Techniques of Post-Irradiation Examination (PIE) for Water Reactor Fuel and IAEA PIE Facilities/Techniques Database

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for Advanced and Innovative Fuel Technologies“
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IAEA
International Atomic Energy Agency

Post-Irradiation Examination of Water Reactor Fuel (PIE) and IAEA PIE Facilities/Techniques Database

Classification of PIE Techniques (1)

- Destructive Methods in Hot Cells:

  Microstructural, elemental and isotopic analyses, measurement of physical and mechanical properties

- Non-Destructive Methods in Hot Cells:

  Visual inspection, detection of failed fuel rods and defect location

  Dimensional measurements of fuel rods and assemblies

  Gamma scanning, including tomography
  Fission gas release determination
  Neutron and X-ray radiography

Classification of PIE Techniques (2)

- Pool-side Inspection:
  - FA tightness monitoring (sipping test)
  - Visual inspection
  - Dimensional measurements
  - Gamma-scanning
  - Detection of leaky fuel rods in fuel assemblies
  - Removal and analysis of deposit probes from the cladding surface of the periphery fuel rods
  - Measurement of oxide film thickness from the cladding surface of the periphery fuel rods
  - Measurement of elastic parameters of FA spring units

Classification of PIE Techniques (3)

- The following is applied to inspect a fuel rod removed from FA:

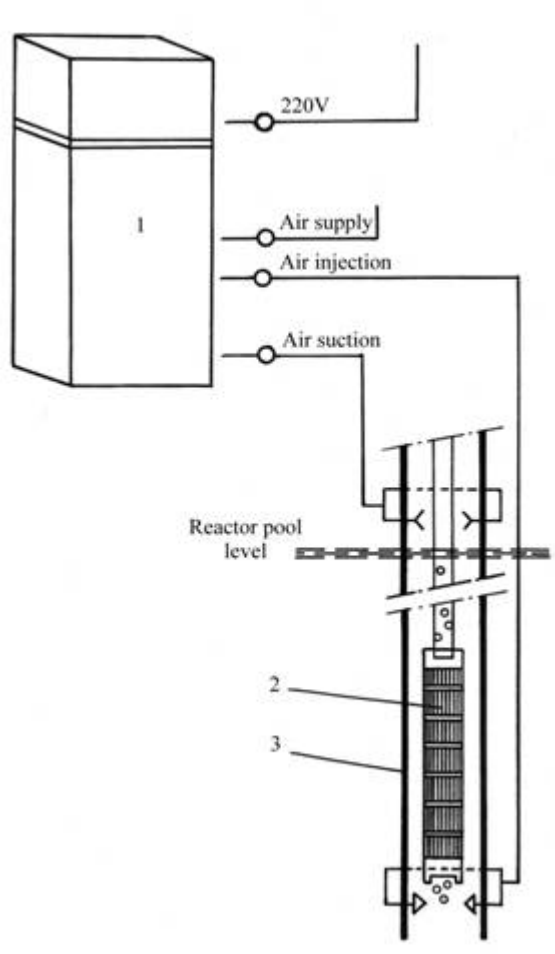
Visual inspection
Dimensional measurement
Gamma-scanning
Eddy-current testing
Removal and analysis of deposit probes from the cladding surface
measurement of oxide film thickness on the cladding surface
Measurement of the cold gap between fuel and cladding

FA Sipping Test (1)

Principle - to identify FA with leaky rod/rods by isolation of FA in a restricted volume, pushing fission gases to be released and radiation-spectrometric analysis of released gases. Sipping test might be done on-line in the fuel discharge machine mast (Qualitative) or in the cask in a spent fuel pool (Qualitative or Quantitative).

System – "Wet" (typical for Nuclear Power Plants-NPPs) or "Dry" (not widely used at NPPs)

FA Sipping test (2) – In-mast On-line



1-Control cabinet
2-FA
3-Manipulator crane mast

FA is lifted into the mast. Due to hydrostatic pressure change, fission products are released from leaky rod into water. FPs soluble in water are captured by injected air and transferred for Xe-133 gamma analyzer and compared with value averaged for 10 FAs.

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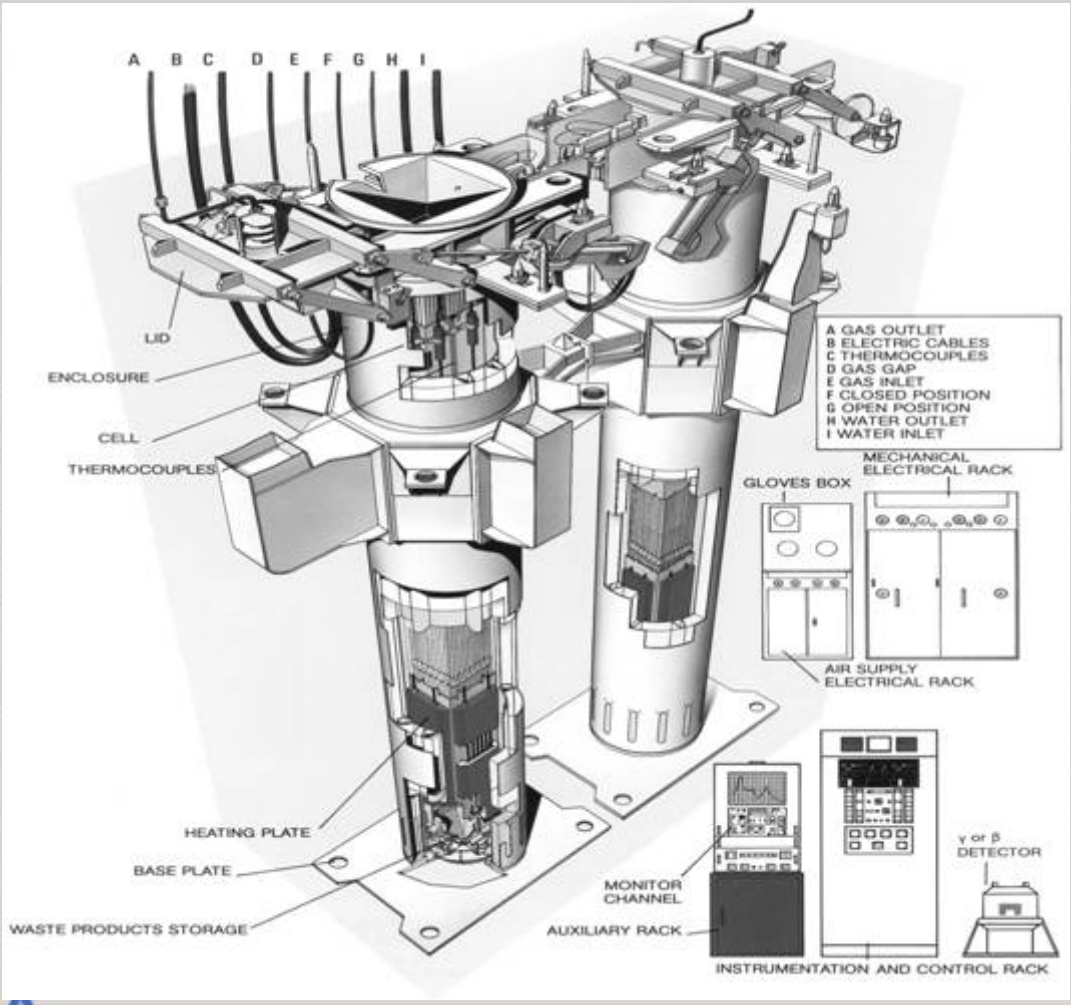
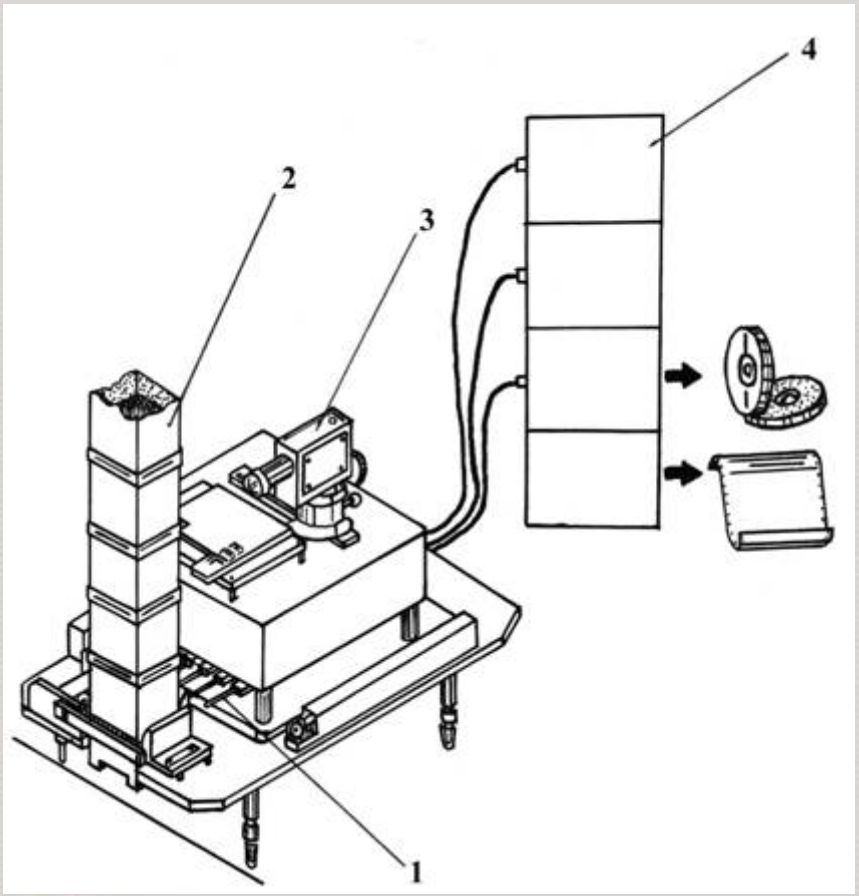
FA Sipping Test (3) – In-pool Canister

