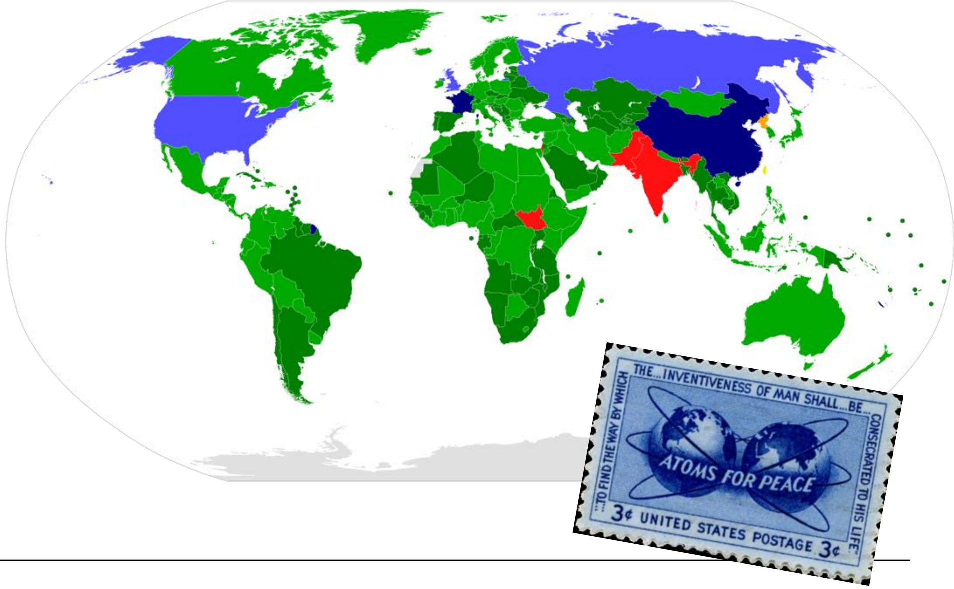


Yan-Jie Schnellbach | schnellbach@nvd.rwth-aachen.de
Nuclear Verification and Disarmament
III. Physikalisches Institut B
RWTH AACHEN UNIVERSITY

Safeguards: Non-Proliferation of Nuclear Weapons



- Main obstacle for obtaining nuclear weapons:
  - Acquiring enough fissile material
  - Main isotopes of interest: ^{235}U, ^{233}U, ^{239}Pu, ^{241}Pu
  - Low/no natural abundance
- Safeguards: accountancy of special nuclear materials + maintaining continuity of knowledge (CoK)
  - Detect diversion of “significant quantity” (SQ) in timely fashion
- Usually cooperative – fulfilling NPT treaty obligations



Safeguards, Verification & Near-field Monitoring

- Using combination of principles:
  - Design information verification (DIV) of facilities
  - Nuclear material accountancy using non-destructive analysis (NDA) and destructive analysis (DA)
  - Containment and surveillance (C/S) to maintain CoK after initial accountancy
  - Unattended/remote monitoring – information without inspector access

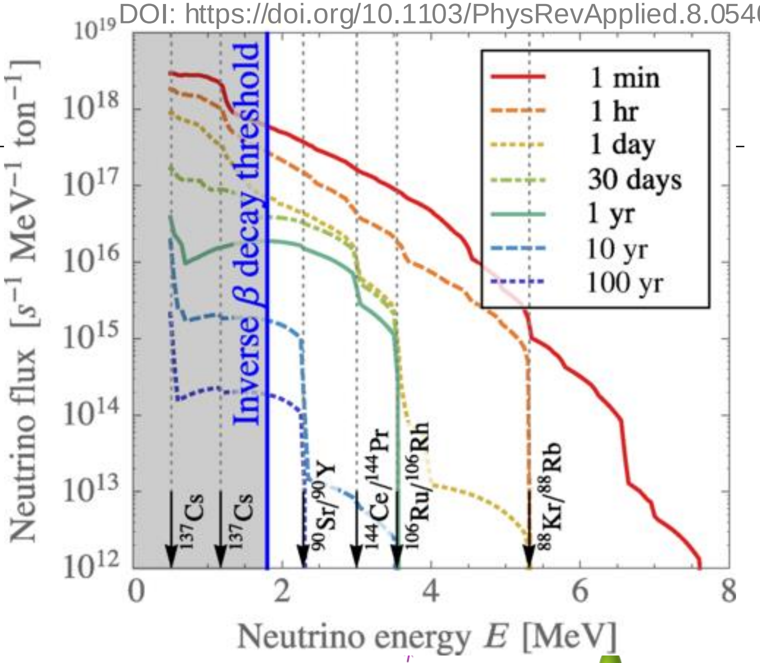
- Near-field antineutrino detectors as safeguards: mainly C/S, but overlap with NDA and remote monitoring:
  - Measurement of reactor power
  - Verification of reactor burn-up
  - Monitoring of spent fuel / ^{90}Sr

- Also: “nuclear renaissance” – SMRs, advanced reactors etc.

