Operating Nuclear Reactors in Ukraine: Enhancement of Safety and Performance

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Operating Nuclear Power Plants of Ukraine

Four Nuclear Power Plants / 15 units with total 13 835 MWe Installed Capacity

NPPs	UNITS	REACTOR TYPES	CAPASITY (MWe)	BEGINNING of CONSTRUCTION	CONNECTION to the GRID/ COMISSIONING	EXPIRATION
ZAPORIZHZHYA NPP	1	WWER-1000/320	1000	04.1980	10.12.1984	10.12.2014
	2	WWER-1000/320	1000	04.1981	22.07.1985	22.07.2015
	3	WWER-1000/320	1000	04.1982	10.12.1986	10.12.2016
	4	WWER-1000/320	1000	01.1984	18.12.1987	18.12.2017
	5	WWER-1000/320	1000	07.1985	14.08.1989	14.08.2019
	6	WWER-1000/320	1000	06.1986	19.10.1995	19.10.2025
SOUTH-UKRAINE NPP	1	WWER-1000/302	1000	03.1977	31.12.1982	31.12.2012
	2	WWER-1000/338	1000	10.1979	06.01.1985	06.01.2015
	3	WWER-1000/320	1000	02.1985	20.09.1989	20.09.2019
RIVNE NPP	1	WWER-440/213	415	08.1976	22.12.1980	22.12.2010
	2	WWER-440/213	420	10.1977	22.12.1981	22.12.2011
	3	WWER-1000/320	1000	02.1981	21.12.1986	21.12.2016
	4	WWER-1000/320	1000	-	10.10.2004/ 06.06.2006	06.06.2036
KHMELNITSKY NPP	1	WWER-1000/320	1000	11.1981	22.12.1987	21.12.2017
	2	WWER-1000/320	1000	-	07.08.2004/ 15.12.2005	15.12.2035

State policy in the sphere of nuclear energy utilization

In line with the strategical plans for further growth and development of the nuclear power sector, safety enhancement of the nuclear power units in operation is one of the major tasks of the state policy in the sphere of nuclear energy utilization

State policy in the sphere of nuclear energy utilization (2)

Top level regulatory document “General Provisions on Safety”, updated in 2008, requires that

“Utility’s technical policy should be based on the principle of the continuous of NPPs safety enhancement taking into account the national and international experience, recommendations of the international organizations, results of the scientific and technical researches and developments”

Safety criteria (CDF, LERF) for operating and future NPPs define in consistent with the IAEA safety standards.

Safety criteria	Operating NPPs		New NPPs	
	Strictly value, 1/y	Target value,1/y	Strictly value, 1/y	Target value,1/y
CDF	$<10^{-4}$	$<10^{-5}$	$<10^{-5}$	$< 5 \cdot 10^{-6}$
LRF	$<10^{-5}$	$<10^{-6}$	$<10^{-6}$	$<10^{-7}$

Evolution of Safety Upgrade Approach

Safety Upgrade of Ukrainian NPPs

“Old” units

“New” units (K2R4)

