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Radiological Characterization of the RA RR in Vinča Institute: Approach and Experiences

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- Status and preliminary results
- Characterization data base
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Background information

- RA RR: tank type D_2O cooled and moderated, Soviet design
- Reactor block in main reactor room (ground floor)
- Primary cooling system with number of components and long pipelines in underground floor (~70 rooms)
- Ventilation building, ventilation ducting
- Fuel: Russian TVR-S type fuel elements
  - LEU - metal U, 2 % U-235
  - HEU - UO_2 in Al matrix, 80 % U-235
- Operations: 1959 to 1984 at 6.5 MW of thermal power
- Temporary shutdown for modernization in 1984
- Extended shutdown stage until 2002
- Final shutdown in 2002, two main goals:
  - repatriation of the SNF
  - decommissioning of the facility
- Vinča Institute Nuclear Decommissioning Program
- Governmental support and funding, IAEA technical assistance

Characterization process and purposes

Characterization process

- **Objectives**
- **Planning**
- **Operational history**
- **Calculation methodology and tools**
- **Sampling and measurement process**
- **Analyses, comparisons, adjustments**
- **Determination of radionuclide inventory**

Characterization

- **SNF - for repackaging and transport**
- **Materials and waste - for clearance**
- **Surfaces, SSCs - for decommissioning purposes**

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Characterization approach

- IAEA TRS 389
- Measurements - for contamination
- Calculations - for activation
- Both approaches where possible
- Proper selection of measuring instrumentation
- Operation history, unplanned events
- Graded approach
  - Zones, systems
  - Nuclides
  - Types of measurements and analyses
  - Scaling factors for hard-to-detect nuclides
  - Importance of trace elements
- Background determination
- Experiences from SNF related activities
- Experiences and inventories from similar facilities

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Scope and objective

- **Characterization Plan in 2003, amendments in 2007**
  - **RA main building** (underground floor, ground floor, first floor, second floor – attic)
  - **Ventilation center NC**
  - **Ventilation duct**
  - **RA building surrounding**
- **OBJECTIVE - complete, accurate information on quantity, type and distribution of radionuclides to support SNF removal and decommissioning activities**
- **Results to be used for detailed planning of decommissioning activities (techniques, safety issues, protective measures, waste quantities, costs)**

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Operational history

- **Radiological state of RA facility today influenced by operations and by incidents that occurred**
  - **25 years of operation, several short shutdown priods**
  - **23 years out of operation (since 1984)**
  - **Co-60 contamination of the primary coolant circuit in 1963**
  - **spill of ~ 300 l of D_2O from the primary cooling system during repair work in 1965**
  - **failure of one fuel element in 1970**
  - **spread of the radioactive dust with Co-60 from the hot cells in early 1980's**
  - **some other activities with radioactive materials in building**
  - **presence of leaking SNF in four wet storage ponds**
  - **liquids drained, stored locally – 5.5 m^3 of used D_2O in the storage tank (RA underground floor)**

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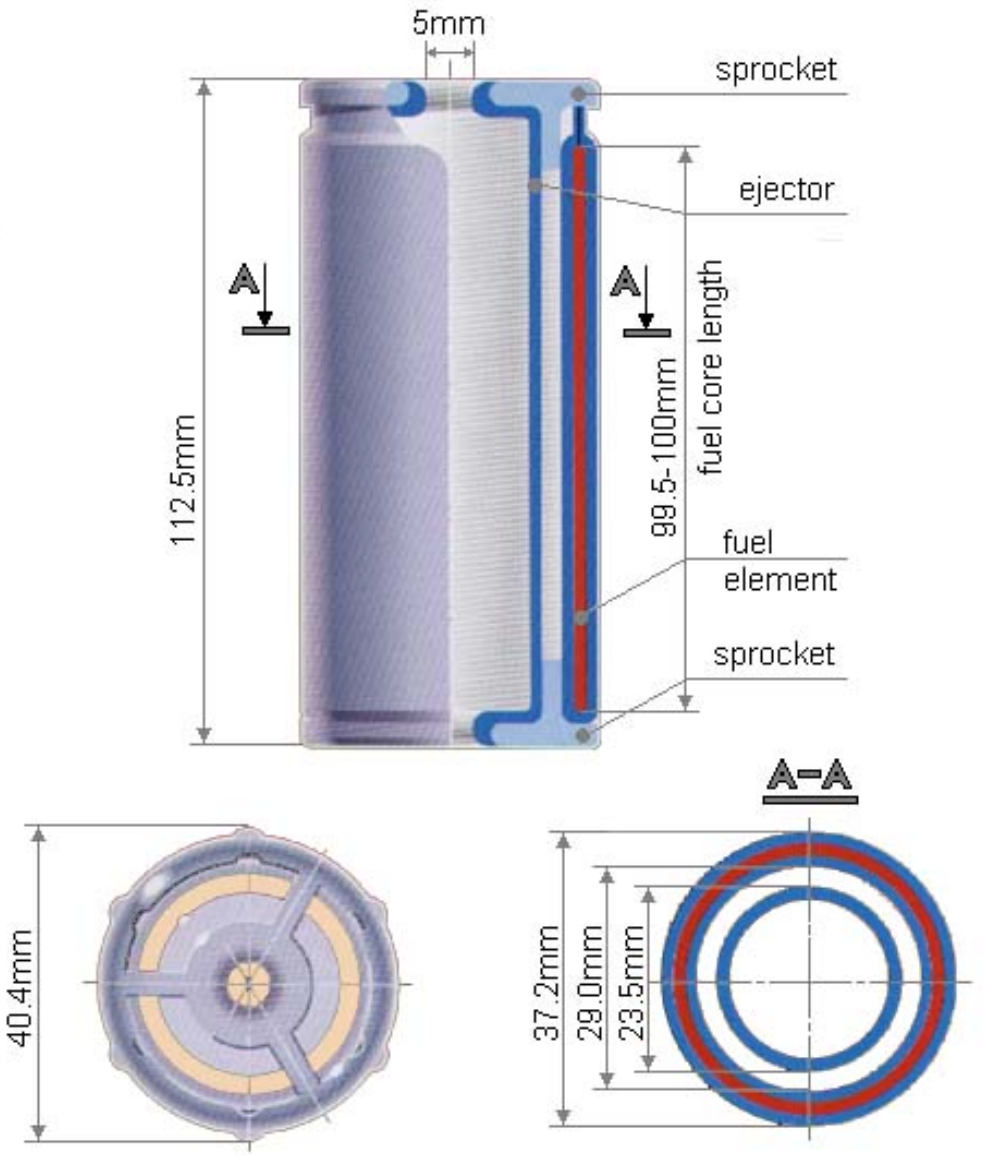
SPENT FUEL



LEU 2%

metal U

HEU 80%

UO_2 in Al

8030 spent FE

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Storage period 20 - 40 years

250 stainless-steel containers

30 aluminium barrels

6656 LEU FE

894 HEU FE

480 HEU FE still in dry RA core

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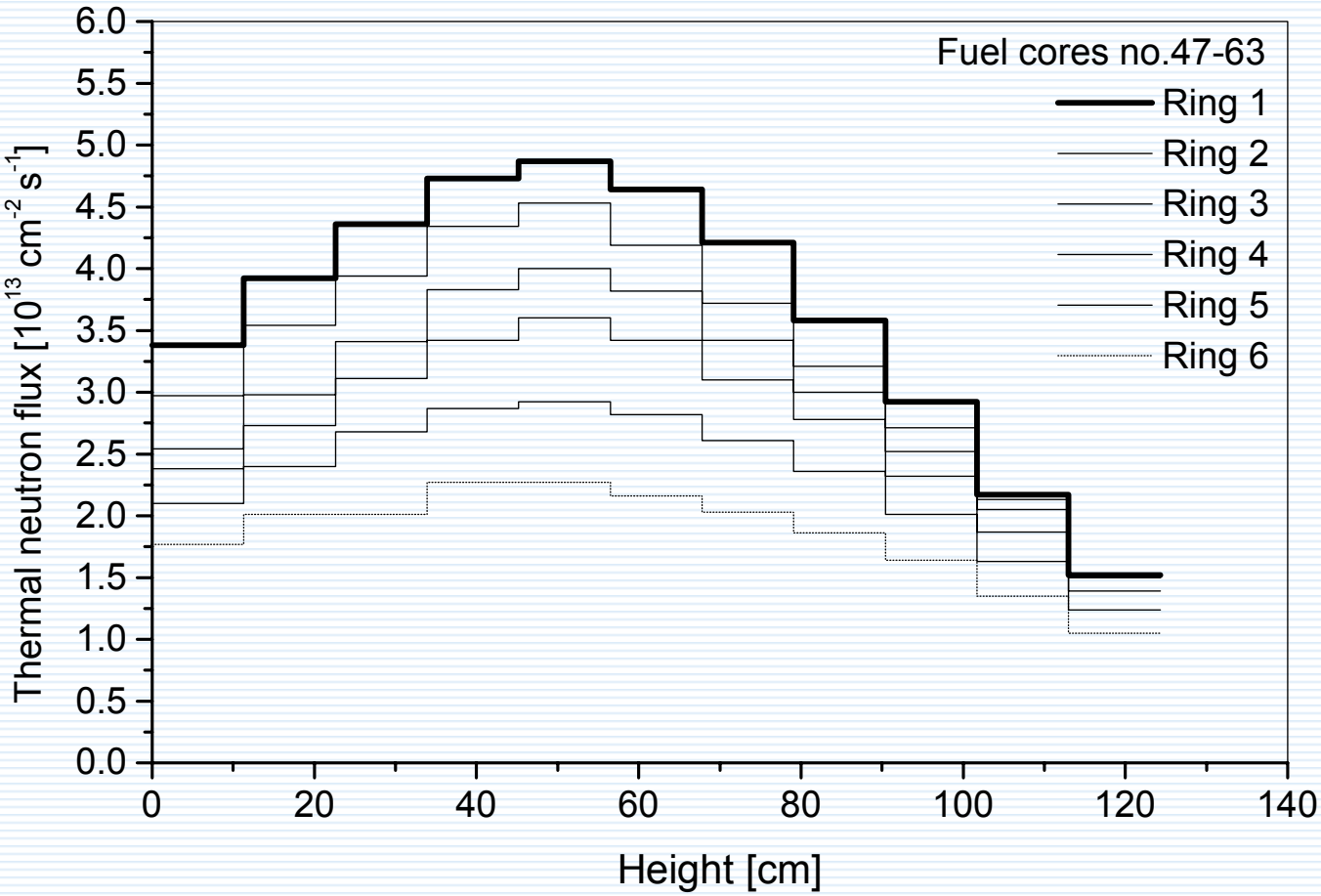

Evaluated thermal neutron flux in six radial rings and eleven axial nodes – based on operational records, available for 4 main phases in reactor operation