Yan-Jie Schnellbach | schnellbach@nvd.rwth-aachen.de
Nuclear Verification and Disarmament
III. Physikalisches Institut B
RWTH AACHEN UNIVERSITY

Brdar, V. and Huber, P. and Kopp, J., “Antineutrino Monitoring of Spent Nuclear Fuel”,
Phys. Rev. Applied, vol. 8, issue 5, pg 054050 (2017).
DOI: https://doi.org/10.1103/PhysRevApplied.8.054050

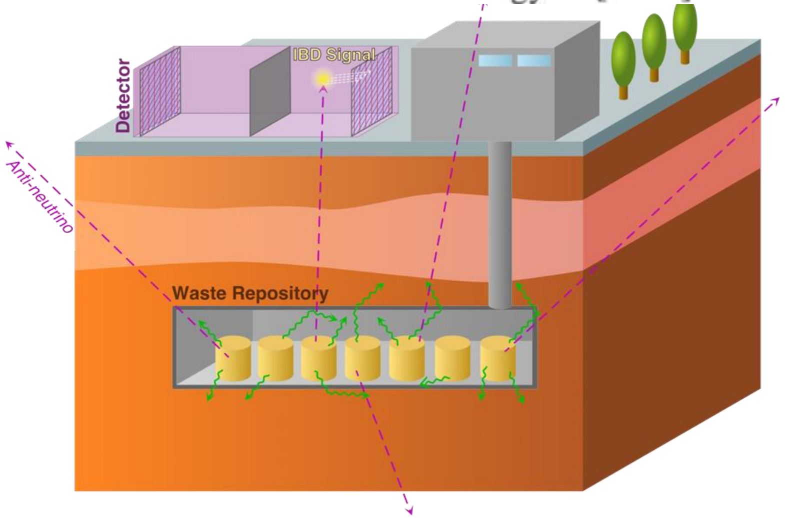
Spent Nuclear Fuel Monitoring



- Spent Nuclear Fuel (SNF) produced in large amounts by power plants
  - C. 300,000 t in storage
  - Yearly discharge of c 7,000 t per year

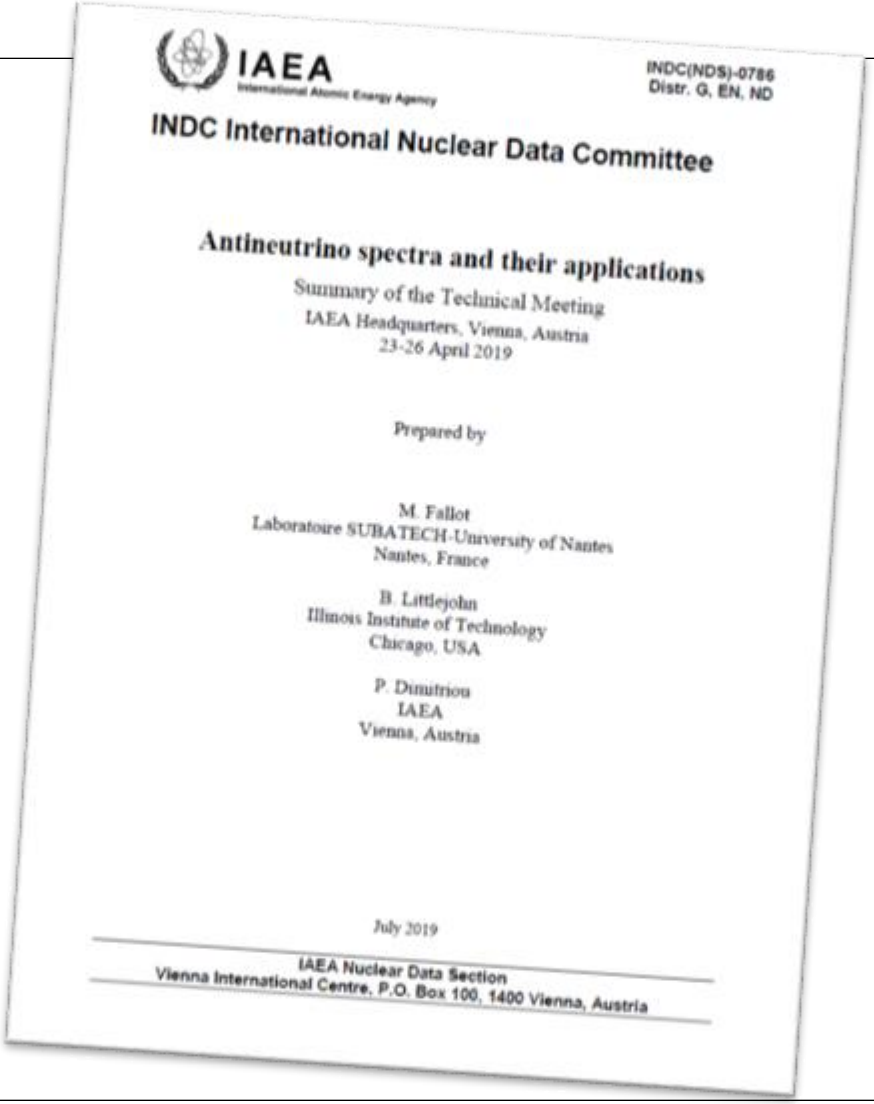
- Monitoring for safeguards + environmental