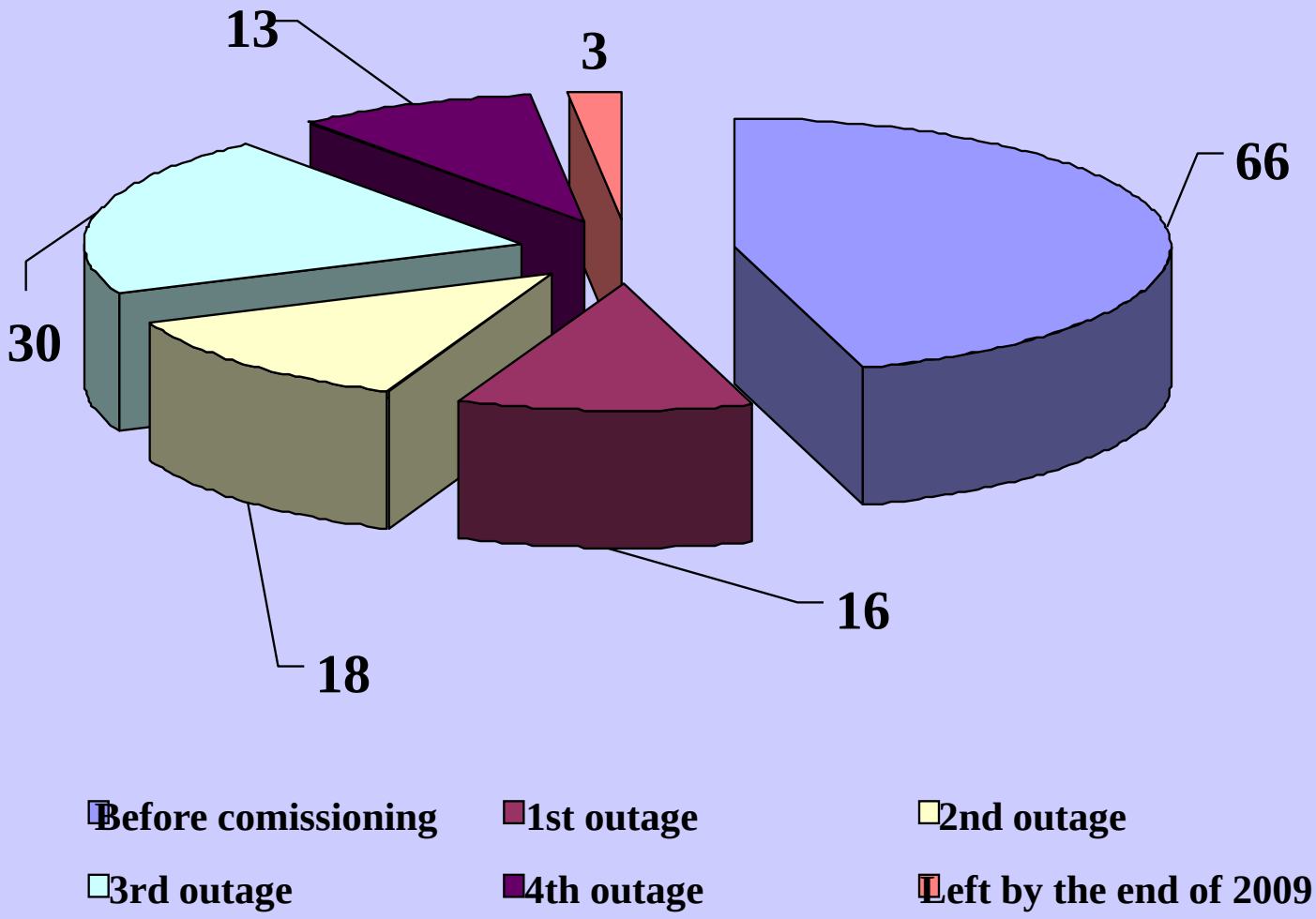
Comprehensive Program of NPP Modernization and Safety Upgrade + topical Action Plans (Upgrade Package)

Safety Upgrade Concept for existing NPP Units + Action Plans (Upgrade Package)