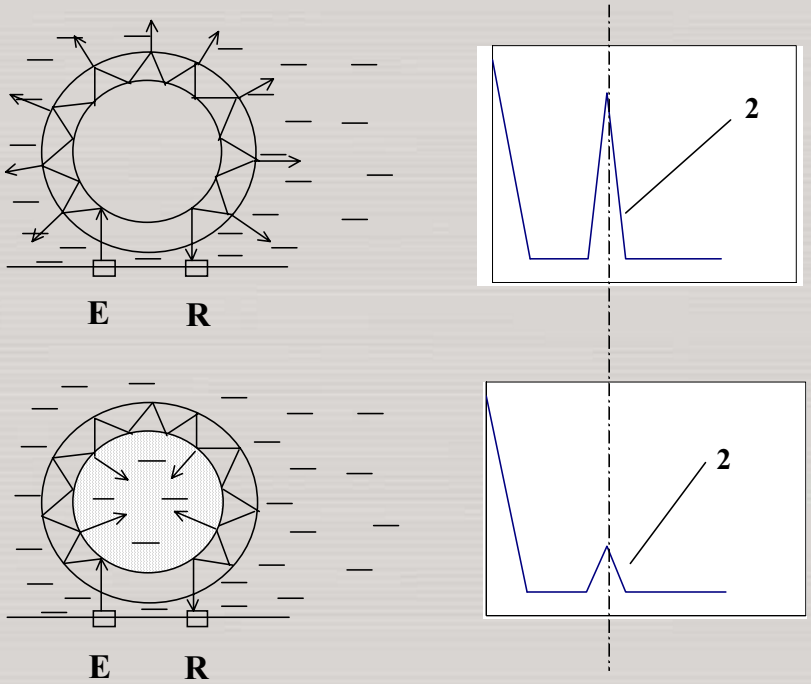


Single FR Leak Detection in a FA (1)

UT, circular wave propagation (BBR-B & W)

1-set of ultrasonic probes; 2-FA; 3-video camera; 4-cabinet





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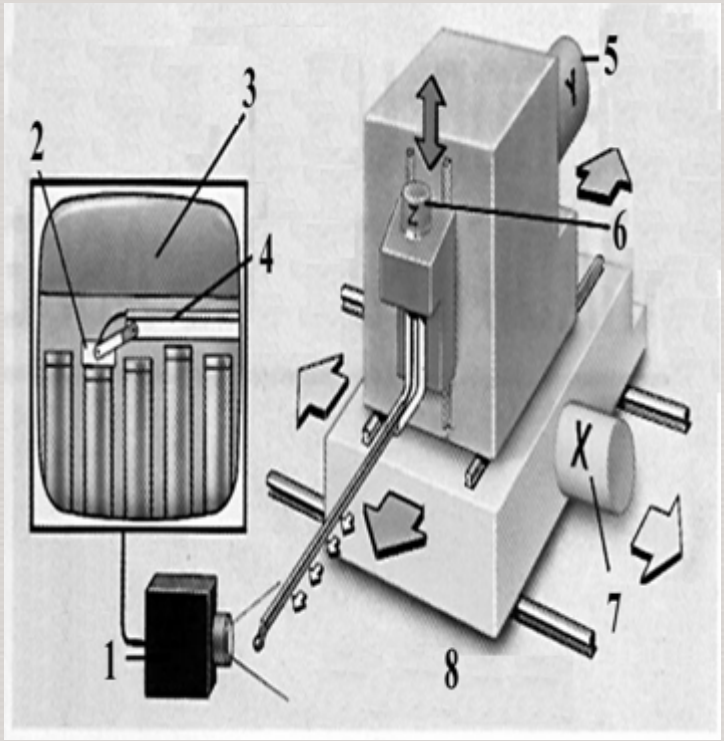
Single FR Leak Detection in a FA (2)

UT, vertical wave propagation (FRAGEMA)
1-video camera; 2-UT probe; 3- top nozzle; 4-manipulator; 5-7-motors; 8 X &Y-motion table



Fuel Assembly Dimensional Measurements (1)

1) Visual comparison of the geometry of the object video image with the gauge or coordinate scale – simple, non-contact, all inspection stands are equipped with TV-systems with image analyzing possibilities. Good for measurements of length, cross-section size, gaps and diameters for peripheral row, bow amplitude in case of banana-shape, etc.
2) Devices with Linear Variable Differential Transformers (LVDTs) or of another type (e.g. non-contact UT-example is on the next slide) are used for more precise (usually error is in the limit of ±0.1 mm) or complicated (when TV systems are no good) dimensional measurements.

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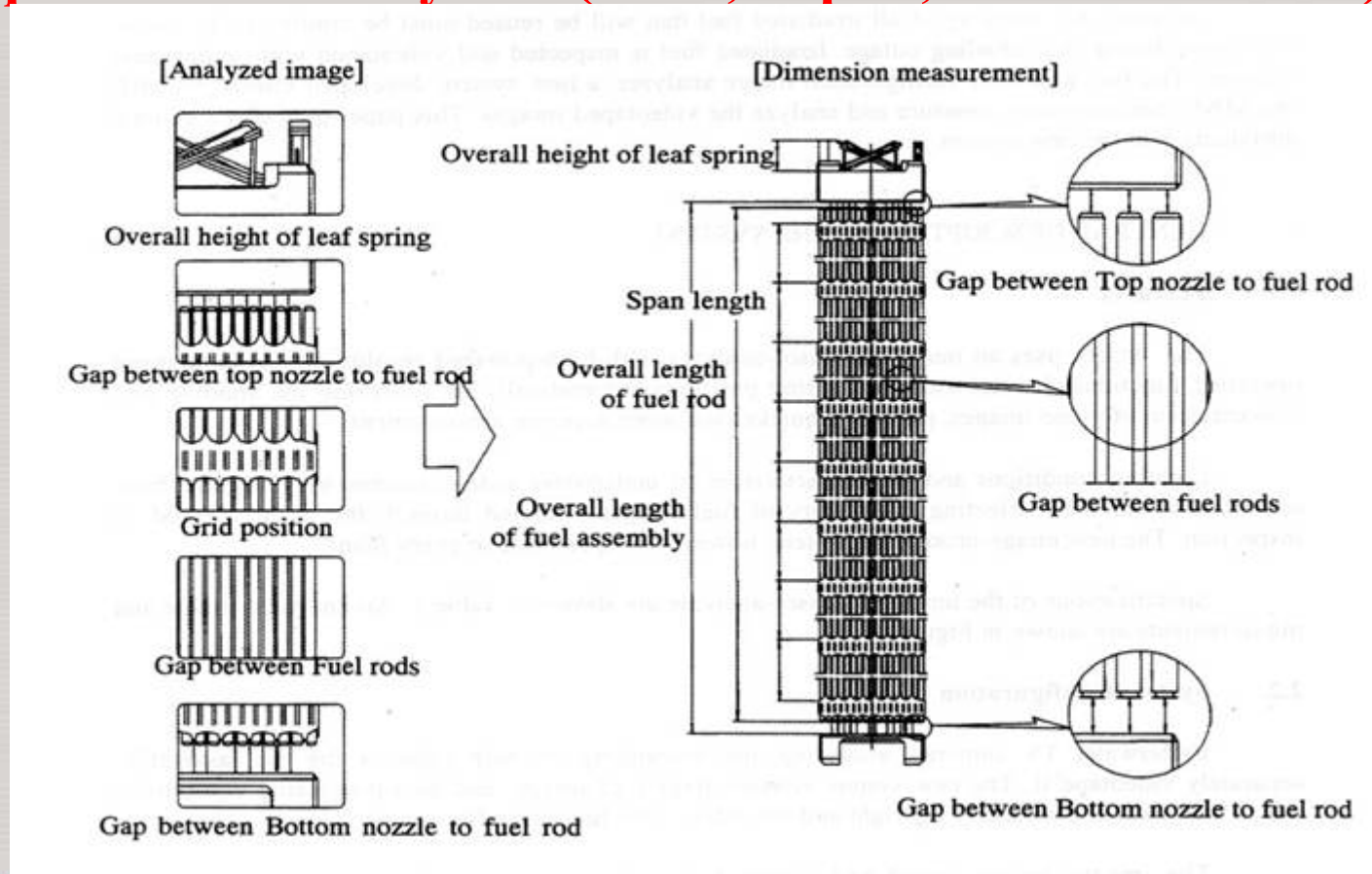
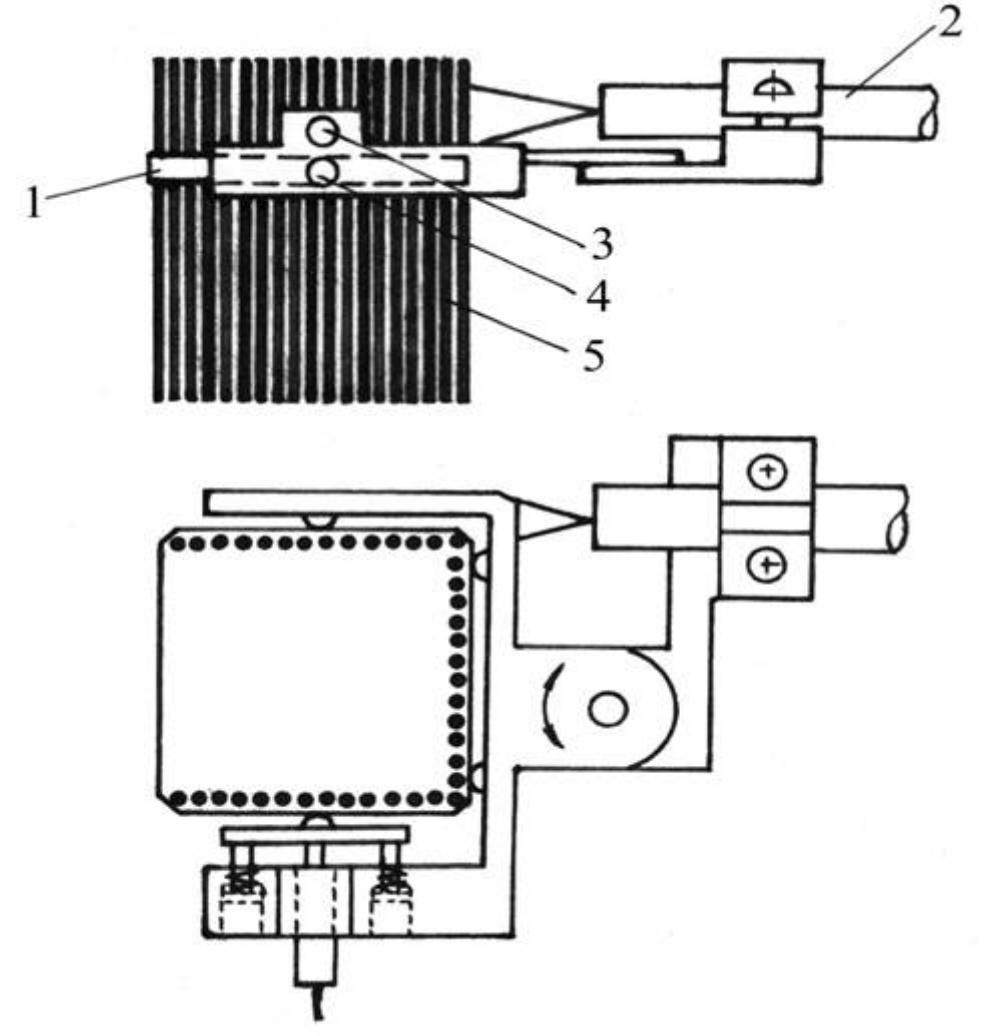
Fuel Assembly Dimensional Measurements (2) – What might be measured using TV cameras and image processors-analyzers (MHI, Japan, TECDOC-1050)