- Challenging signature: ^{90}Sr main isotope
  - Endpoint at 2.2 MeV – close to IBD threshold



Nuclear Databases

- Several IAEA meetings on antineutrino spectra
  - Technical meetings on input to nuclear databases
  - Meetings in 2019, 2023 and next year
- Near-field measurements are maturing
  - High statistics from larger experiments (e.g. Double Chooz)
  - Turning into precision physics
- Various spectral anomalies still observed
  - Interest in understanding these


IAEA
International Atomic Energy Agency

INDC(NDS)-0786
Distr. G, EN, ND

INDC International Nuclear Data Committee

Antineutrino spectra and their applications

Summary of the Technical Meeting
IAEA Headquarters, Vienna, Austria
23-26 April 2019

Prepared by

M. Fallot
Laboratoire SUBATECH-University of Nantes
Nantes, France

B. Littlejohn
Illinois Institute of Technology
Chicago, USA

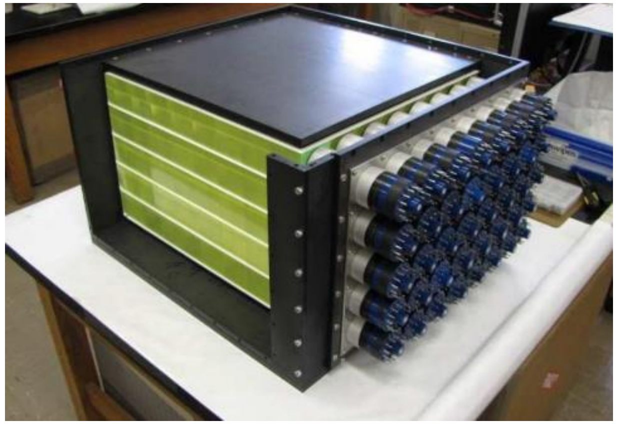
P. Dimitriou
IAEA
Vienna, Austria

July 2019

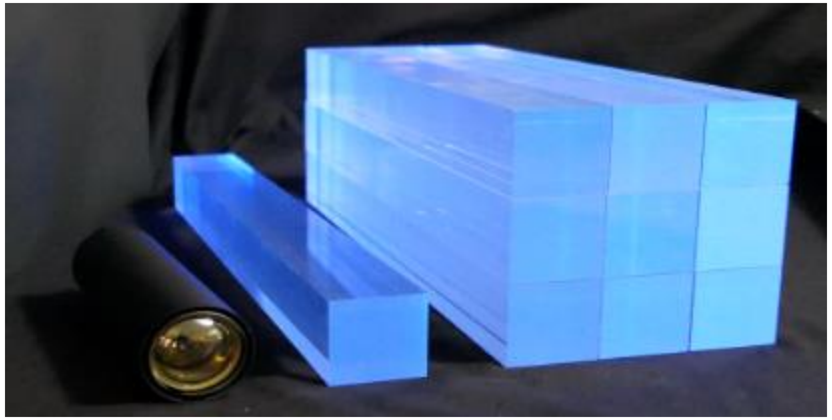
IAEA Nuclear Data Section
Vienna International Centre, P.O. Box 100, 1400 Vienna, Austria

Surface Detection (Near-field) - < 1km

- Predominant technologies:
  - Plastic scintillator
  - Liquid scintillator
  - Some form of segmentation (2D/3D)
  - Many: doping (e.g. Gd or ^{6}Li)
  - Many: some form of particle ID capability (e.g. PSD)
  - Veto capability against cosmics



- Application-focussed R&D:
  - Many have deployed prototypes at reactors
  - Aiming at tonne-scale devices
  - Goal of most projects: advance technological readiness
    - Improved burn-up determination
    - Control backgrounds & systematics
    - Improve fence distance



Yan-Jie Schnellbach | schnellbach@nvd.rwth-aachen.de
Nuclear Verification and Disarmament
III. Physikalisches Institut B
RWTH AACHEN UNIVERSITY

Surface Detection (Near-field)

MiniCHANDLER – 80 kg
- Solid plastic scintillator
- Deployed at North Anna Nuclear Generating Station

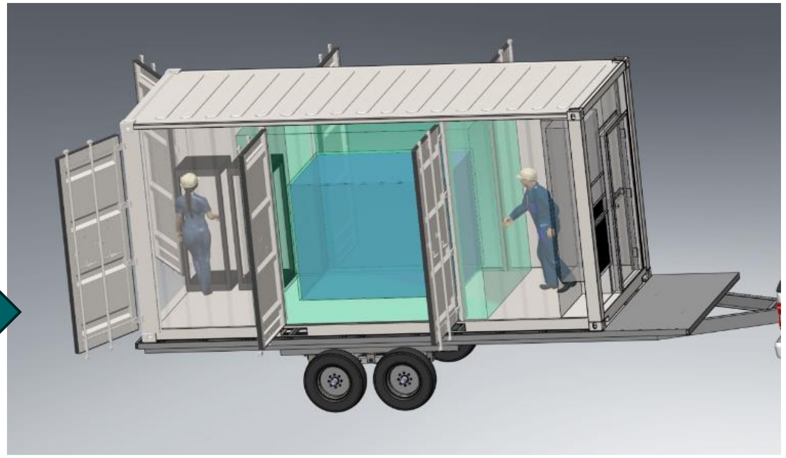
ROADSTR – 100 kg
- Technology testbed
- Neutron characterisation