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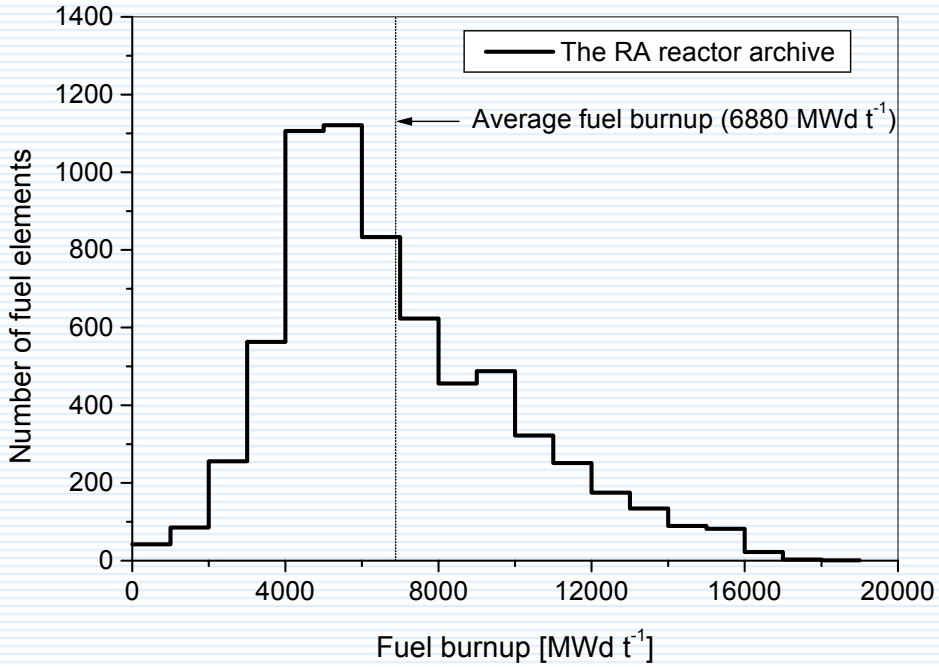
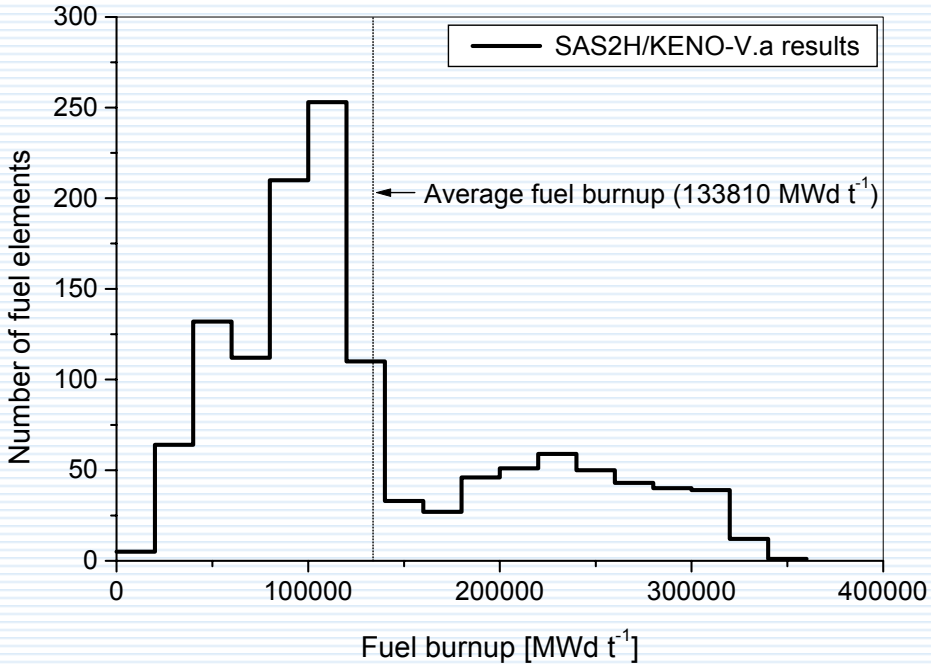
LEU SNF burnup



HEU SNF burnup



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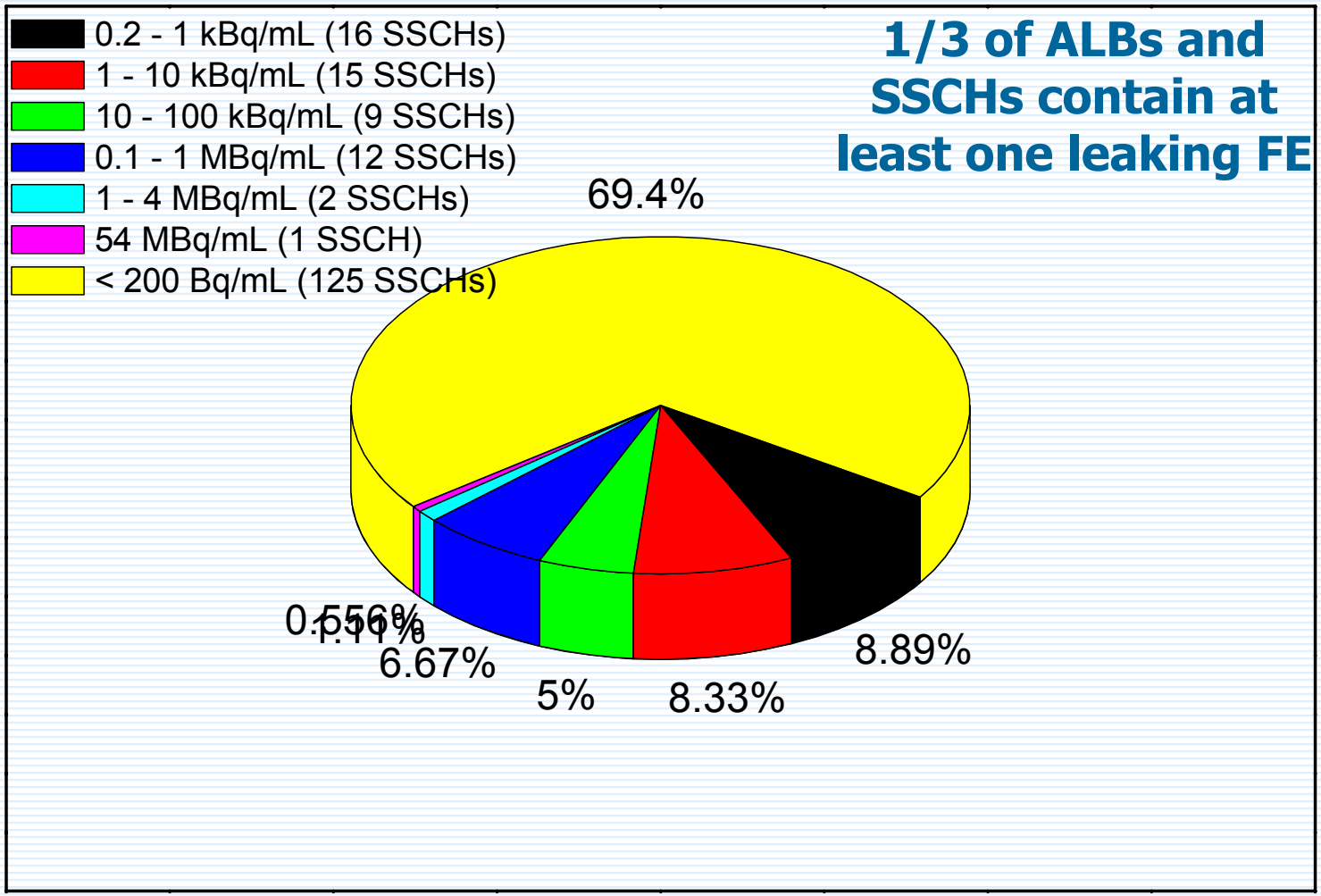

Water A(^{137}Cs) in SSCHs

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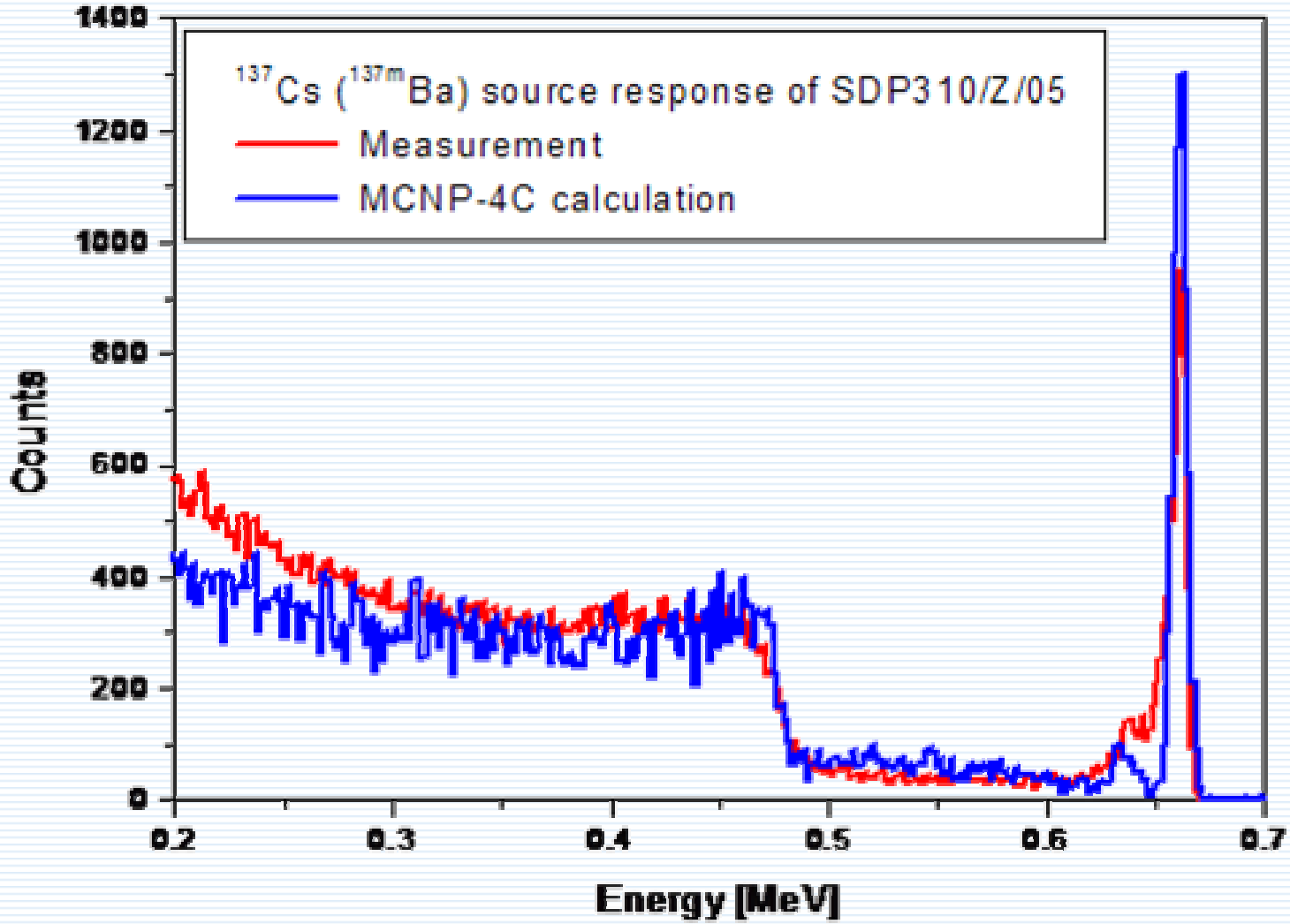

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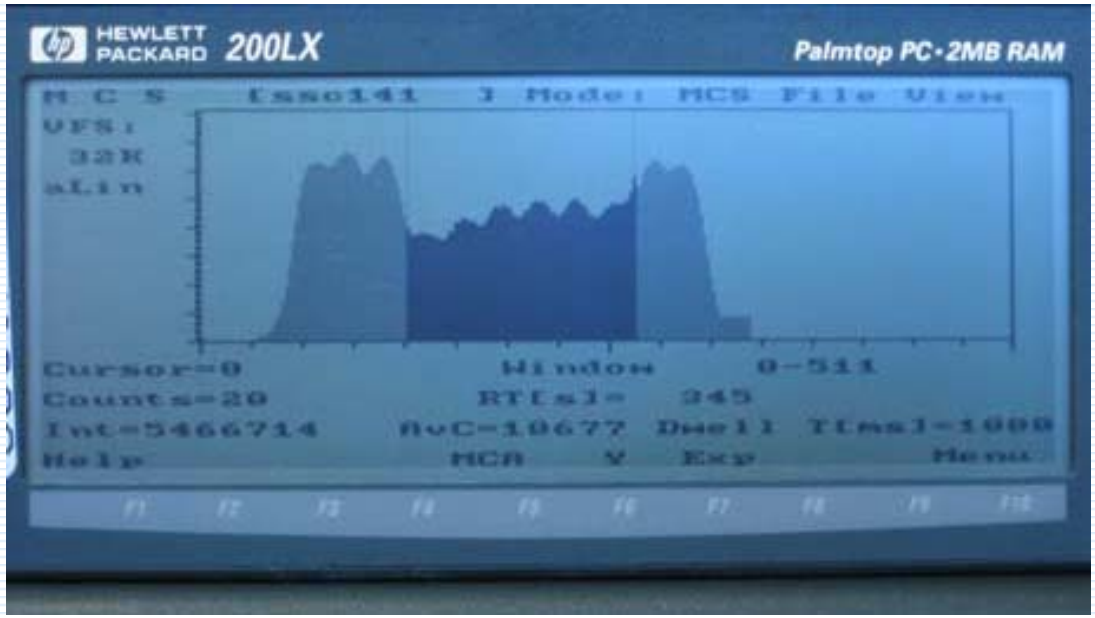