Post-Irradiation Examination of Water Reactor Fuel (PIE) and IAEA PIE Facilities/Techniques Database



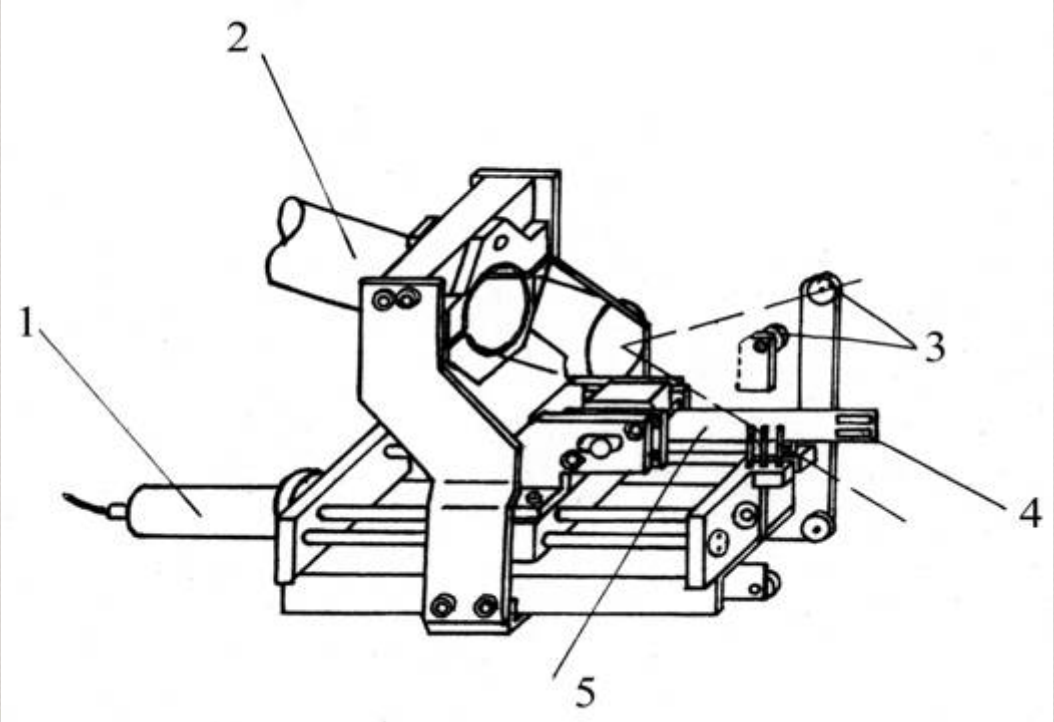
FA Dimensional Measurements (3) – Distance between Spacer Grids (SG) – Siemens-KWU

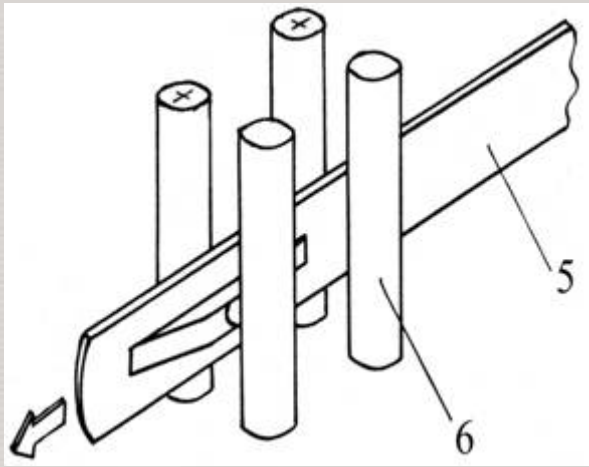
1-SG; 2-TV camera; 3-LVDT; 4-pneumocylinder; 5-FA

U-form jointer with one detector comes up to the SG and it is pressed to it by pneumocylinder. Device allows to measure distance between SGs with error within ±0.01 mm.