PROSPECT – 3.6t
- Liquid scintillator
- Deployed at HFIR

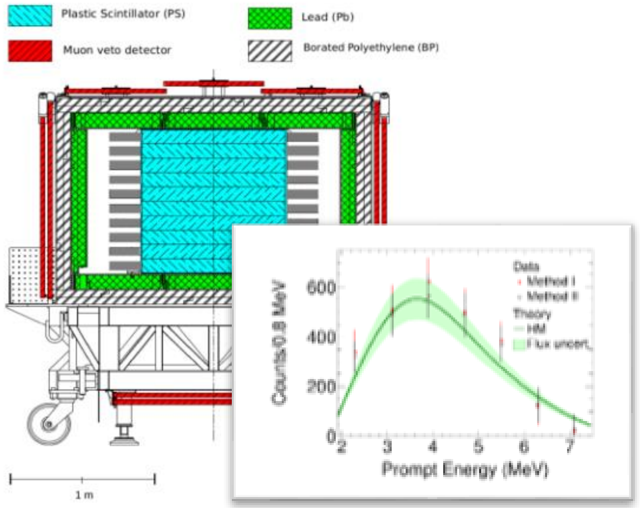
Talk by M. Mendenhall on Wednesday

MAD
(Mobile Antineutrino Demonstrator)
- Goal to demonstrate ton-scale mobile detector
- Advance TRL

Talk by E. Bernard on Wednesday



Surface Detection (Near-field)

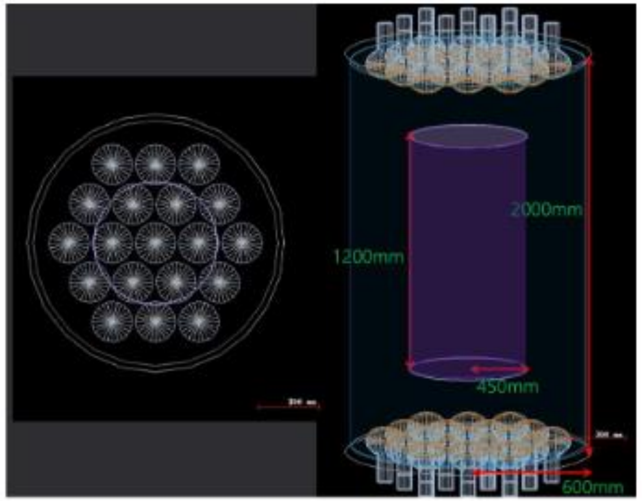


ISMRAN (Indian Scintillator Matrix for Reactor Anti-Neutrino)

- Plastic scintillator + Gd
- Deployed at DHRUVA 100 MWth research reactor
- Preliminary energy spectra measured

VIDARR

- Plastic scintillator + Gd
- Previously deployed at Wylfa Nuclear Power Plant
- Upgraded and currently at Sellafield – ^{90}Sr monitoring

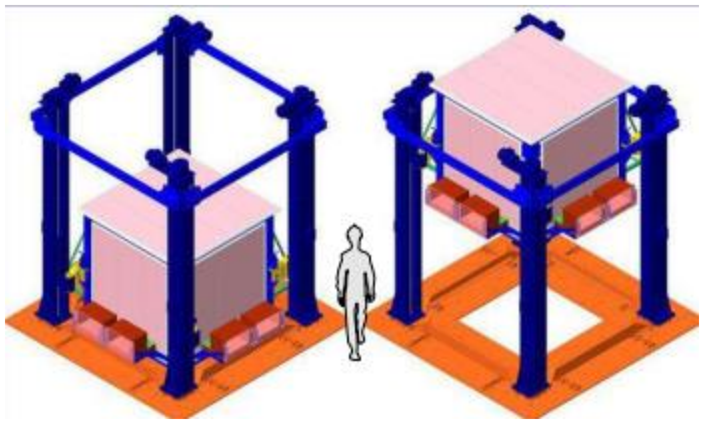


RENE (Reactor Experiment for Neutrino and Exotics)

- Collaboration founded Nov 2022
- Liquid scintillator-based

Talk by B. Yang on Wednesday

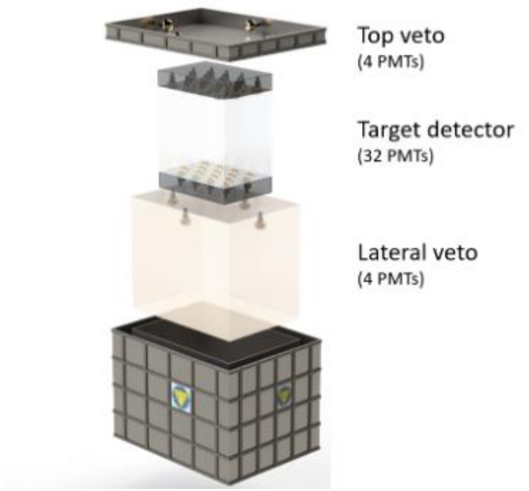
Surface Detection (Near-field)