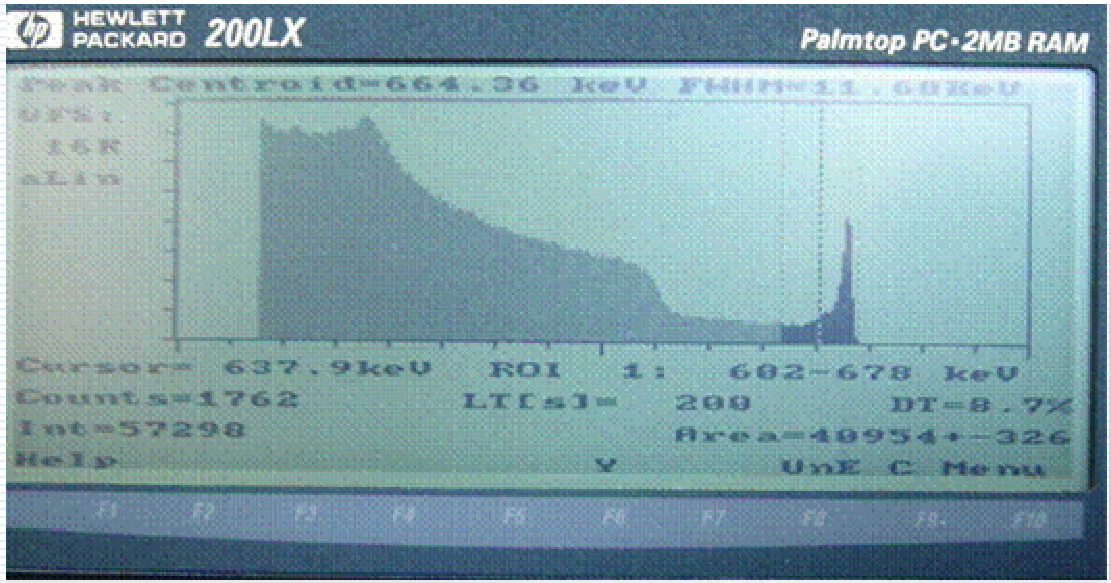

SNF characterization

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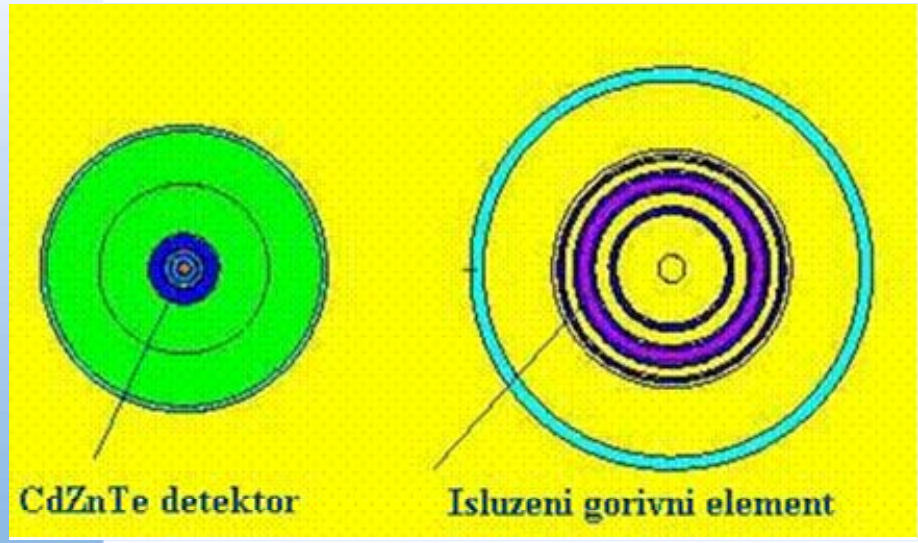

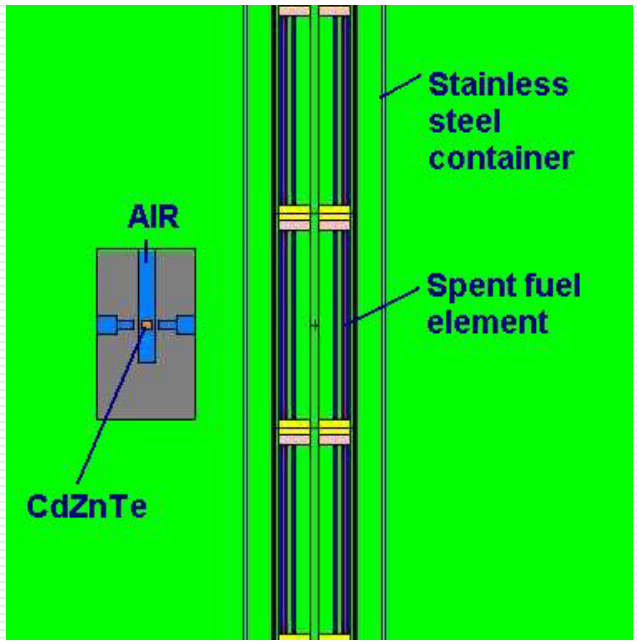

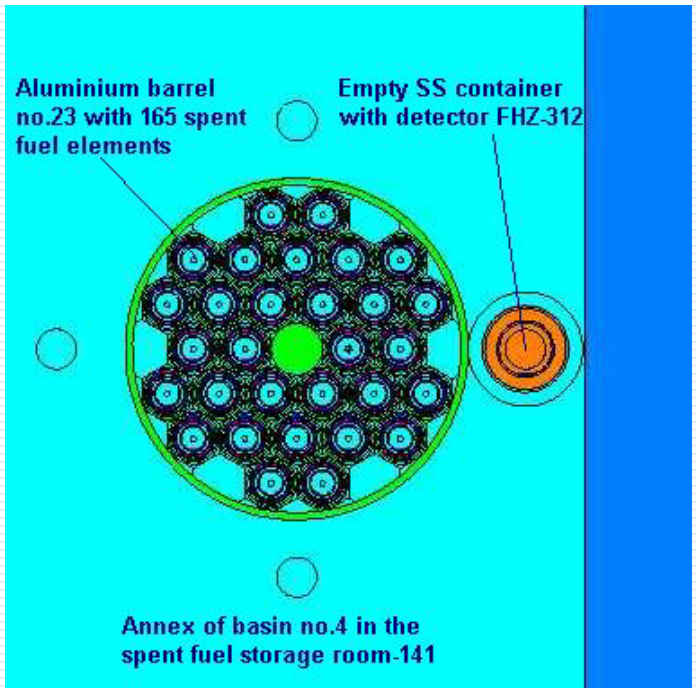

Radiation and nuclear safety during SNF operations: 3D calculation models

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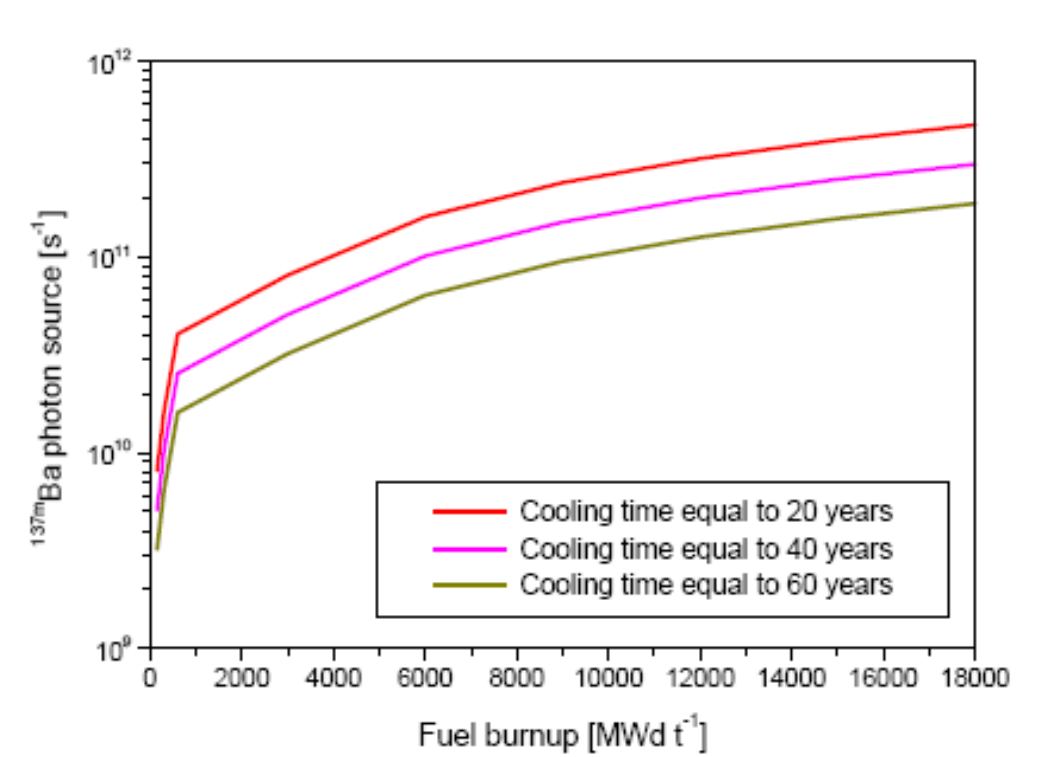