Fuel Assembly Dimensional Measurements (4) – FR's Gap

1-motor; 2-TV camera; 3-guide rollers; plate springs; 5-probe; 6-FR





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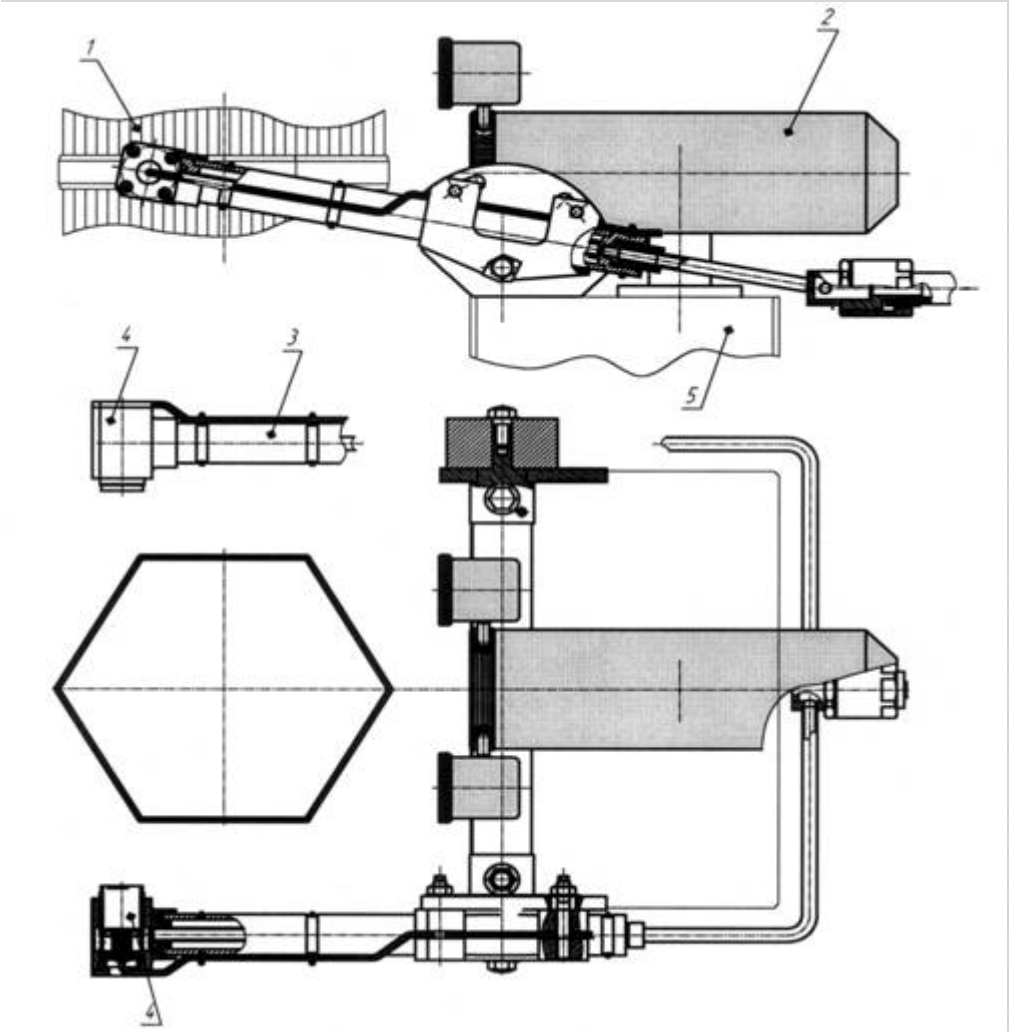
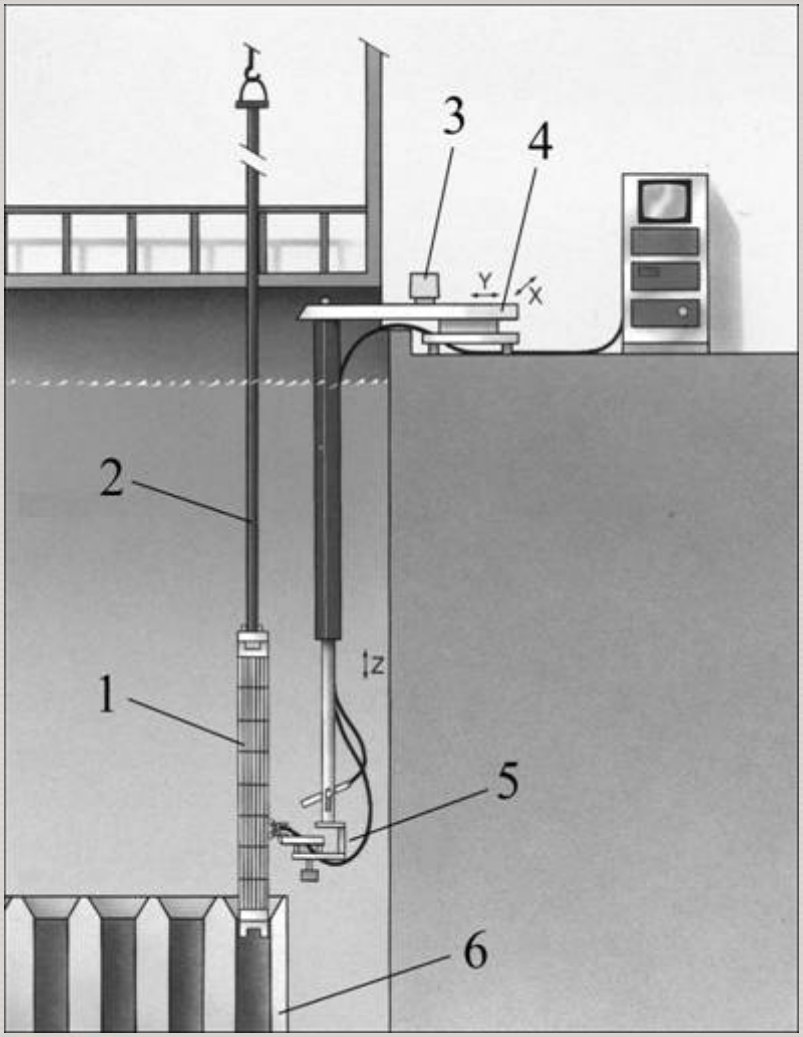


FA Dimensional Measurements (4) – RIAR, Russia

1-FA; 2-TV camera; 3-cramp; 4-ultrasonic detectors; 5-motion table

Device allows to measure FA bowing and twisting, what is necessary in case of $-shape FA bow. Error of the determination of the distance between the detectors and FA surface does not exceed 8 μm, and twisting angle-0.03 degrees.

Post-Irradiation Examination of Water Reactor Fuel (PIE) and IAEA PIE Facilities/Techniques Database



Measurement of Oxide Layer Thickness on FA

1-FA; 2-handling tool; 3-Z-motor; 4-X-Y-table; 5-EC probe
High-frequency electromagnetic field generated by a probe induces EC in the FR sub-surface layer. Amplitude of these ECs is a function of oxide thickness and causes variation in probe impedance. Measurement channel evaluates this variation and supplies signal proportional to the thickness. Usually EC probe is included brush device.

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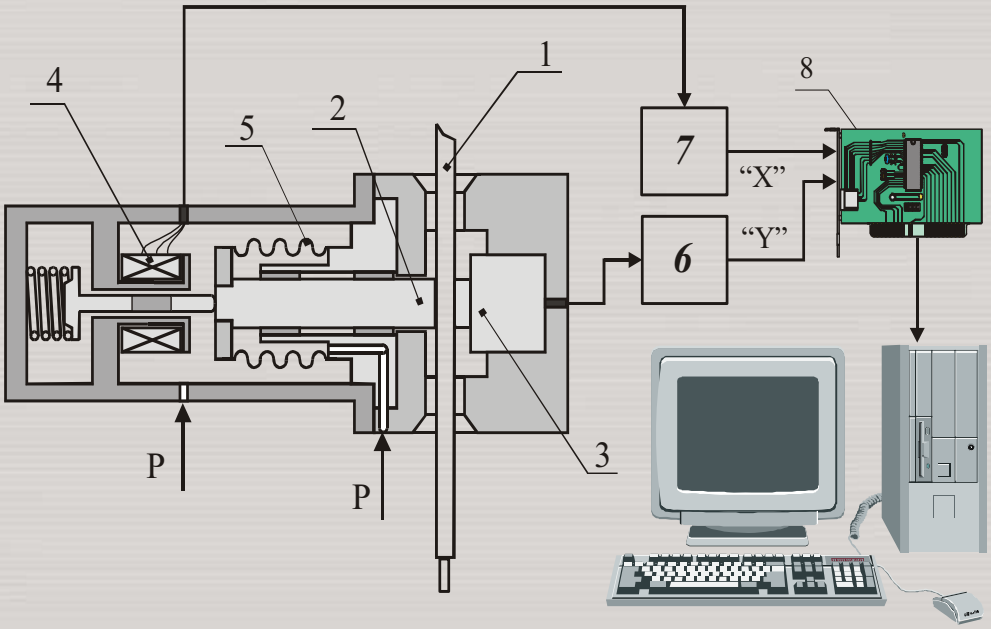
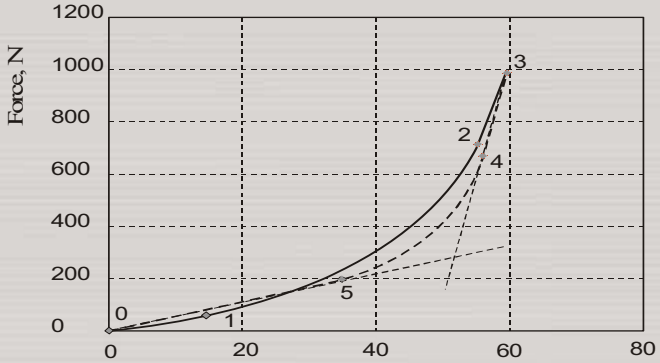
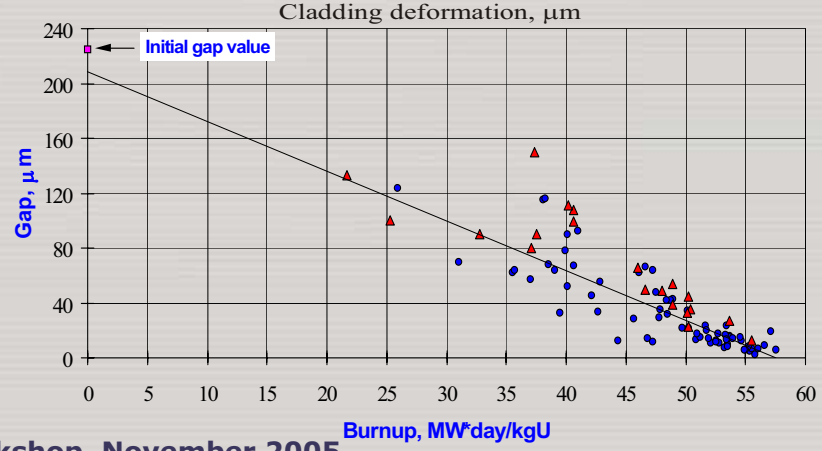
Measurement of Cold Gap on FR –RIAR, Russia

1-FR; 2-loading bar; 3-piezoelectric force transducer ; 4-LVDT; 5-bellows; 6-charge amplifier; 7-normalizing amplifier; 8-analog/digital converter