DANSS (Detector AntiNeutrino based on Solid Scintillator)

- Plastic scintillator + Gd
- Deployed at Kalinin Nuclear Power Plant (4x 3.1 GW^{th} PWR)
- Long-running data taking since ’16

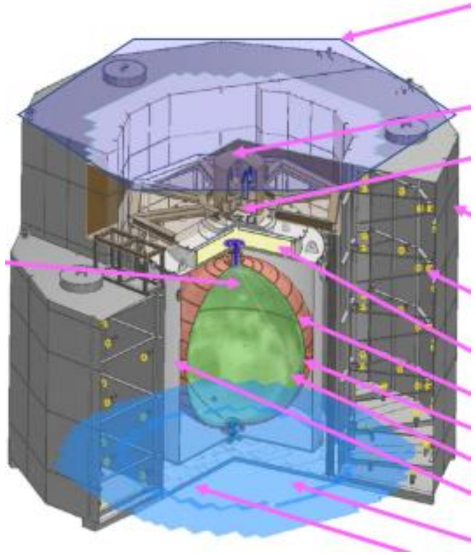
Talk by I. Alekseev on Wednesday



ANGRA Neutrino Experiment

- Water + Gd (Cherenkov)
- Deployed at Angra dos Reis nuclear power plant
- Recently performed ON/OFF Analysis

Talk by E. Kemp on Wednesday



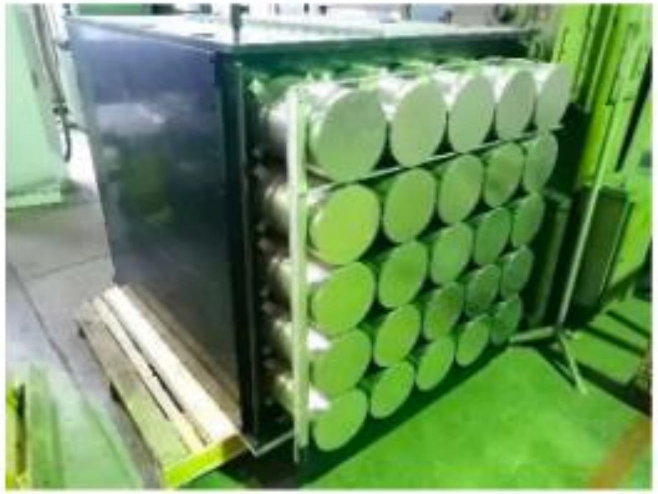
TAO (Taishan Antineutrino Observatory)

- Liquid scintillator + Gd
- Cooled to -50 C
- Near Taishan 1 reactor (4.6 GW^{th})

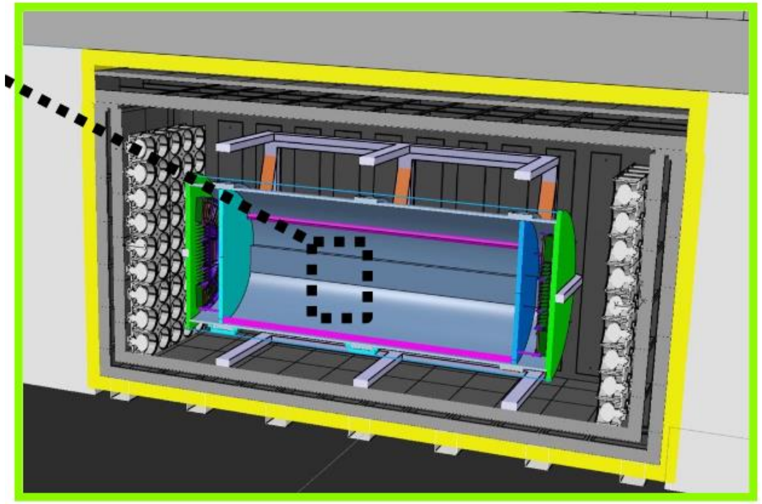
Talk by H. Steiger on Wednesday

Surface Detection (Near-field)

NEOS-II (Neutrino Experiment for Oscillation at SBL)
- Gd-loaded LS (LAB-based)
- Deployed at Hanbit-5 reactor (2.8 GWth) tendon gallery
- Results are being finalised



Neutrino 4+
- Gd-loaded LS
- Deployed at Reactor SM-3 (90 MWth HEU research reactor)
- Upgrade to Neutrino 4
- Data collection expected end of this year ('24)



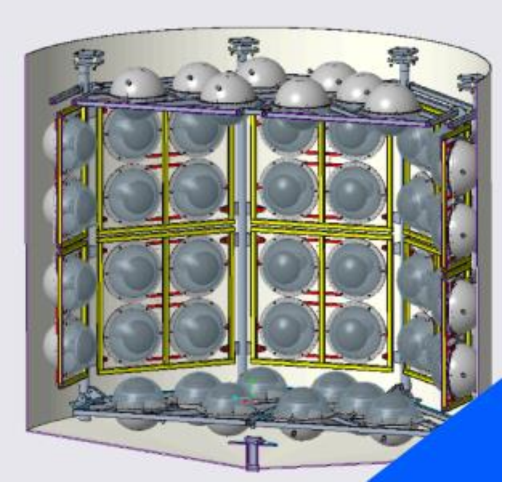
CLOUD (Chooz LiquidO Ultranear Detector)
- Novel opaque scintillator
- AntiMatter-OTech Project
- Technology still in R&D phase
- Proposal to be deployed at Chooz w/ 10k IBD events/day