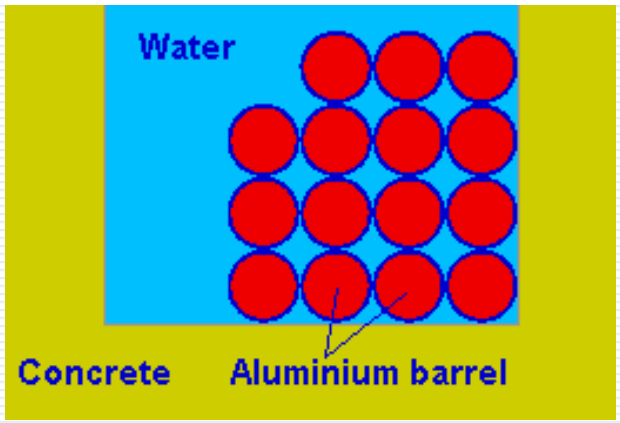

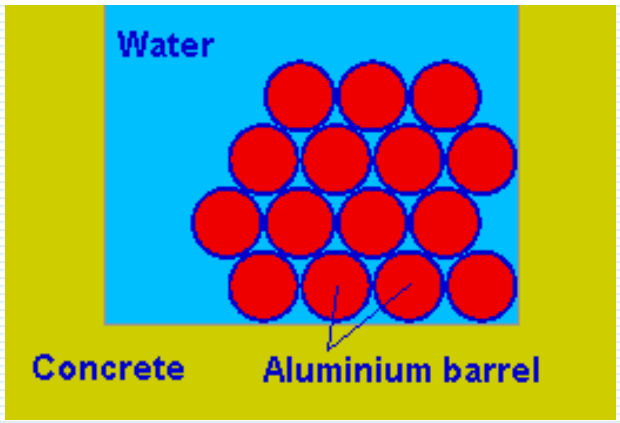

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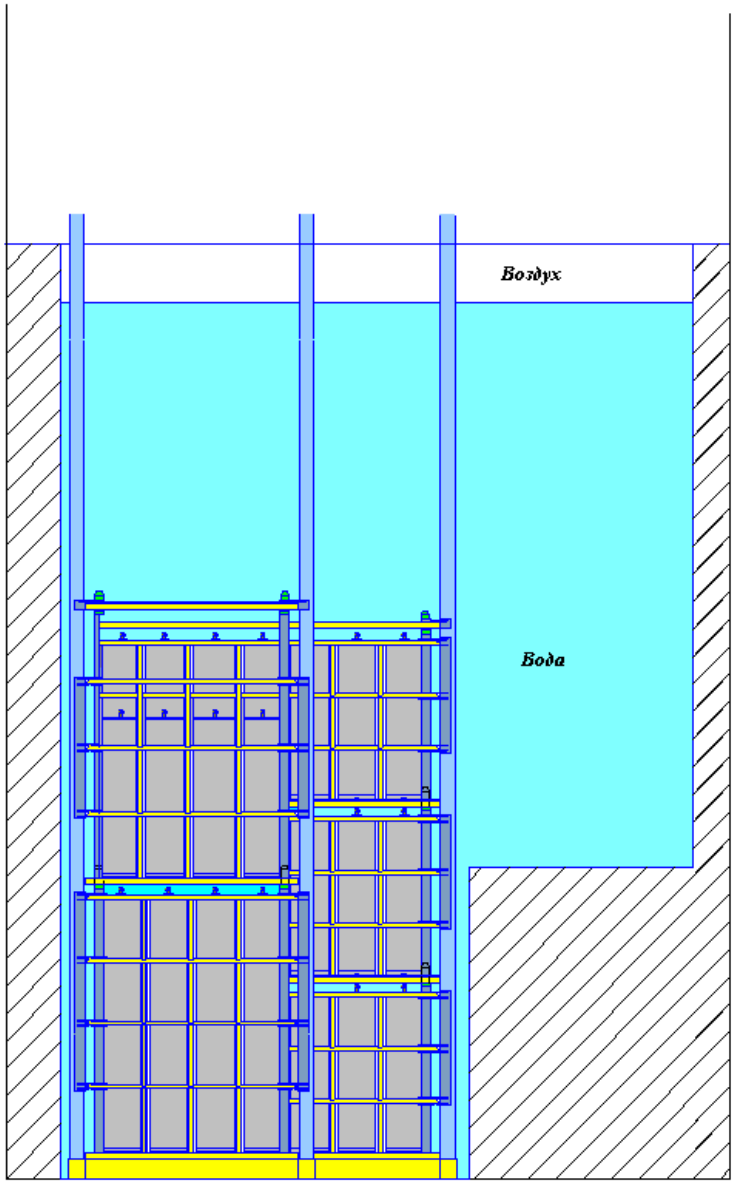

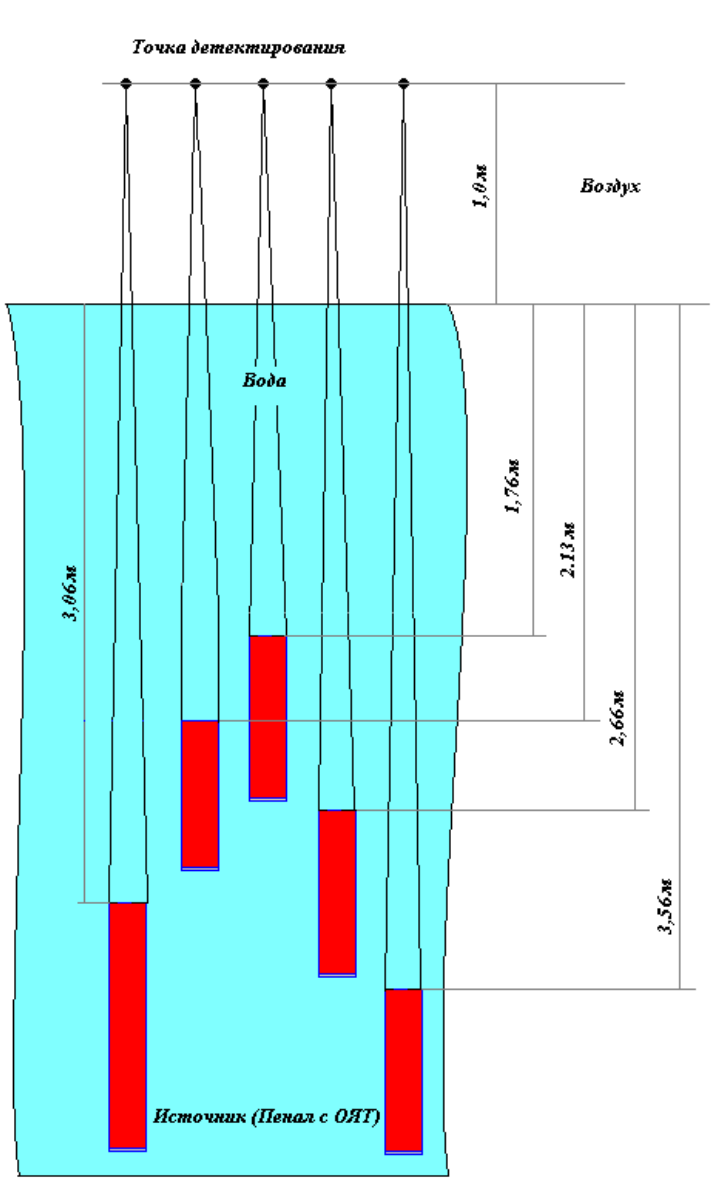

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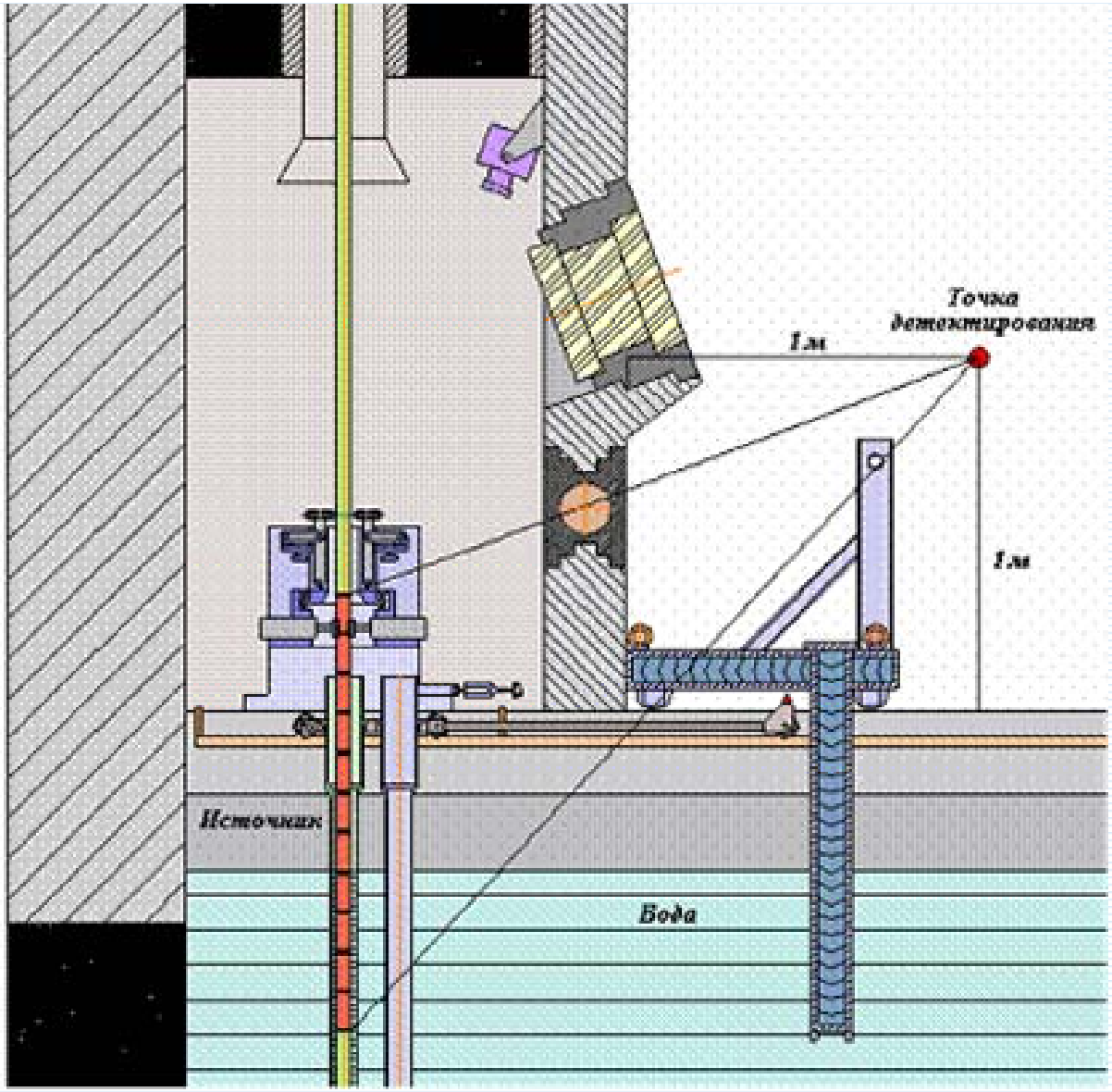

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Expected radionuclide inventory

- **Total SNF activity ~4000 TBq**, comprising FPs and actinides
  - **SNF in pools over 40 years**: poor chemical conditions of pool water and long storage time, corrosion of the fuel cladding, leakage of the FP
- **Main radiological risks after SNF removal**
  - **Reactor block**: high activation, especially near experimental channels and thermal column - expected inventory of the same order as in CP-5 reactor
  - **Primary coolant circuit**: ~20 TBq Co-60 contamination in 1963; remaining activity high even after 44 years of decay; Cs-137 and other FPs due to one fuel failure
  - **Used D_2O**: drained from the primary system, high content of Co-60
  - Activity of irradiated 5.5 m^3 D_2O in storage tank >1000 TBq
  - **Hot cells**: Co-60 contamination, numerous radioactive sources and one damaged irradiated fuel element stored
  - **Water in the ponds**: 200 m^3, 100 Bq/ml (Cs-137)
  - One third of SNF containers > 100 Bq/ml (Cs-137)
  - Other remains in SNF pools: contaminated structures, resins, sludge, some of the repackaging tools and waste –mainly Cs-137 and low activities of Co-60

Measurements

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Methods and techniques used

- **Total external surface contamination measurements**
  - dose rate, fixed/loose contamination, and spectrometry
  - geometry, surface conditions, nature and extent of radioactive contaminants
- **Clear operating procedures** - physical limitations of the equipment and techniques
- **Radiation fields' measurements**
  - gamma spectroscopy, dose rate measurements
  - MORSE (SCALE-4.4a) and MCNP-4C for dose rate – specific radiation source intensity relation
  - relation dose rate - specific activity established by KENO-V.a/ORIGEN2.1 or MCNP-4C/ORIGEN2.1
- **Loose contamination** - taking and counting smear samples
- **Laboratory gamma spectrometry** - for detailed analysis of samples
- **In situ gamma spectrometry** - for characterization of components and pipelines
- **Alpha and beta spectrometry** – for limited number of samples, scaling factors

Methods and techniques used

- Grid - RA facility divided into discrete sampling areas (survey units)
- Detailed drawing for each unit
- Sample populations compared to background population
- **Unbiased sampling** - applied to areas with none/little surface contamination, or to homogeneous areas (floors, walls, ceilings, corridors, and stairs)
- **Biased sampling** - applied wherever it was known that contamination exists or was likely to occur