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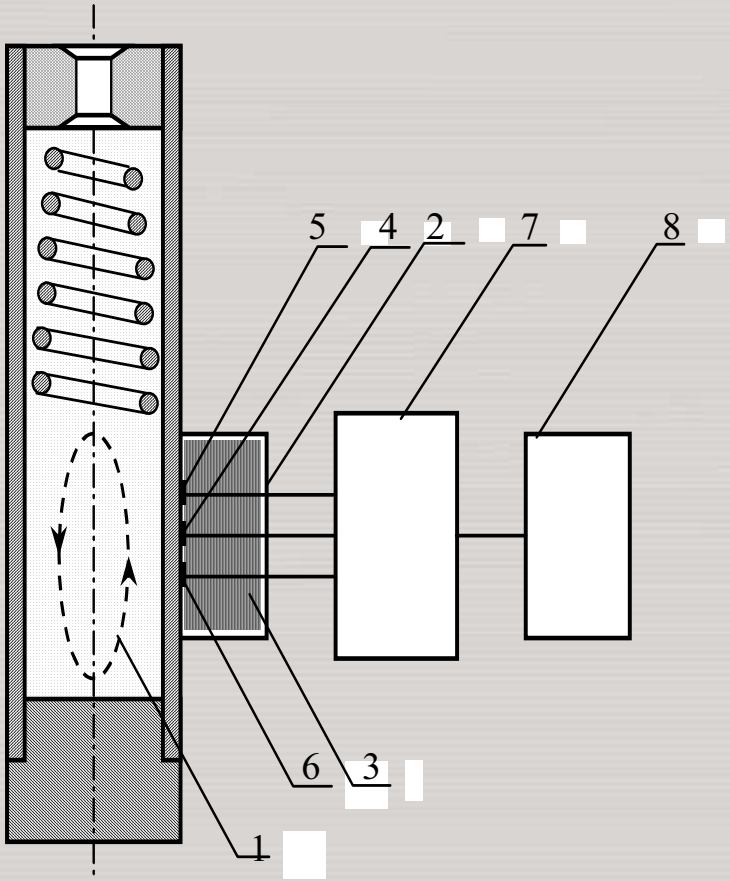

Measurement of FR Internal Gas (He and FPs) Pressure-VNIINM, Russia

1-gas plenum; 2-pressure probe; 3-rubber bed; 4-heater; 5,6-thermoresistors; 7-power/measurement block; 8-PC
Range of gas pressure measurement, MPa-0.1-5.0
Range of He pressure measurement, MPa-0.1-3.0
Error of total pressure measurement, MPa-0.15
Range of FP pressure measurement, MPa-0.1-2.0
Total time of one FR measurement, min-15
Environment-water or air
Data for WWER-1000 FR (3.6% U-235, 34.7 MWd/kgU, 3 years): Free volume-28 cm^3; Total gas pressure-2.4 MPa; He-97.81%; Kr-0.22%; Xe-1.84%; N_2-0.11%; O_2-0.02%

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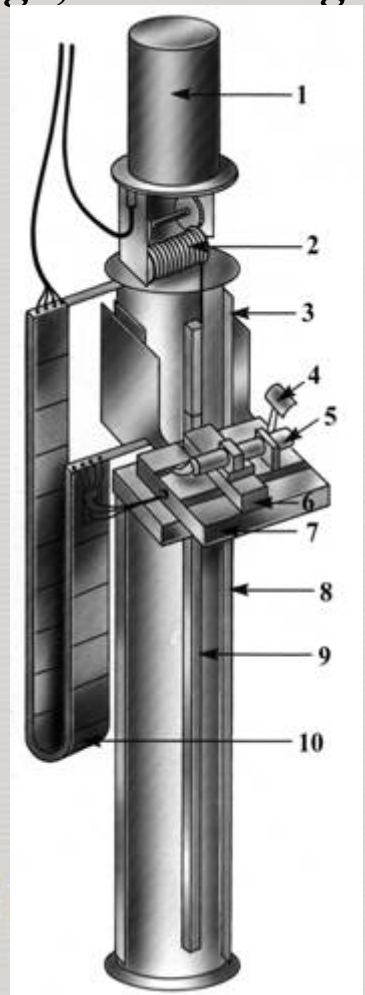
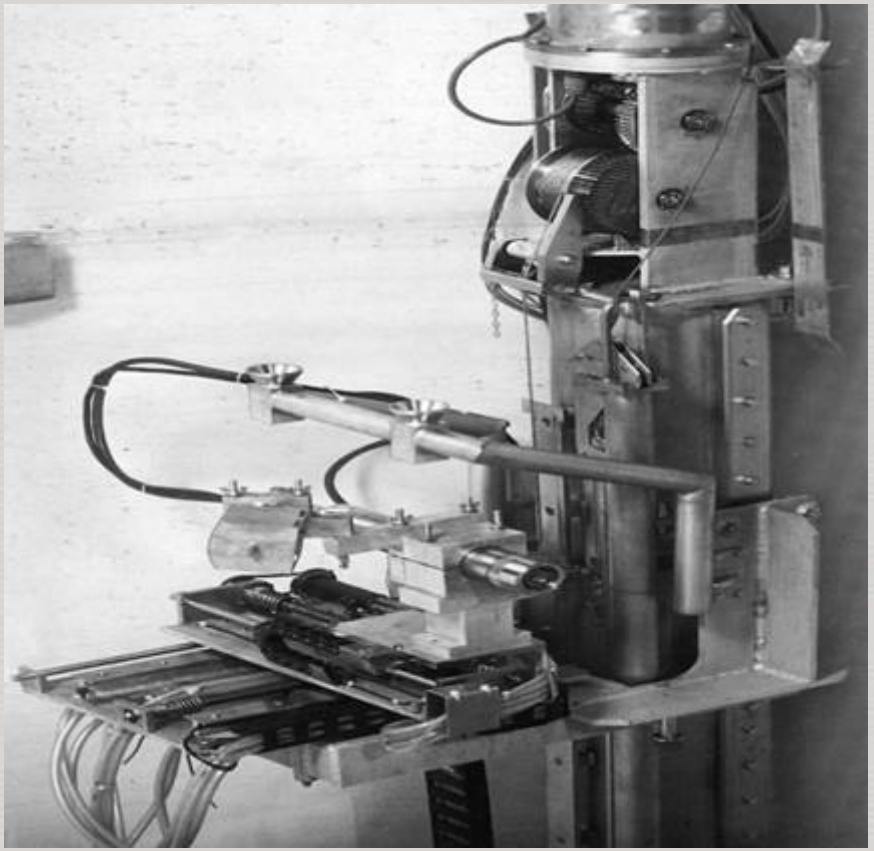
Multi-Site FRAGEMA Examination Stand

1-Z drive unit; 2-Z winch; 3-Z carriage; 4-projector; 5-TV camera; 6-Y carriage; 7-X carriage; 8-Z rails; 9-Z beam; 10-cable chain





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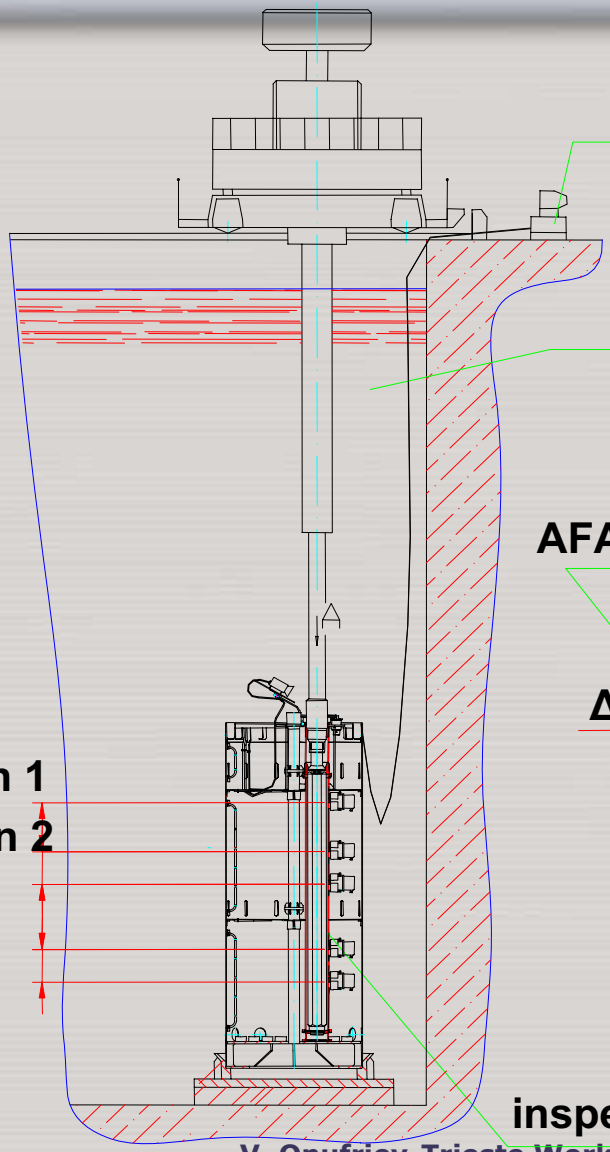

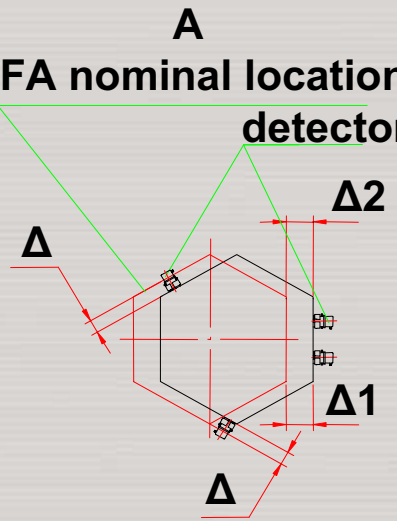

Δ, Δ1, Δ2 - cross-section of AFA bowing

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Fuel Assembly Repair and Reconstitution

1) In case of finding one or more leaky fuel rods in the FA, it might be repaired. **Repair** of FA assumes removal of the leaky rod/rods from the skeleton and insertion of the mock-up (usually Zr bar) or similar good fuel rod. Equipment for removal of separate fuel rods for examination might be used in this case.
2) In case of significant damage of the FA skeleton (mainly Spacer Grids), Reconstitution might be carried out. **Reconstitution** assumes removal of intact fuel rods from the skeleton and their insertion into a new skeleton. Special equipment is required for this procedure.