Yan-Jie Schnellbach | schnellbach@nvd.rwth-aachen.de
Nuclear Verification and Disarmament
III. Physikalisches Institut B
RWTH AACHEN UNIVERSITY

Far-field Reactor Monitoring – 10-100s km

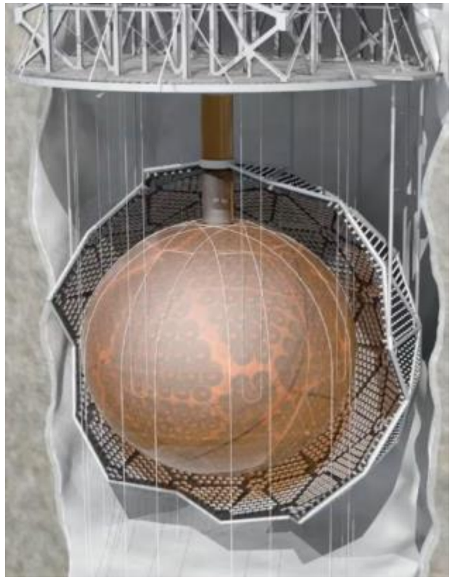
- Comes in two safeguard-adjacent flavours:
  - Surveillance – usually across borders
  - Cooperative monitoring – verification & science diplomacy
- Technically, great challenges:
  - Long baseline – low signal due to distance
  - Neutrino oscillations have significant impact on rate
  - Require large and/or underground detector – geological restrictions on locations
- Large physics detectors effectively prototypes

Large-scale / Underground Detectors



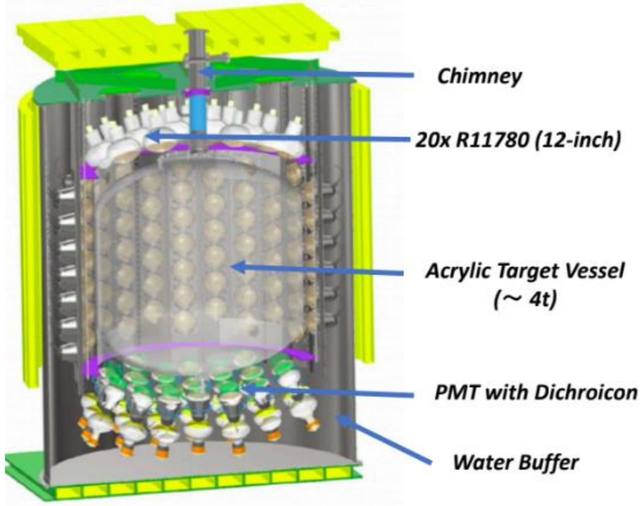
BUTTON (Boulby Underground Testbed Towards Observing Neutrinos)
- 30t Cherenkov detector
- Testbed for kt-scale tank
- Testbed for different media
- Testbed for detector R&D

Talk by D. Bhattcharya on Tuesday



SNO+ (Sudbury Neutrino Observator)
- Kton-scale water/liquid scintillator detector
- Long baseline measurement of CANDU reactors

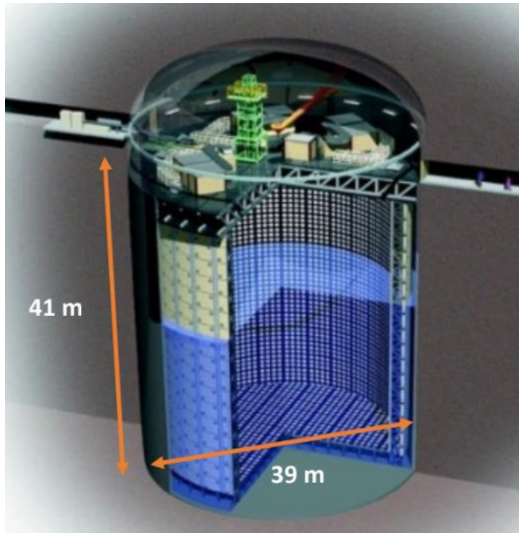
Talk by W. Parker on Wednesday



EOS / THEIA
- 4t water-based LS
- Testbed for scaling technologies (media, fast PMTs etc)
- Path towards THEIA (25/100 kt detectors)