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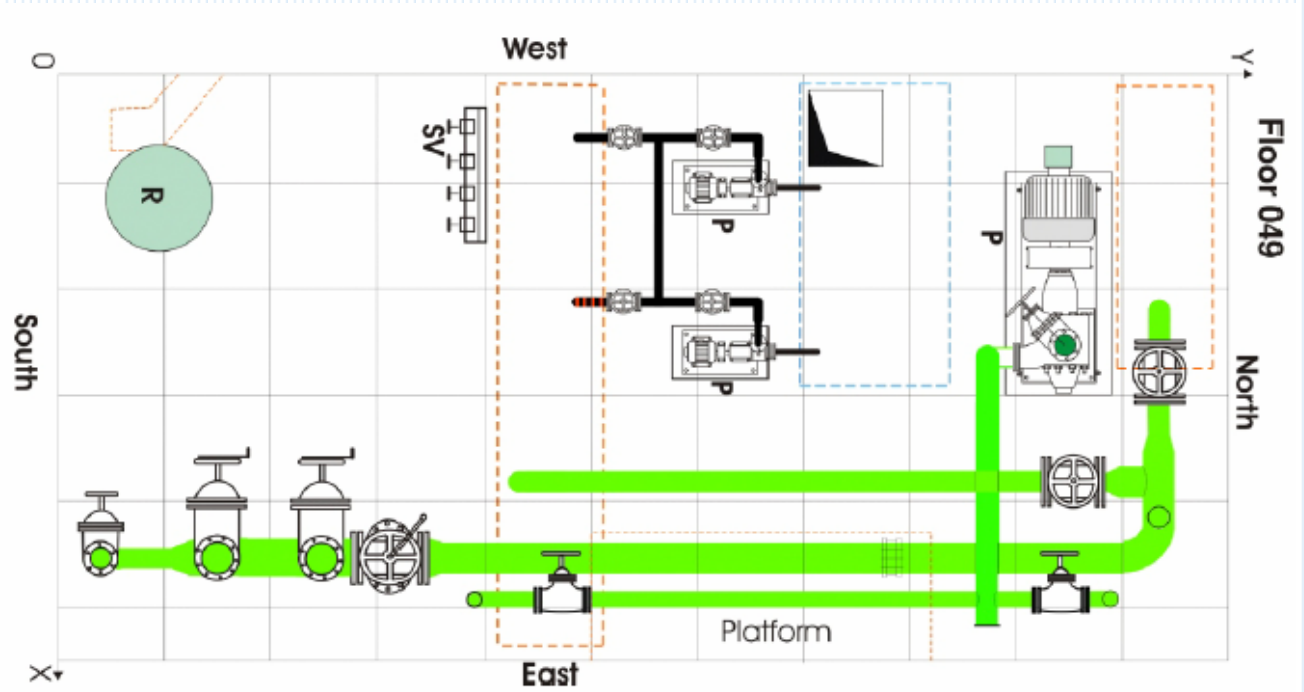
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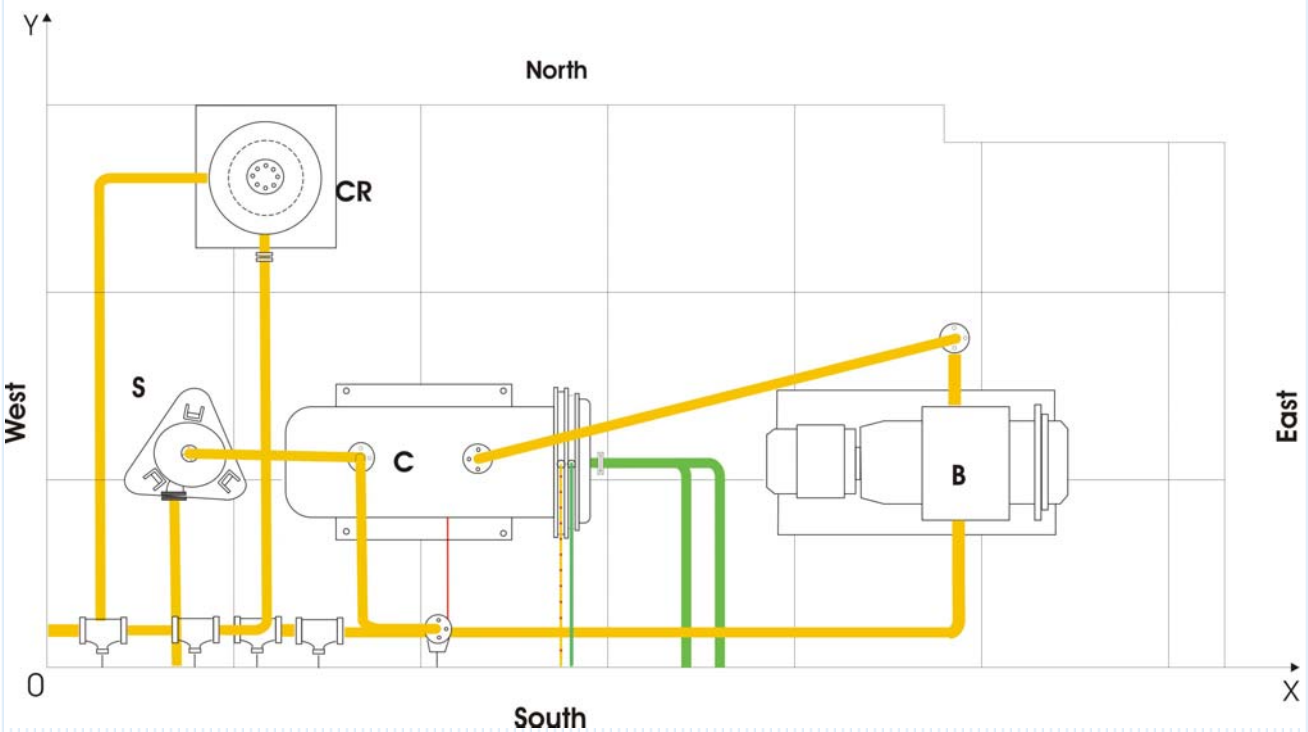
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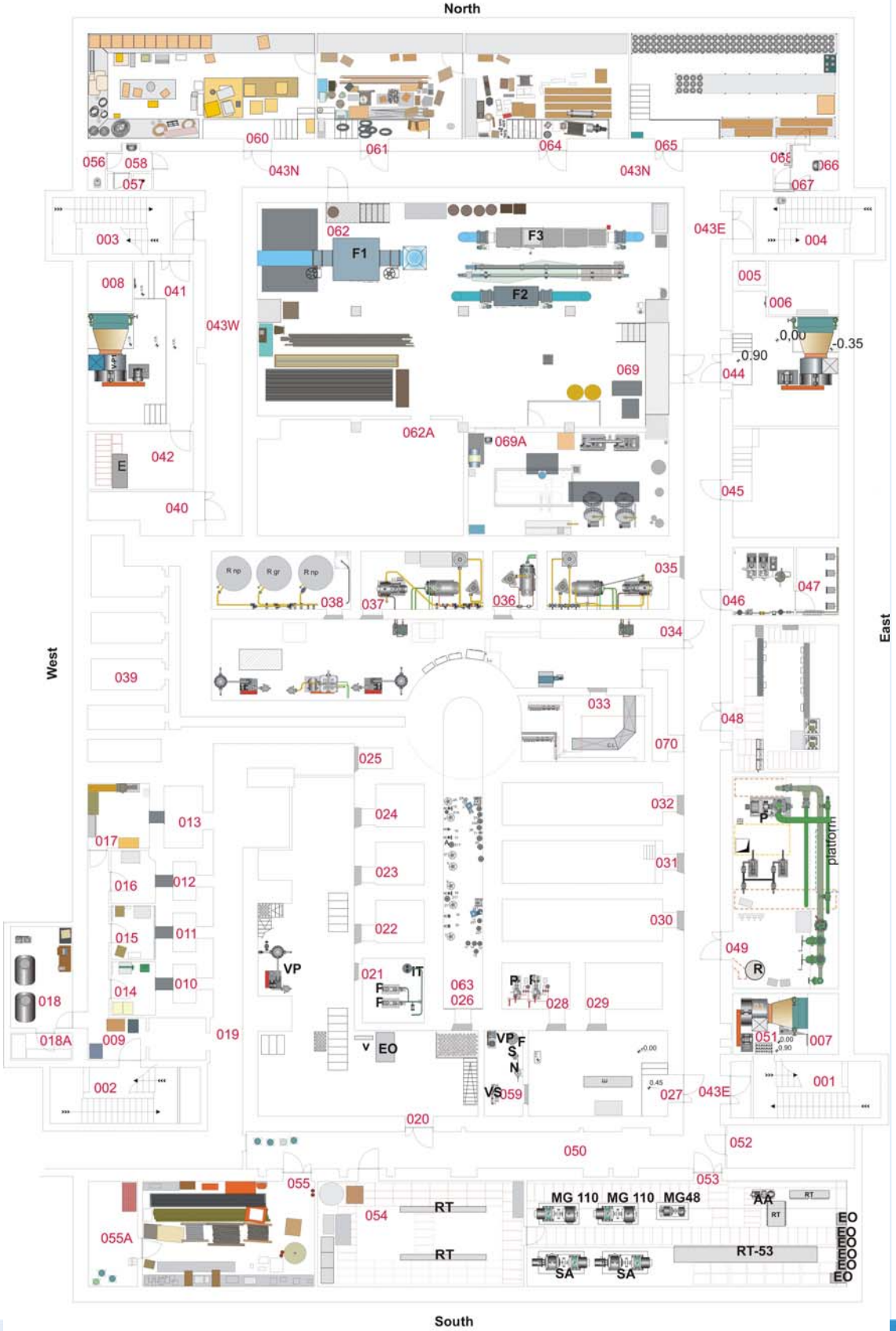

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Instrumentation

- **Instrumentation selection criteria**
  - **detectors suited for energy of the emitted radiation**
  - **resolution, efficiency and MDA sufficient to meet defined data quality**
- **Contamination measurements**
  - **digital survey meter E-600 with "smart" probes**
  - **SHP 380AB, SHP 360, HP 210T, SPA-3**
- **Gamma dose rate measured by portable survey meter FH40G**
- **Smear counting**
  - **Canberra Alpha/Beta/Gamma System 2404**
  - **gas flow proportional detector for alpha and beta**
  - **NaI(Tl) detector for gamma**
- **Instrument checks**
  - **periodical - plateau, HV, alpha/beta discrimination voltage**
  - **daily - background, efficiency check, critical level, detection limit, MDA**

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Instrumentation

- **Gamma spectrometry analyses of the smears with increased beta, gamma or both beta and gamma readings**
  - **Canberra Gamma Spectroscopy System with extended range high efficiency high resolution stationary Ge detector GX5020**
- **Airborne contamination**
  - **iCAM air monitor - two Si detectors**
  - **AMS-4 air monitor - two closed gas-filled proportional counters**
    - **On-line measurements, alarms for activity and rate of activity changes**
    - **Gamma spectrometry of used paper filters**
- **Portable gamma spectroscopy equipment**
  - **Semiconductor Ge detector with 5 cm thick lead collimator on mobile cart**
  - **Semiconductor CdZnTe detector (5 mm^3) with tungsten collimator**
  - **Scintillation NaI detector, 1.5" x 1.5" with lead collimator**
  - **Scintillation NaI detector, 3" x 3", not collimated**
  - **Scintillation NaI detector, diam. 1", thick. 1 mm, with stainless steel collimator, for X-ray energy spectra of hard-to-detect nuclides**

E-600 Survey Meter

- E-600 - An advanced survey meter designed to work with a variety of external radiation detector probes.

- Features include data logging, background subtraction, scaler counting, peak trap counts, smart probes, three detector channels, pulse height analysis and more.