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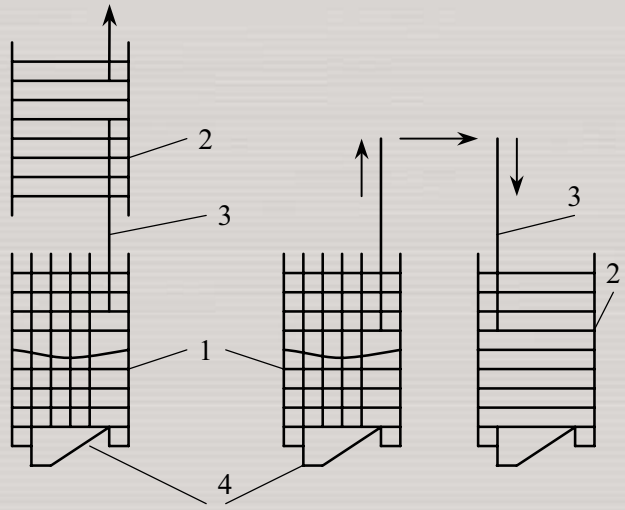
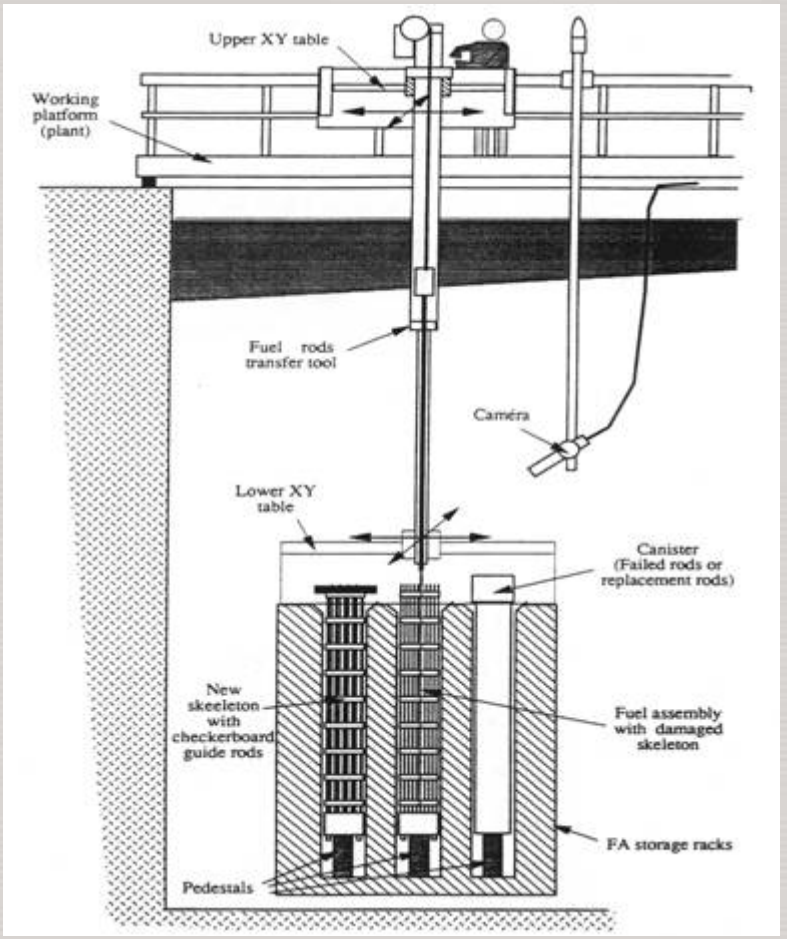
Fuel Assembly Reconstitution

(left-scheme of two methods, right-FRAMATOME stand

1-FA with damaged skeleton;
2-new skeleton; 3-FR, 4-top nozzle





Post-Irradiation Examination of Water Reactor Fuel (PIE) and IAEA PIE Facilities/Techniques Database

IAEA Activities in PIE Area (1)

1) Co-ordinated Research Project (CRP) on Examination and Documentation Methodology for Water Reactor Fuel (ED-WARF-1), 1983-1988 with publication in 1991 Guidebook on Non-Destructive Examination of Water Reactor Fuel, TRS-322.
2) CRP on Examination and Documentation Methodology for Water Reactor Fuel (ED-WARF-2), 1990-1995 with publication in 1997 Guidebook on Destructive Examination of Water Reactor Fuel, TRS-385 and Catalogue on PIE Facilities and Techniques (collection of tables) in 1996.

Post-Irradiation Examination of Water Reactor Fuel (PIE) and IAEA PIE Facilities/Techniques Database

IAEA Activities in PIE Area (2) – Technical Meetings

1) TMs on PIE Techniques for Water Reactor Fuel:

1990 (IWGFPT-37, 1991)
2001 (IAEA-TECDOC-1277, 2002)

2) TM on Poolside Inspection, Repair and Reconstitution of Water Reactor Fuel:

1992 (IAEA-TECDOC-692, 1993)
1997 (IAEA-TECDOC-1050, 1998)
2003 (IAEA-Working Material, 2003)

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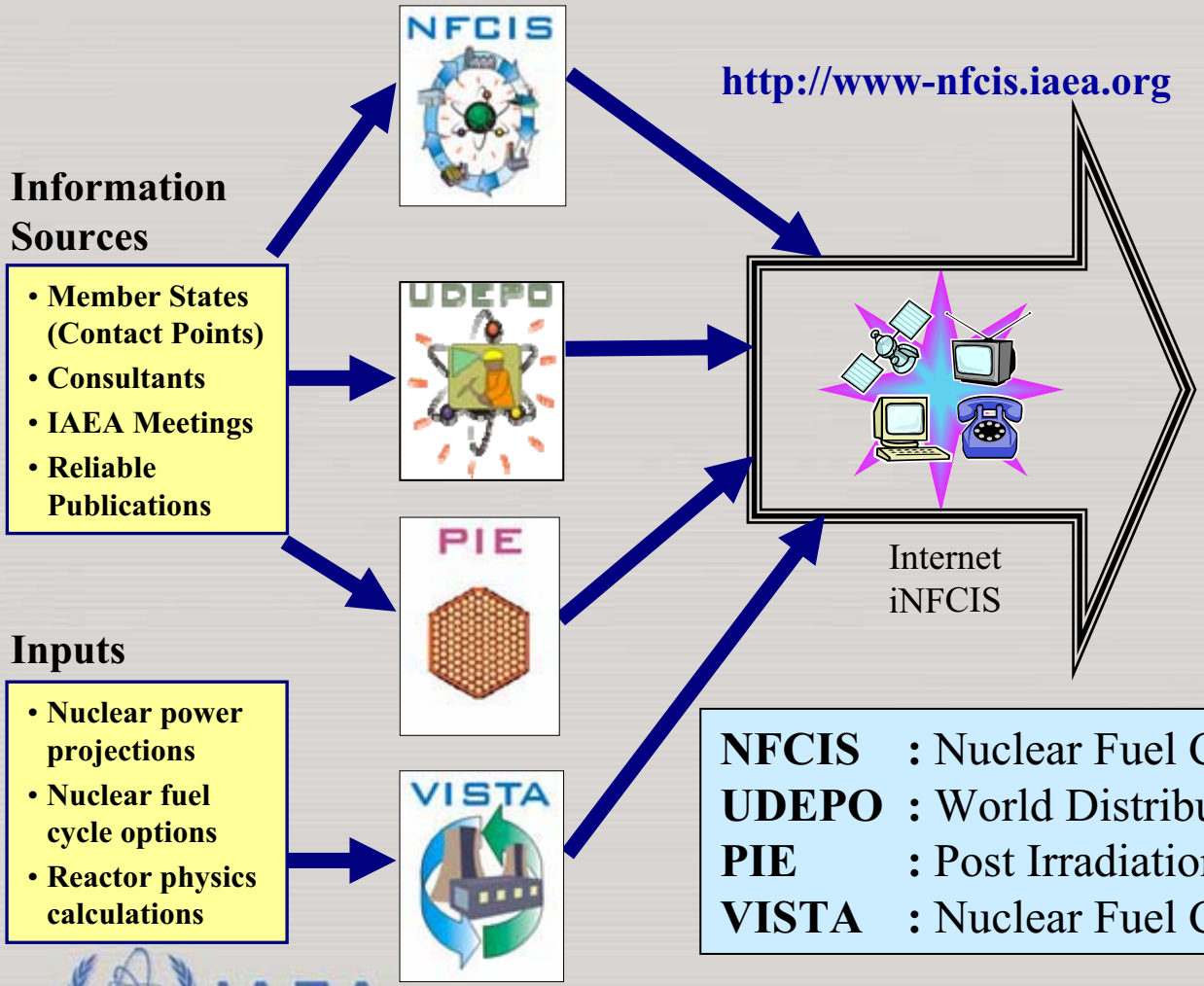
IAEA Databases Related to the Nuclear Fuel Cycle