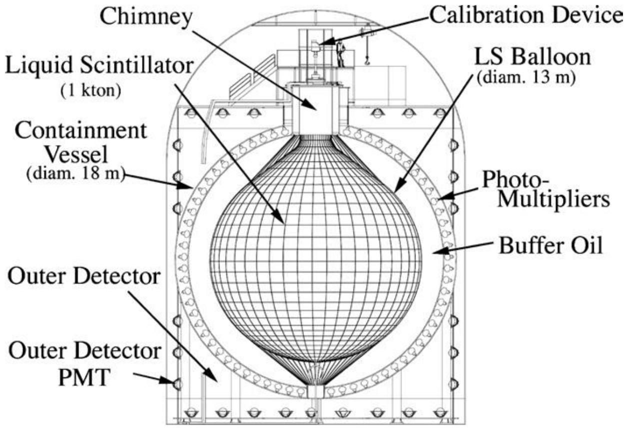
Talk by H. Steiger on Wednesday

Large-scale / Underground Detectors



SuperK-Gd
- 50 kton Cherenkov detector
- Since 2020: added Gd
- Enhanced sensitivity to reactor neutrinos + supernova neutrinos

Talk by R. Rogly on Wednesday



KamLAND-Zen
- 1 kton LS detector
- Saw Japanese reactors in early 2000s
- KamLAND-Zen for double beta decay search + future upgrades

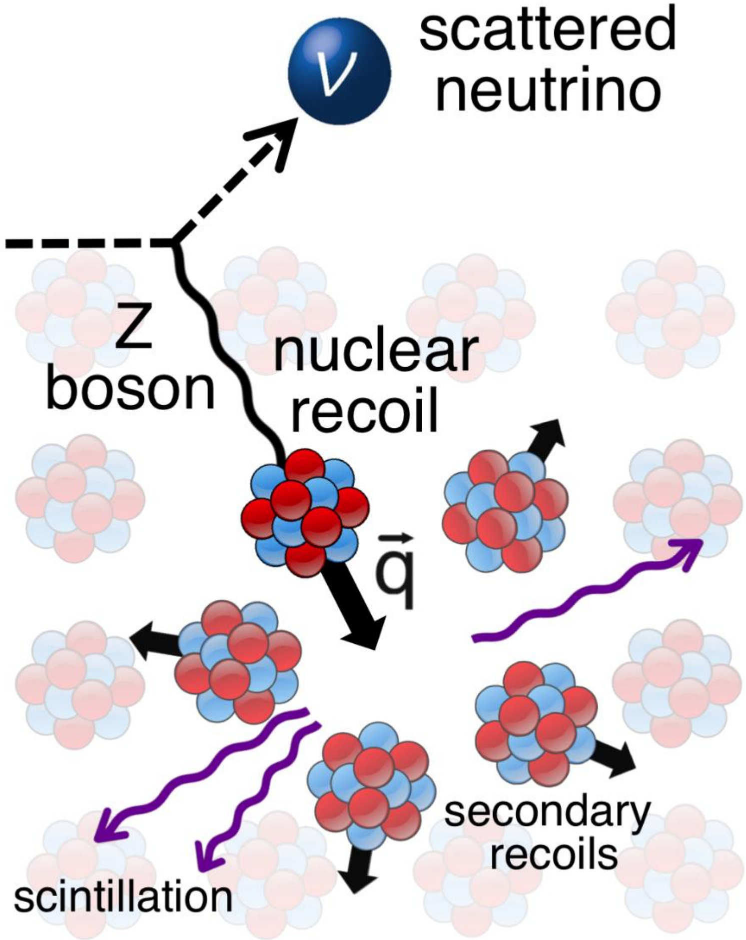
Talk by K. Weerman on Wednesday

Ocean Bottom Detector
- 20 kg LS prototype planned
- Future scale-up to kton-scale detector
- Goal: geoneutrino
- Also important R&D for underwater deployment

Talk by D. Morita on Wednesday

Yan-Jie Schnellbach | schnellbach@nvd.rwth-aachen.de
Nuclear Verification and Disarmament
III. Physikalisches Institut B
RWTH AACHEN UNIVERSITY

Coherent Elastic Neutrino-Nucleus Scattering: CEvNS



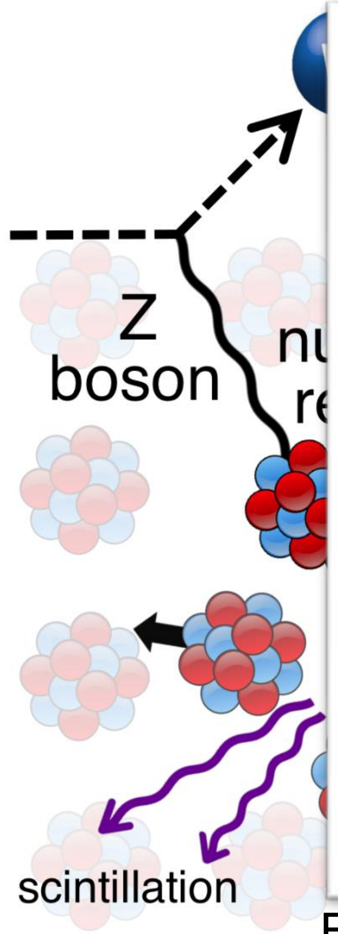
- Proposed by D. Freedman in 1974, unobserved until 2017
- Large cross-section
  - Allows smaller detectors
  - No IBD threshold
  - Lots of interesting ideas for applications
- But: small recoil energy – hard to detect!