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E-600: Features

- Accepts "Smart" and conventional GM, scintillator and proportional detectors
- Custom backlit LCD display with analog and digital presentation
- Multiple operating modes
- Background subtraction capability
- Data Logging (500 points)
- Bult-in pulse height analysis - 3 channels
- Built-in Speaker
- Audio and Visual Alarms
- Real time clock
- Time saver PC assisted calibrations
- Rugged construction

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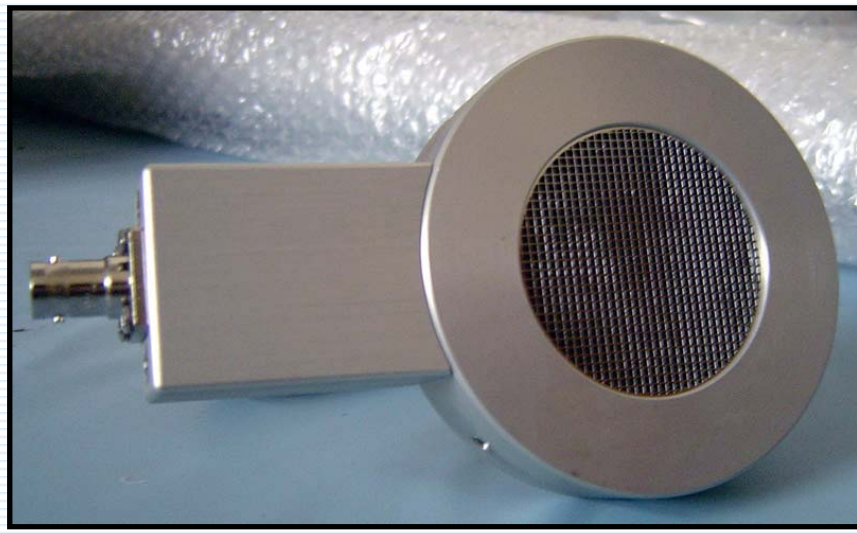
HP-210T: Pancake GM Detector

HP-210 Series Pancake GM Detectors:

- The Model HP-210 series hand probes provide a sensitive beta detector featuring a "Pancake" GM tube with a thin mica window.
- This series is designed for contamination surveys on personnel, table tops, floors, equipment, etc.



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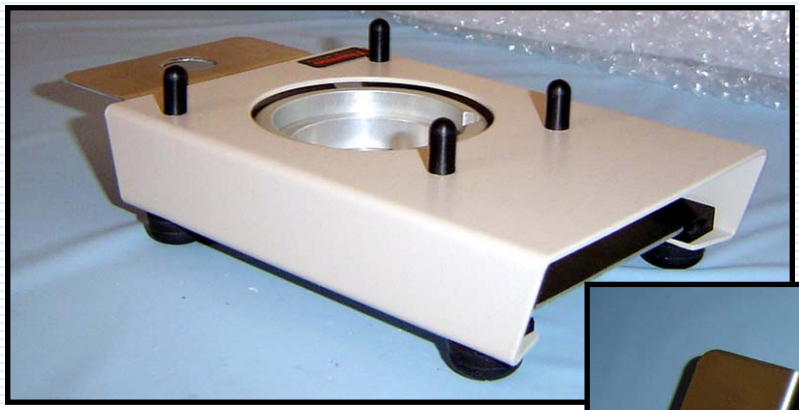
Model HP-210T

- Tungsten shield with 4:1 window to background ratio
- weight: 1.9 kg



Optional Sample Holder:

- **SH-4A Sample Holder** for the HP-210 series probes

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- Application: Beta/Gamma surveys
- Detector Type: GM, non energy compensated
- Operating Voltage: 900 V +/- 50V
- Dead Time: 50 uSec nominal
- Mica Window Size: 4.4 cm diameter
- Mica Window Thickness: 1.4 to 2.0 mg/cm^2
- Background Sensitivity: ~3,600 cpm/mR/h (Cs137)
- Beta/Gamma Efficiency: ~22% Cs137, ~16% Co60
- Beta Efficiency (4 Pi): ~ 32% Sr90/Y90, ~ 15% Tc99, ~ 6% C14
- Alpha Efficiency (4 Pi): ~ 25% Am241
- Operating Temp: -30° to +60° C
- Housing: Aluminum
- Connector: BNC
- Size: 16.5cm long, 8.9cm wide, 9.7cm high

HP-210T

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HP-360: Sensitive Beta Detector

- The HP-360 hand probe provides a sensitive beta detector, featuring a "Pancake"
- GM tube with a thin mica window. It is designed for contamination surveys on personnel, table tops, floors, equipment, etc.

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HP-360

- Application: Alpha/Beta/Gamma surveys; frisking
- Detector Type: GM, non compensated
- Operating Voltage: 900V +/- 50V
- Dead Time: 50 µs nominal
- Mica Window Size: 4.4cm diameter
- Mica Window Thickness: 1.4 to 2.0mg/cm^2
- Background Sensitivity: ~ 3,600cpm /mR/h (Cs137)
- Beta/Gamma Efficiency: ~ 22% Cs137; ~ 16%Co60
- Beta Efficiency (4Pi): ~32% Sr90/Y90; ~15% Tc99; ~6% C14
- Alpha Efficiency (4Pi): ~25% Am241
- Operating Temp: -30° to +60° C
- Housing: ABS Plastic
- Connector: BNC
- Size: 24.8cm long, 6.8cm wide, 7.0cm high
- Weight: 0.2 kg

SPA-3 Gamma Scintillator

- Application: High sensitivity gamma measurements
- Detector Type: 5.1cm diameter by 5.1 cm thick NaI(TI)
- Operating Voltage: 1,000 V nominal
- Dead Time: 14 us nominal
- Background Sensitivity: ~ 1.2 Mcpm/mR/h (137Cs)
- Energy Range: ~60 keV to 2 MeV
- Operating Temp: -30° to +60° C
- Housing: Aluminum body
- Connector: CJ-1
- Size: 6.7cm diameter x 28.3 cm long
- Weight: 1.5 kg

HP-380AB Probes

- The HP-380AB Hand Probes are general purpose survey and frisking probes with excellent sensitivity to alpha and beta with minimum interference from gamma backgrounds
- The probe design is constructed from lightweight aluminium which promotes ruggedness and ergonomic handling

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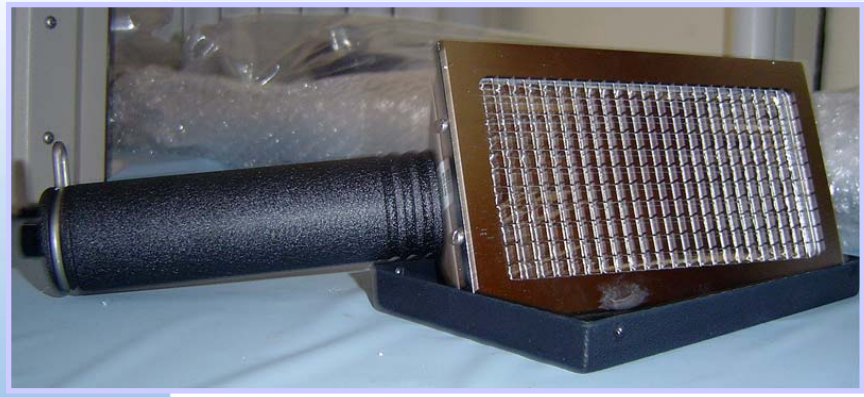

HP-380AB

- Application: Alpha/beta surveys; frisking
- Detector Type: Dual phosphor scintillator
- Operating Voltage: 600V nominal
- Window Area: 100cm^2
- Window Thickness: 0.87 mg/cm^2 aluminized mylar
- Background Sensitivity: ~12,000 cpm/mR/h (Cs137)
- Beta Efficiency (4Pi): ~22% Sr90/Y90, ~ 9% Tc99
- Alpha Efficiency (4Pi): ~18% Pu239
- Operating Temperature: -40° to +60°C
- Housing: Cast aluminum body
- Connector: MHV (Smart detector version uses Smart connector)
- Size: 29.2cm long, 7.0cm wide, 8.3 cm high
- Weight: 0.59 kg

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AMS-4 Air Monitor

- The AMS-4 is a radiation-in-air detection system, designed to provide early warning to workers exposed to potential airborne releases of beta emitting particulates, iodine or noble gases
- Its lightweight and robust design accommodates both fixed and portable use applications

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AMS-4 Air Monitor: Specifications and options

- Detectors: 2" Diameter sealed proportional
- Window: 2 to 3 mg/cm^2 mica
- 4 Pi Efficiency: 90Sr/90Y: 17% 99Tc: 8.5%
- Sensitivity: 90Sr90Y: 4.0 x 10-11 µCi/cc
  99Tc: 8.0x10-10 µCi/cc
- Size: 32.5cm high, 27.9cm wide, 22.2cm deep
- Weight: 3.4 kg
- Power: 100-265 V AC, 50/60 Hz
  - RF Modems
  - Portable Printer
  - RS-485 Interface

- Pump
- In-line Detector Head
- Noble Gas Detector
- Calibration Sources
- Networking Software
- Iodine Detector

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Smear counting on Canberra 2404 alpha/beta/gamma counting system

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Home made ISOCS system

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Clearance measurements

- Characterization of operational and transition waste to be removed
  - Clean – recycling, reuse, conventional waste
  - Contaminated – decontamination or radioactive waste
  - Activated – cutting, dismantling, RAW
- Low background area
- Local temporary storage places, collecting areas
- Special attention to the radioactive materials, chemical hazards, flammable materials, liquids

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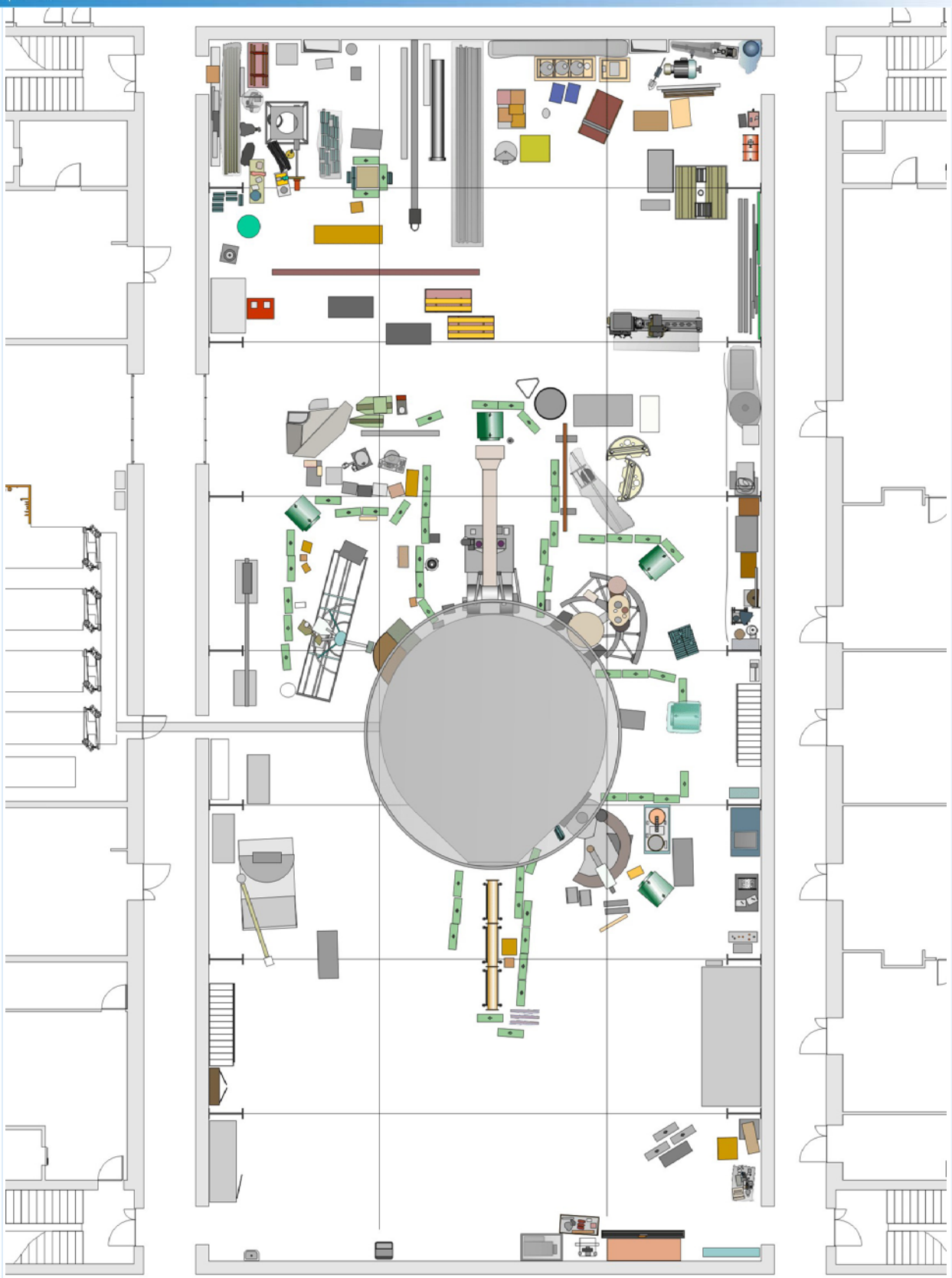