Information Sources

- **Member States (Contact Points)**
- **Consultants**
- **IAEA Meetings**
- **Reliable Publications**

Inputs

- **Nuclear power projections**
- **Nuclear fuel cycle options**
- **Reactor physics calculations**

- Navigation through facilities
- Search capabilities
- Summary reports for country specific or worldwide
- Country nuclear fuel cycle profiles
- Long term nuclear fuel cycle requirements for different scenarios

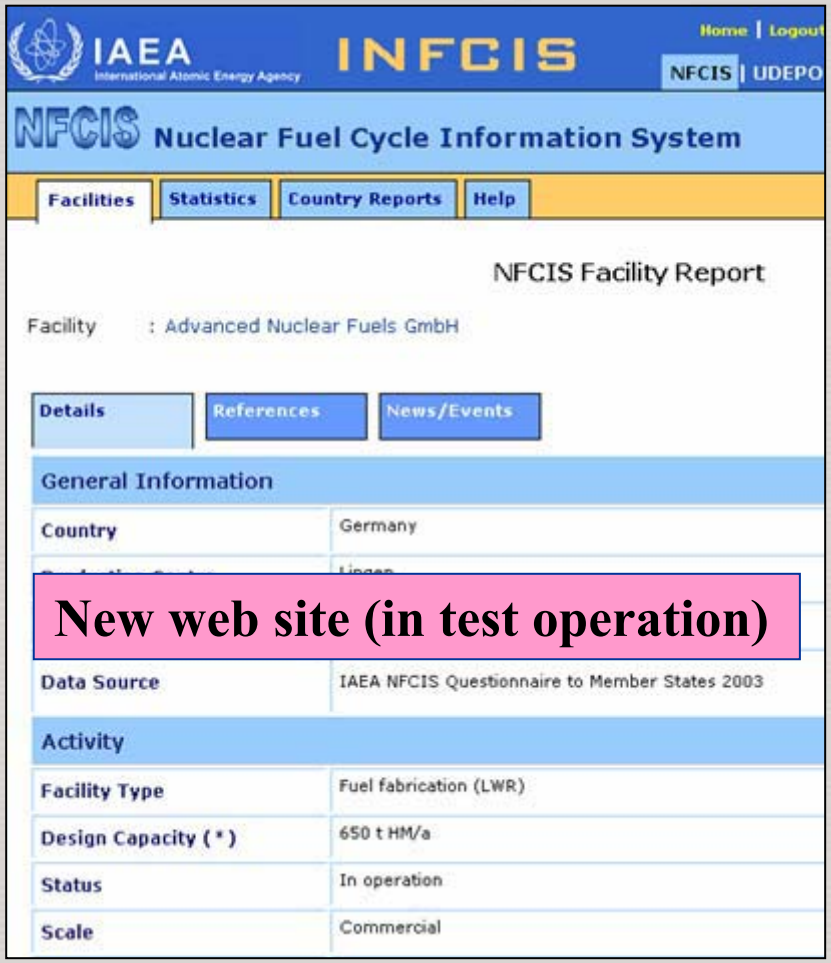
NFCIS : Nuclear Fuel Cycle Information System
UDEPO : World Distribution of Uranium Deposits
PIE : Post Irradiation Examination Facilities Database
VISTA : Nuclear Fuel Cycle Simulation System

IAEA

Post-Irradiation Examination of Water Reactor Fuel (PIE) and IAEA PIE Facilities/Techniques Database

Nuclear Fuel Cycle Information System (NFCIS)

- Directory of Civilian Nuclear Fuel Cycle Facilities Worldwide
- Milling, conversion, enrichment, fuel fabrication, spent fuel storage, heavy water production, zircaloy facilities
- Annual update through questionnaire to officially nominated contact points in member states
- Access on the internet with some search and filter capabilities (www-nfcis.iaea.org)



Post-Irradiation Examination of Water Reactor Fuel (PIE) and IAEA PIE Facilities/Techniques Database

Post Irradiation Examination (PIE) Facilities Database (1)

- Catalogue of PIE Facilities Worldwide
- General and technical information about the facilities
- Access on the internet with some search and filter capabilities (www-nfcis.iaea.org)

Post-Irradiation Examination of Water Reactor Fuel (PIE) and IAEA PIE Facilities/Techniques Database

Post Irradiation Examination (PIE) Facilities Database (2)

- Data are given for 31 Hot Labs from 17 countries including:
  - Characteristics of Cells and Acceptance Info;
  - Description of available Destructive & Non-Destructive Examination Techniques;
  - Rod Refabrication and Instrumentation Description , if any;
  - Availability of Storage and Conditioning Capabilities;
  - Altogether about 100 different PIE techniques described

Post-Irradiation Examination of Water Reactor Fuel (PIE) and IAEA PIE Facilities/Techniques Database

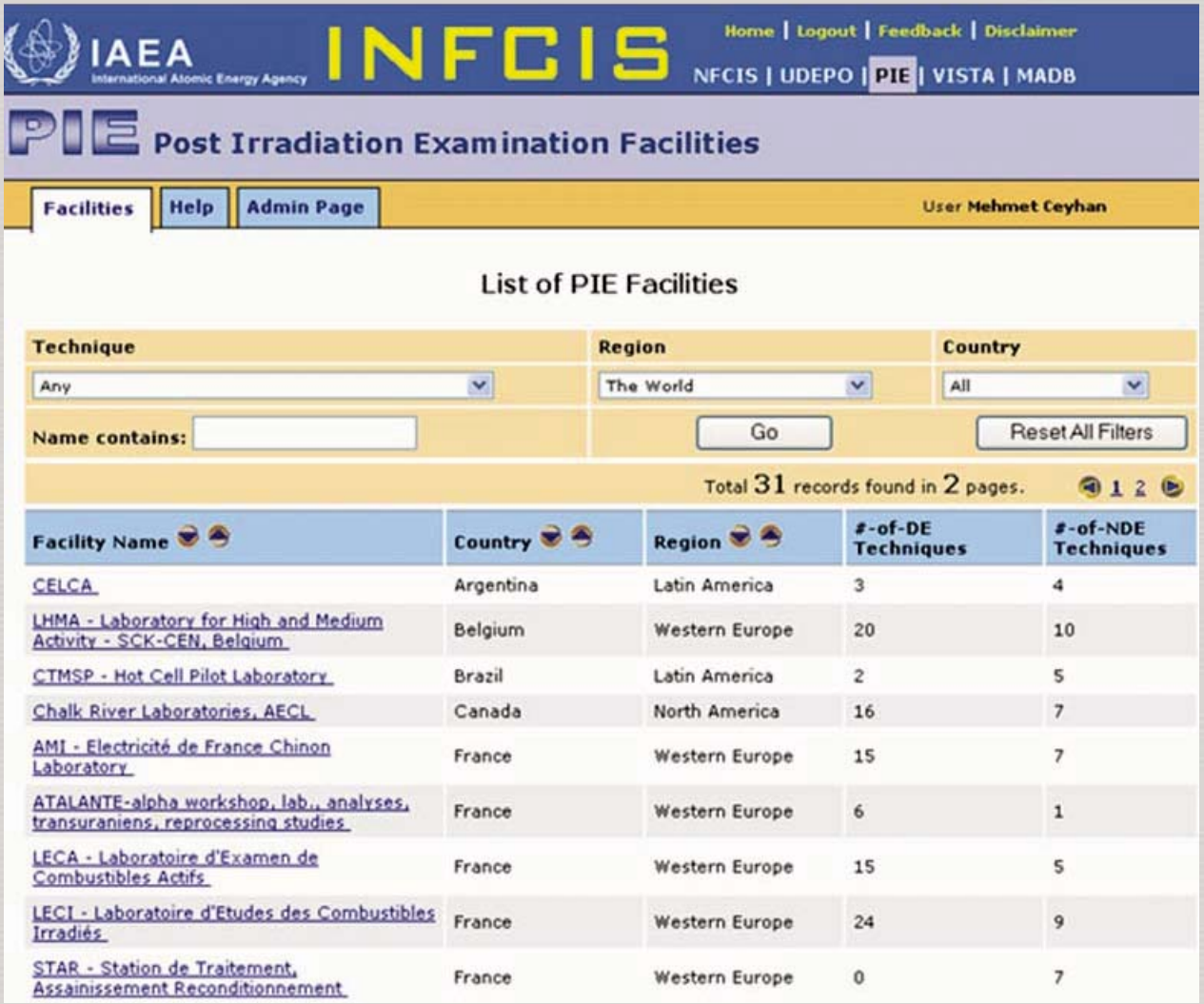
PIE Database - Background

- Created in 1990s
- Published as a working material in 1996
- Transformed into an electronic database in 2003
- Published in the internet in 2004
- Data is being updated through contact points in PIE facilities