- Very active field
  - Many active experiments
  - New technologies / detection approaches are being developed

- Will have seven talks on CEvNS during this workshop, including
  - RICOCHET, CONUS+ on Tuesday
  - COHERENT, NUCLEUS on Wednesday

Yan-Jie Schnellbach | schnellbach@nvd.rwth-aachen.de
Nuclear Verification and Disarmament
III. Physikalisches Institut B
RWTH AACHEN UNIVERSITY

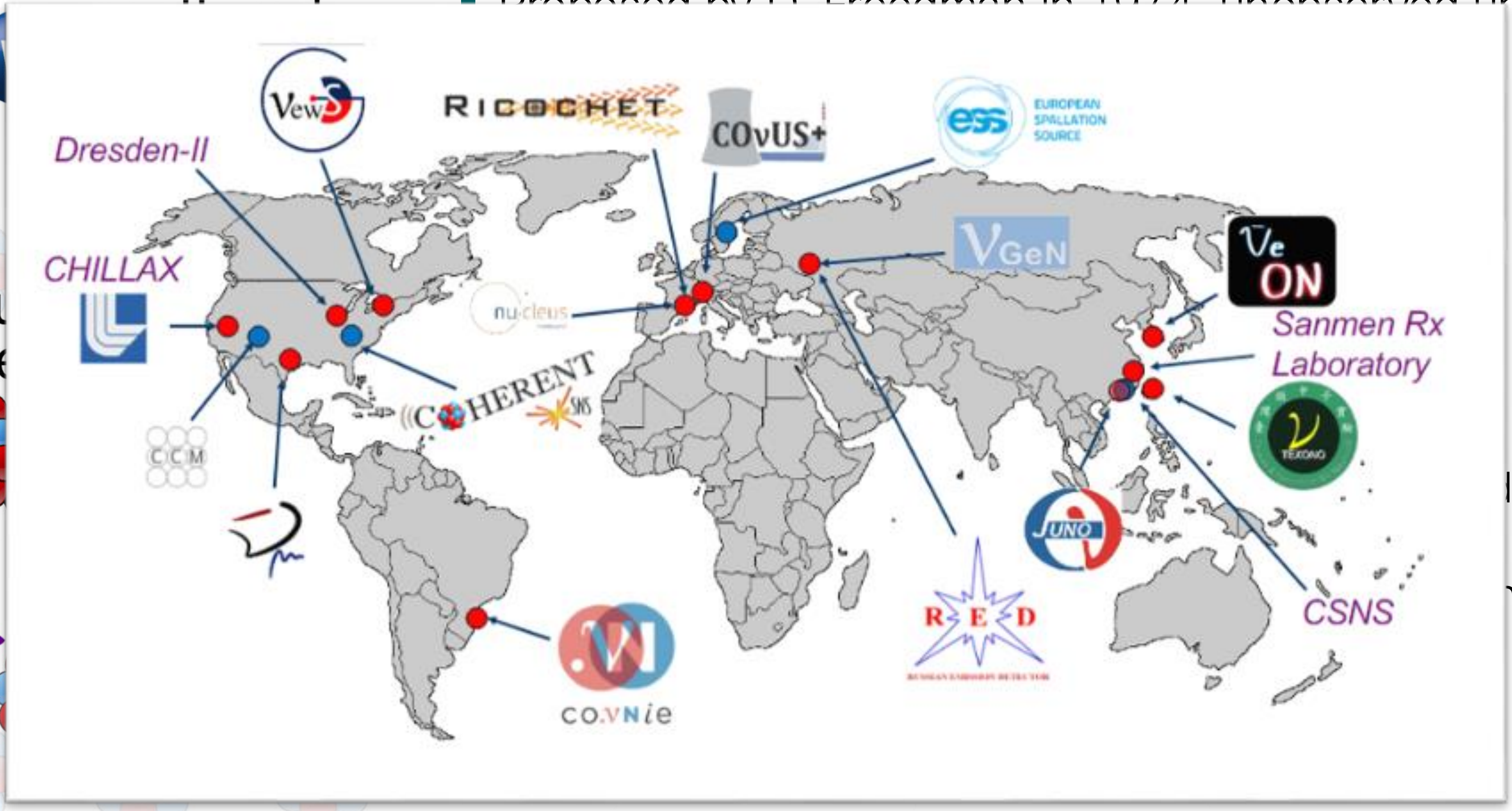
Coherent Elastic Neutrino-Nucleus Scattering: CEvNS



- Proposed by D. Freedman in 1974, unobserved until 2017

…developed

…hop, including



From Matthew Green's summary talk at this year's Magnificent CEvNS Meeting

Summary

- Safeguards still most interesting applications
- Near-field monitoring projects are maturing
  - Stronger focus on application-led R&D
  - Improved background estimation and systematics
- Increased engagement with nuclear data community
- Far-field-capable experiments
  - Still driven by fundamental physics experiments
- CEvNS is a young but very active area with great potential

Yan-Jie Schnellbach | schnellbach@nvd.rwth-aachen.de

Nuclear Verification and Disarmament
III. Physikalisches Institut B
RWTH AACHEN UNIVERSITY