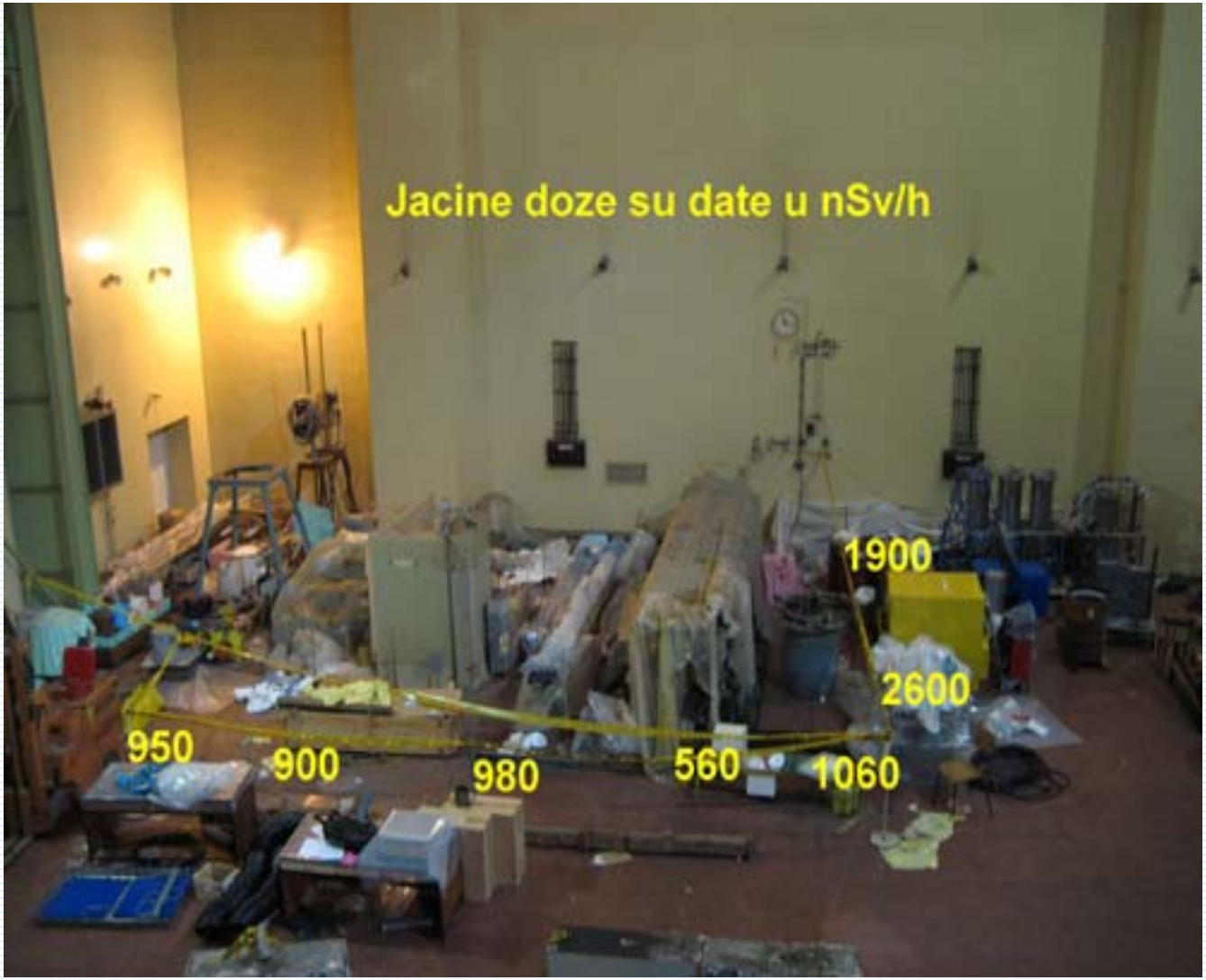

Operational waste to be removed

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Removal of waste from the reactor room

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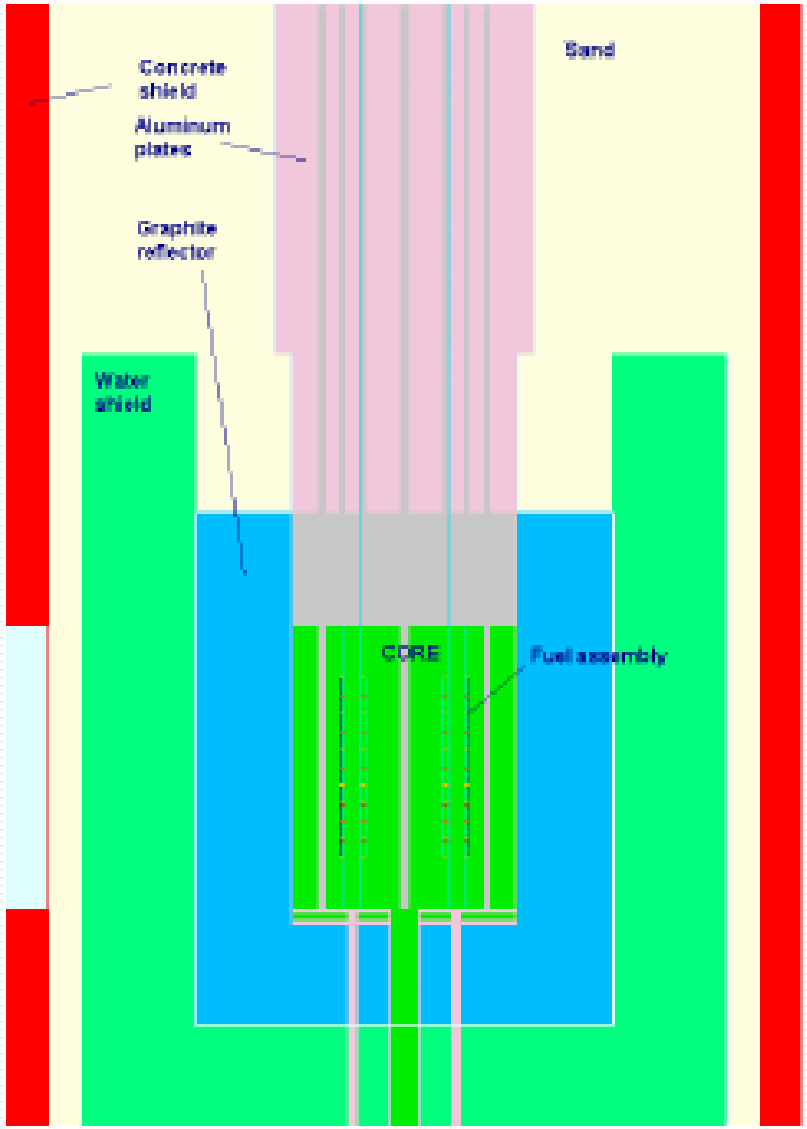
Calculation tools

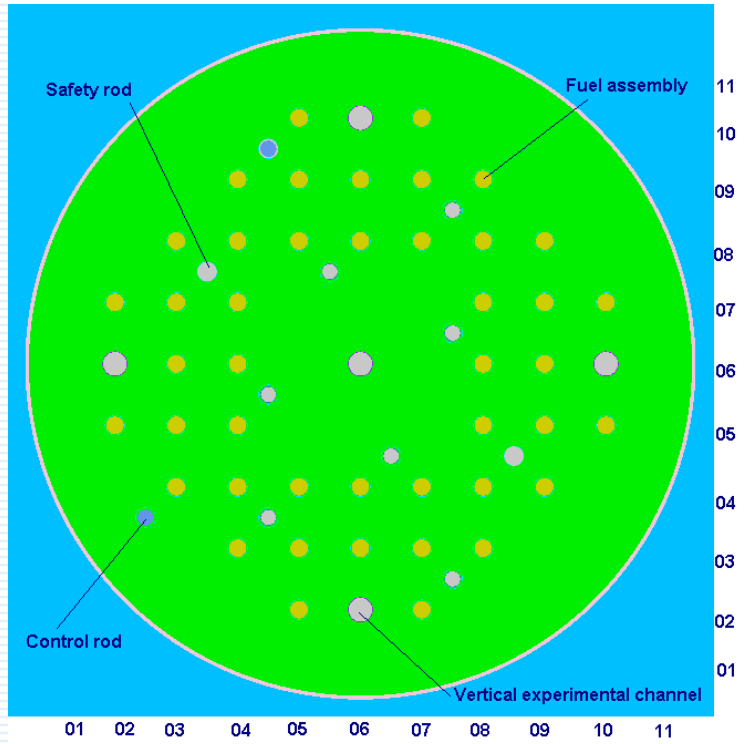
- SNF characteristics (radiation sources, decay heat, radionuclide inventory) determined using three calculation procedures
  - SAS2H control module from SCALE-4.4a, approximate geometrical model
  - MCNP-4C and ORIGEN2.1 codes, coupled by MOCUP driver
  - KENO-V.a and ORIGEN2.1 codes
- Determination of trace elements in the reactor internals, reactor vessel, graphite reflector and bio-shield: radiochemical analysis of inactive or low activated samples of aluminum, stainless steel, graphite, and heavy concrete
- Phases of calculation characterization approach:
  1. Development of 3D models for detailed Monte Carlo calculations
     - ◇ determination of an equivalent fuel composition for each representative core configurations - based on the neutron fluence conservation criterion
     - ◇ such models then used for determining the neutron flux and one-group cross-section data in all zones of the irradiated structures
  2. Development of 1D radial and axial models for 1D transport calculation
     - ◇ used as an extension of 3D calculations for obtaining more detailed flux distributions inside the zones used in 3D calculations, and for uncertainty analyses (variations of the concentrations of trace elements of interest)

Calculation tools

3. Development of the calculation procedures
   - ◇ analysis of the activation in each zone by considering material composition (with trace nuclides) and neutron flux in the zone during the reactor operational lifetime based on the application of four procedures
     - ✓ MCNP (with VMCCS library) and ORIGEN2.1 codes coupled by MOCUP driver
     - ✓ KENO-V.a (with ENDF/B-V 238-group library) and ORIGEN2.1 codes
       - ➢ (for 3D calculations)
     - ✓ XSDRNPM, COUPLE and ORIGEN-S codes
     - ✓ XSDRNPM and ORIGEN2.1 code
       - ➢ (for 1D calculations - design-oriented procedures)