Post-Irradiation Examination of Water Reactor Fuel (PIE) and IAEA PIE Facilities/Techniques Database

PIE Database New Web Site

- List of facilities
- Filtered by
  - available technique
  - facility name



Facility Name	Country	Region	#-of-DE Techniques	#-of-NDE Techniques
CELCA	Argentina	Latin America	3	4
LHMA - Laboratory for High and Medium Activity - SCK-CEN, Belgium	Belgium	Western Europe	20	10
CTMSP - Hot Cell Pilot Laboratory	Brazil	Latin America	2	5
Chalk River Laboratories, AECL	Canada	North America	16	7
AMI - Electricité de France Chinon Laboratory	France	Western Europe	15	7
ATALANTE-alpha workshop, lab., analyses, transuraniens, reprocessing studies	France	Western Europe	6	1
LECA - Laboratoire d'Examen de Combustibles Actifs	France	Western Europe	15	5
LECI - Laboratoire d'Etudes des Combustibles Irradiés	France	Western Europe	24	9
STAR - Station de Traitement, Assainissement Reconditionnement	France	Western Europe	0	7

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PIE Database New Web Site

- Details of the selected facility

Post-Irradiation Examination of Water Reactor Fuel (PIE) and IAEA PIE Facilities/Techniques Database

PIE Database
New Web Site

- Details of selected technique

Technical Information	
Type	NDE
Short Description	The fuel rod defiles in front of the objective of the stereo-macroscope or a video-camera allowing optical observations over the total external surface.
Form of Data Presentation	Pictures (analog & digital) & Videofilm
Comment	
References	
Equipment	Stereo-macroscope & Video-camera
Standards	
Test Parameters	
Type of Specimen	fuel rod
Measured Parameters	Aspect, location and dimensions of visible surface features.
Calculated Parameters	Dimension of features
Features	Magnification max. x15. Accurate axial (± 0.5 mm) and azimuthal (± 1°) location of observations.

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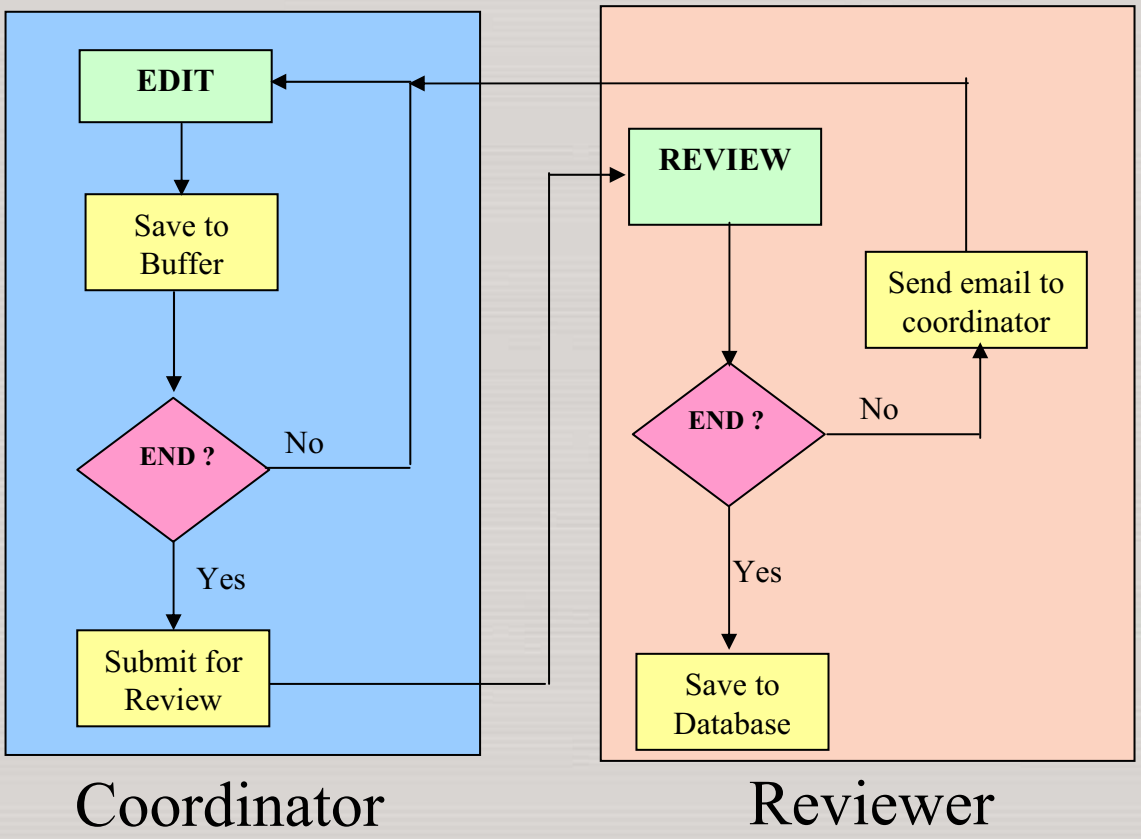
PIE Database
Admin Web Site – Data Update Flowchart and Roles

- Owner
- Coordinator
- Reviewer



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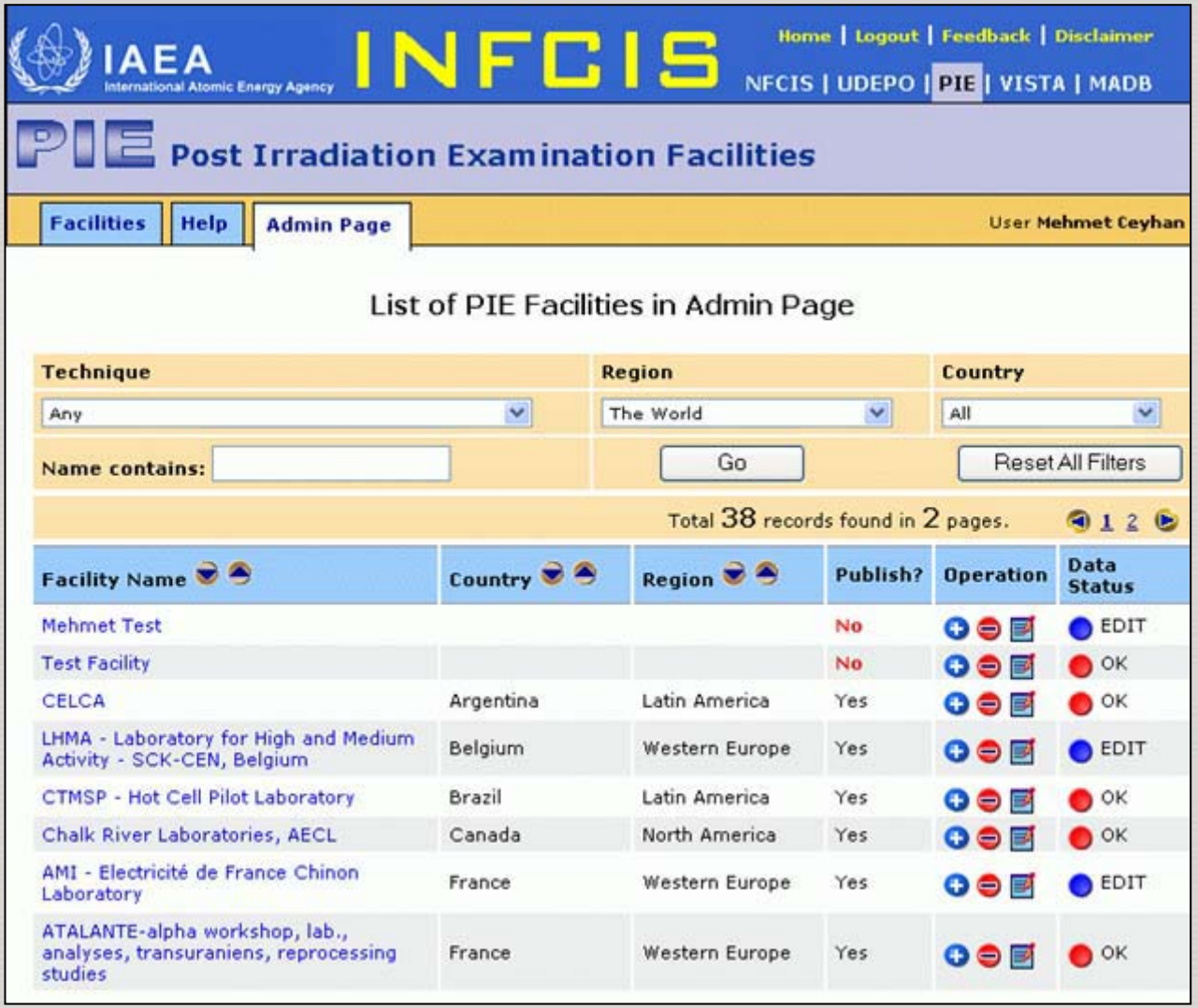
PIE Database Admin Web Site

- Operations:
  - Add facility,
  - Delete facility,
  - Edit facility,
- Statuses:
  - OK,
  - EDIT,
  - REVIEW



Post-Irradiation Examination of Water Reactor Fuel (PIE) and IAEA PIE Facilities/Techniques Database

PIE Database Admin Web Site

- Operations for Coordinator
  - Cancel editing
  - Save to buffer
  - Submit for review
- Operations for Reviewer
  - Send email to coordinat
  - Save to main database