- **Main sources of uncertainties in calculation results**
  - ❑ Uncertainties of the nuclide cross-section data
  - ❑ Approximations used in the material and geometry models (content of trace elements, positions of control rods)
- **Verification of calculation results**
  - ❑ laboratory measurements of the samples taken from accessible parts of the reactor internals and structures





Neutron activation:

3D calculation models

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Current status and preliminary results

- SNF in storage pools - completed
  - burnup calculations, source term determination, dose rate calculations for different conditions – 3D models, reflection
  - fuel burnup measurements and contact dose rate measurements in water and in air
  - excellent agreement between calculated and measured results
- Fuel burnup measurement will be performed in the next several months to verify the calculation results for the last charge placed in the reactor core
- Measurements of water activity in the pools and inside the storage containers - done regularly to estimate leakage rate needed for planning of SNF repackaging and shipment
- 3D models of representative core configurations prepared for Monte Carlo calculations of neutron induced activity
- Operational history data important for these calculations verified during the fuel burnup measurements

Current status and preliminary results

- Survey progress – completed areas:
  - main RA reactor building
  - ventilation building
  - ventilation ducting
- 26000 direct measurements , >9600 smear samples processed
- Clearance of the old experimental equipment located around the reactor block, waste materials and shielding blocks in progress
- Methodology for determining internal contamination in the primary system prepared
- "Hard to detect" nuclides - scaling factors
  - Cs-137 for fission products
  - Co-60 for activation products
  - Am-241 for actinides
  - Experimentally determined for specific materials, locations and systems, time dependent

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Record Management

- Tracking system – unique label for each measurement point, sample and result
- Different formats
  - Computing results already in file
  - Measurement results
    - ◇ paper forms (drawing, survey sheet), listings
    - ◇ files (numbers, arrays of counts, spectra)
- How to store, keep, search and analyze data ?
- MS Excel sheets
- Data Bases
  - linking drawings, spectra, numbers, calibration data
  - calculating efficiency, MDA, activity
- ASAP (S - simple !)

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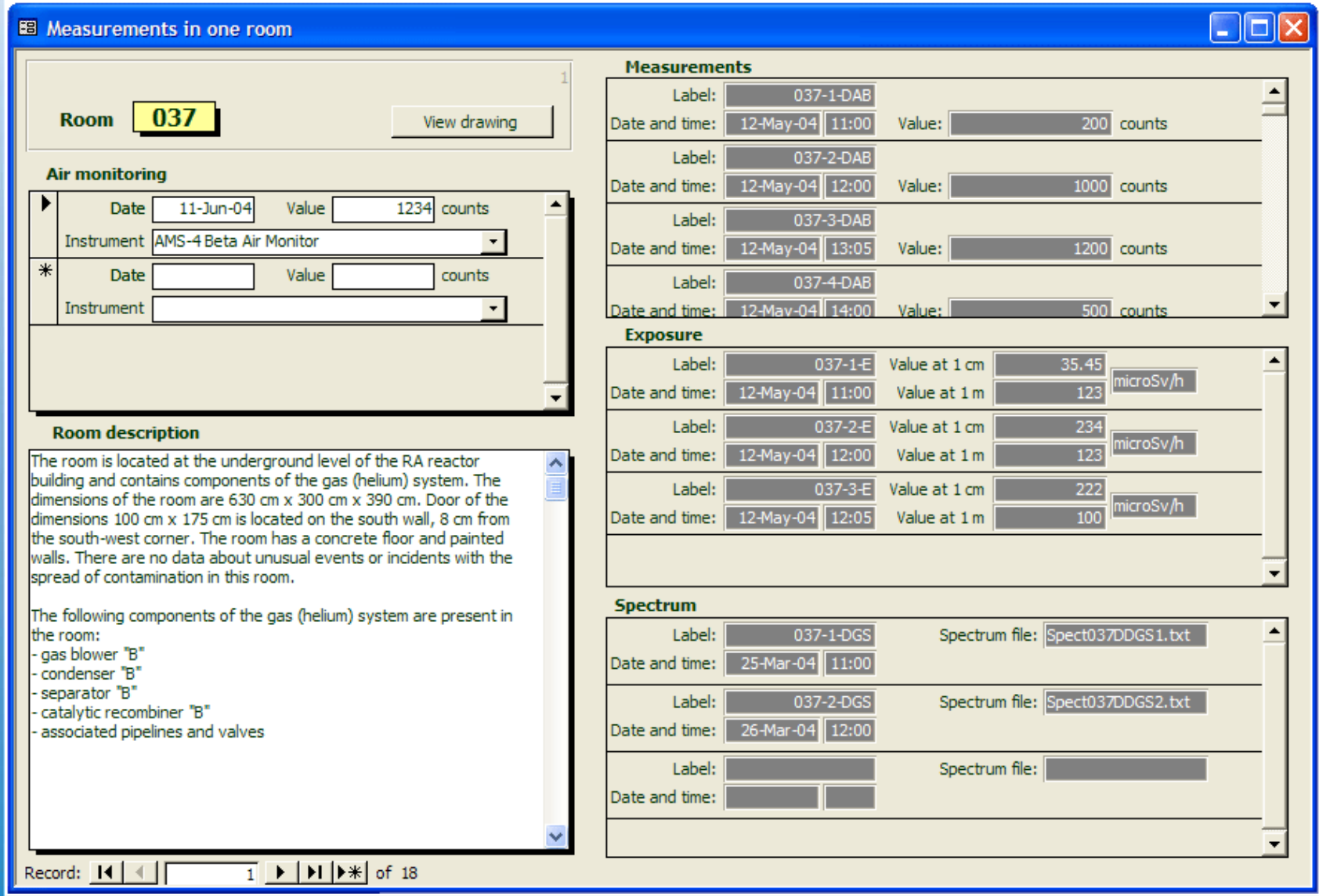
Characterization database



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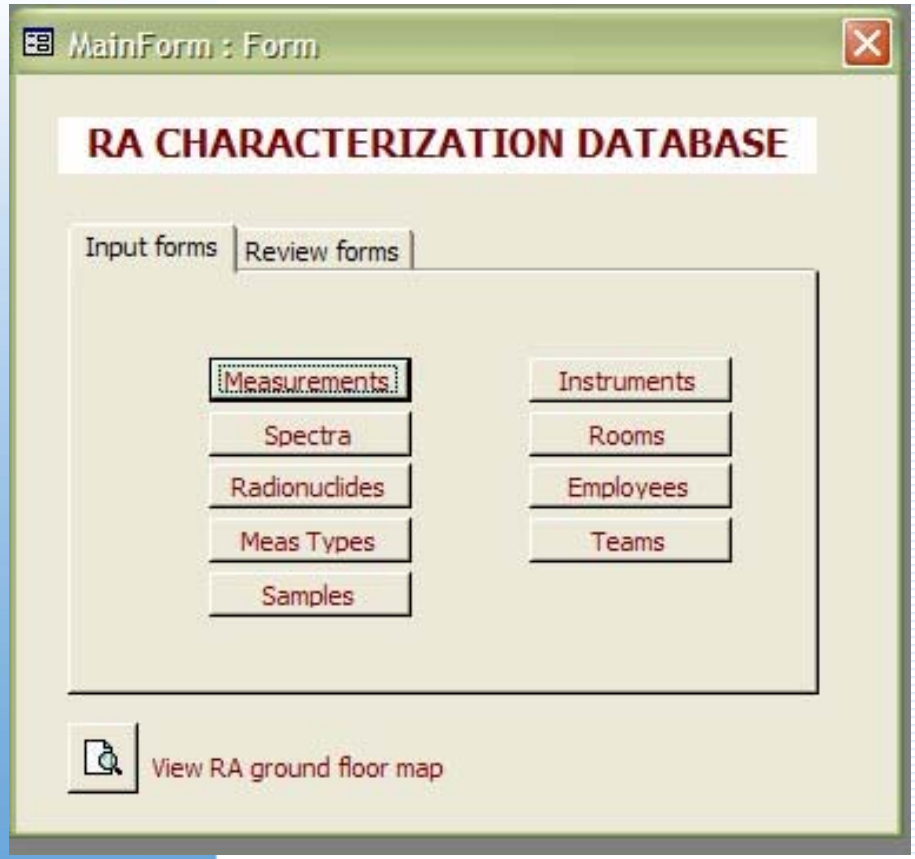
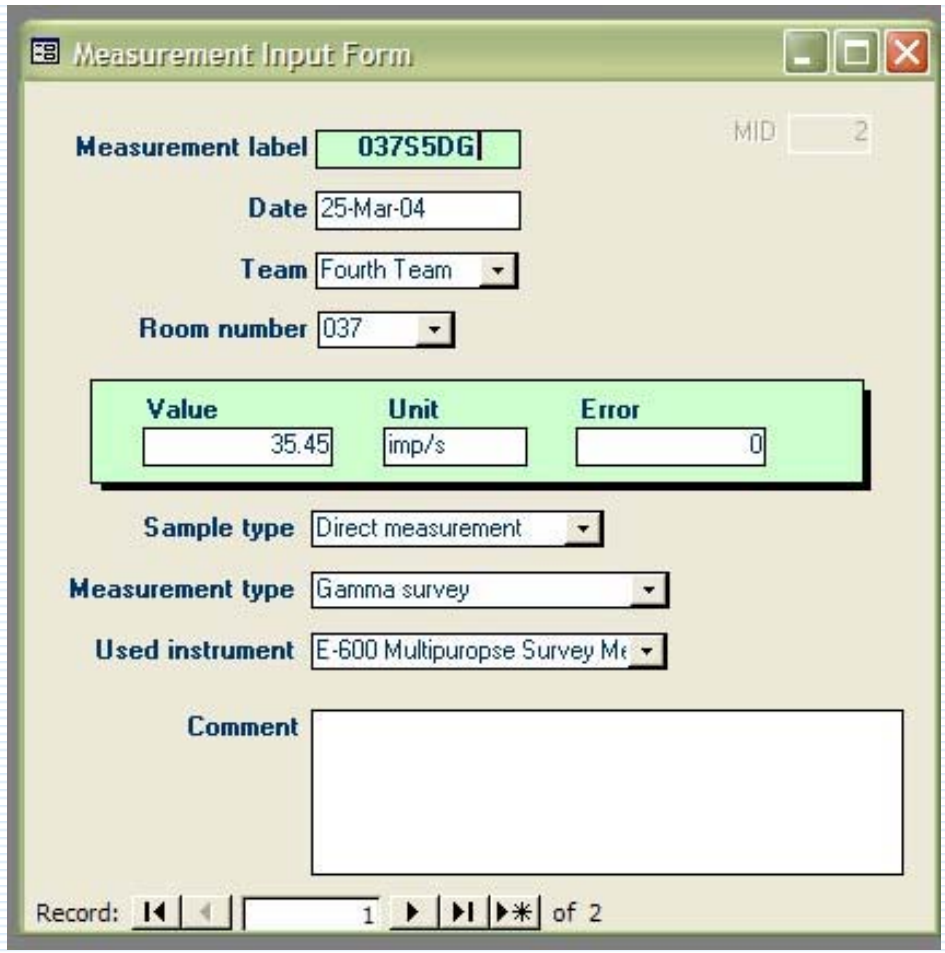
Characterization database





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Summary and lessons learned

- Objectives and criteria
- Background, clearance levels
- Selection of the equipment
- Organization of the teams
- Records, interviews
- Graded approach, grid, statistical analysis
- Scaling factors
- Calculation models, trace elements
- Results in different formats, data bases
- Heavy water reactor – activation, D_2O
- Well documented projects – CP-5, GTRR, DIORIT

- Safety aspects of characterization !
- Characterization waste !

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Thank you for your attention

- **Nuclear Technology & Radiation Protection**
  - **International journal, open access**
  - **http://ntrp.vin.bg.ac.yu**

- **CONUSS 2008**
  - **Sixth International Conference of the Nuclear Society of Serbia, Sep 29 - Oct 2, 2008**
  - **http://nss.vin.bg.ac.yu/CoNuSS2008.htm**

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