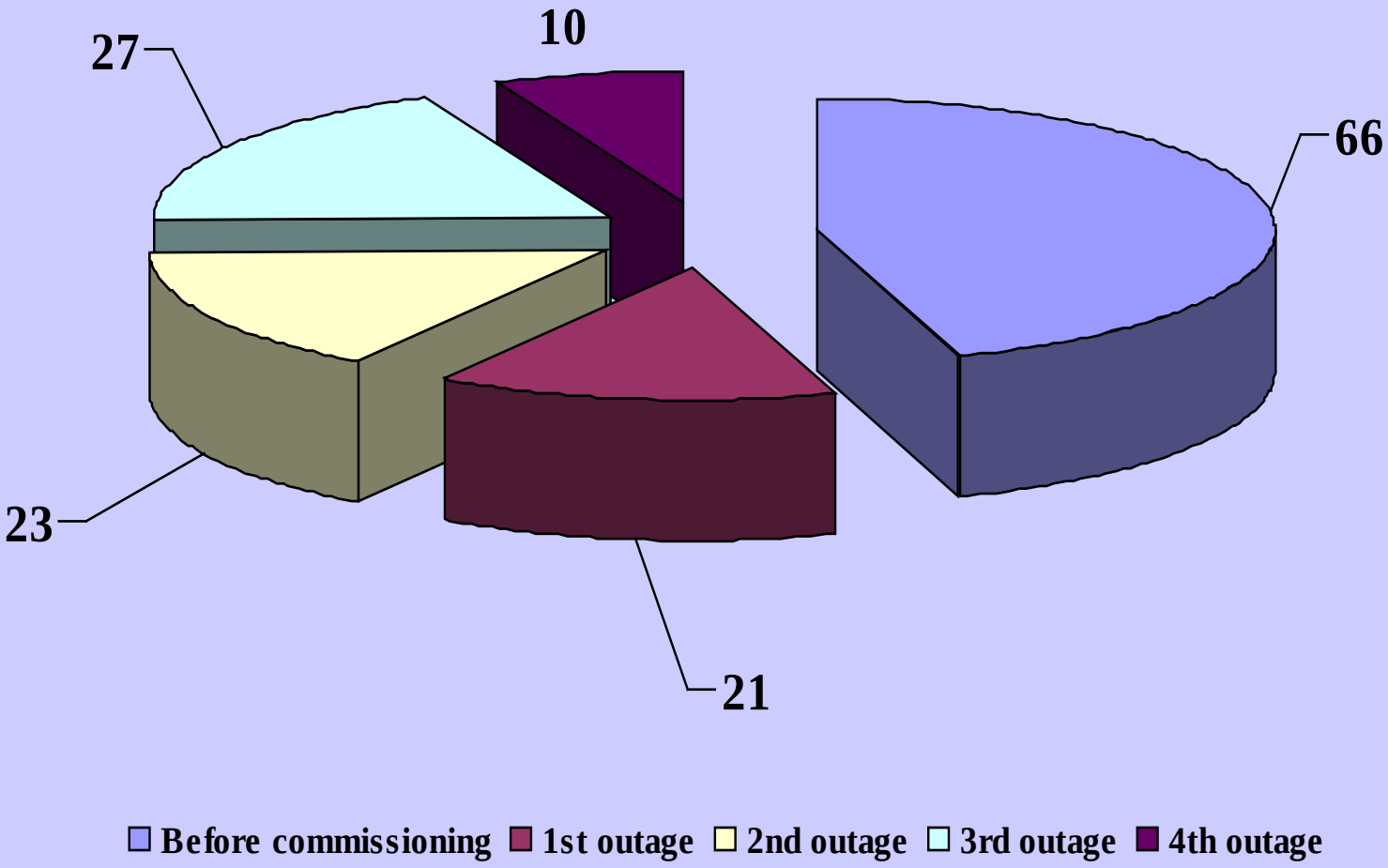
K2R4 Modernization Programme

United NPP Safety Upgrade Programme

Implementation of K2R4 MP at Khmelnitsky-2



Implementation of K2R4 MP at Rovno-4



Previous activities

Comprehensive Program of Modernization and Safety Upgrade of NPP Units
(endorsed by Cabinet of Ministers' Order of 29 August 2002)
Implementation period – 2002-2005

Nuclear Safety Convention (article 6)

Requirements of national regulations introduced after units' commissioning

IAEA Issues Books – IAEA-EBP-WWER-05, IAEA-EBP-WWER-14, IAEA-EBP-WWER-03

Total: 389 measures (pilot and adopted) to be implemented at 13 units.

Implemented by 01/01/2006: 33%.

Lessons learned from the Program implementation

April-August 2005 – review of implementation status of the Comprehensive Program and elaboration of proposal for safety improvement activities after 2005

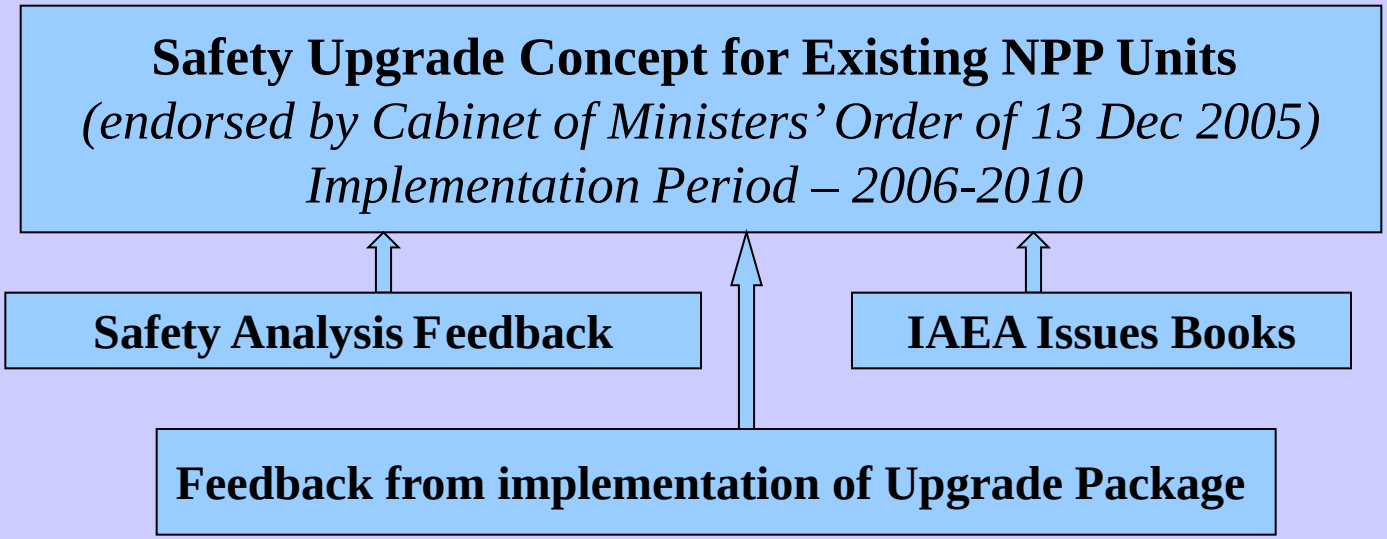
December 2005 – approval of the Safety Upgrade Concept for Existing NPP Units, thus identifying the following areas for safety upgrade for period 2006-2010:

- LOCA from primary to secondary side
- Dependent and common cause failures
- Secondary heat removal
- Pressurized thermal shock and cold overpressure
- Primary heat removal and pressure control
- Containment reliability
- Emergency power supply
- Improvement of emergency processes control
- Elaboration of safety analysis

Action Plan to implement the Concept approved jointly by the SNRCU and Ministry of Fuel and Energy in January 2006

Regulatory monitoring over the Concept implementation and annual review of implementation status

Implementation of safety improvement measures/Ongoing activities

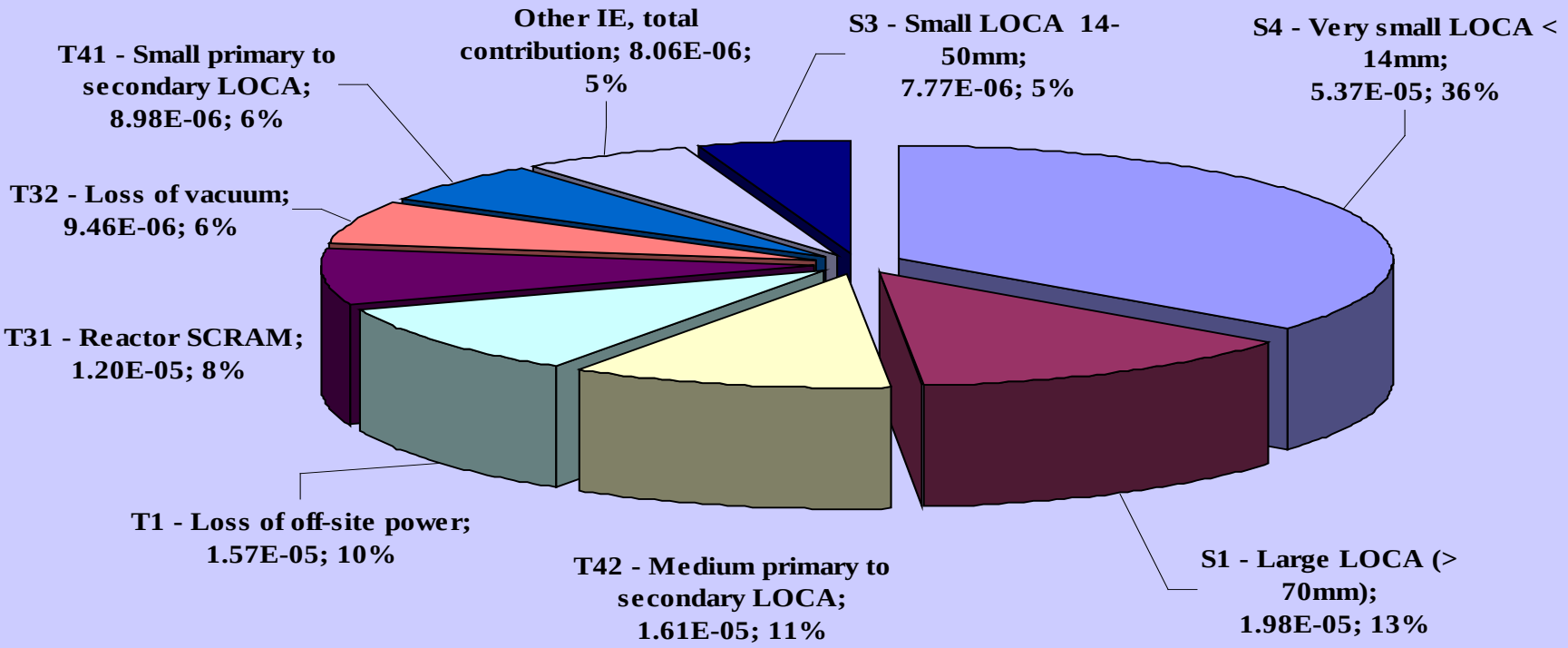


Total: 253 pilot measures and 472 adopted measures at 13 NPP Units.

Implementation approved by SNRCU as of 09 October 2009: 197 pilot measures (79%), 172 adopted measures (37%).

SUNPP-1 PSA Level 1 for internal IE at nominal power (1998)

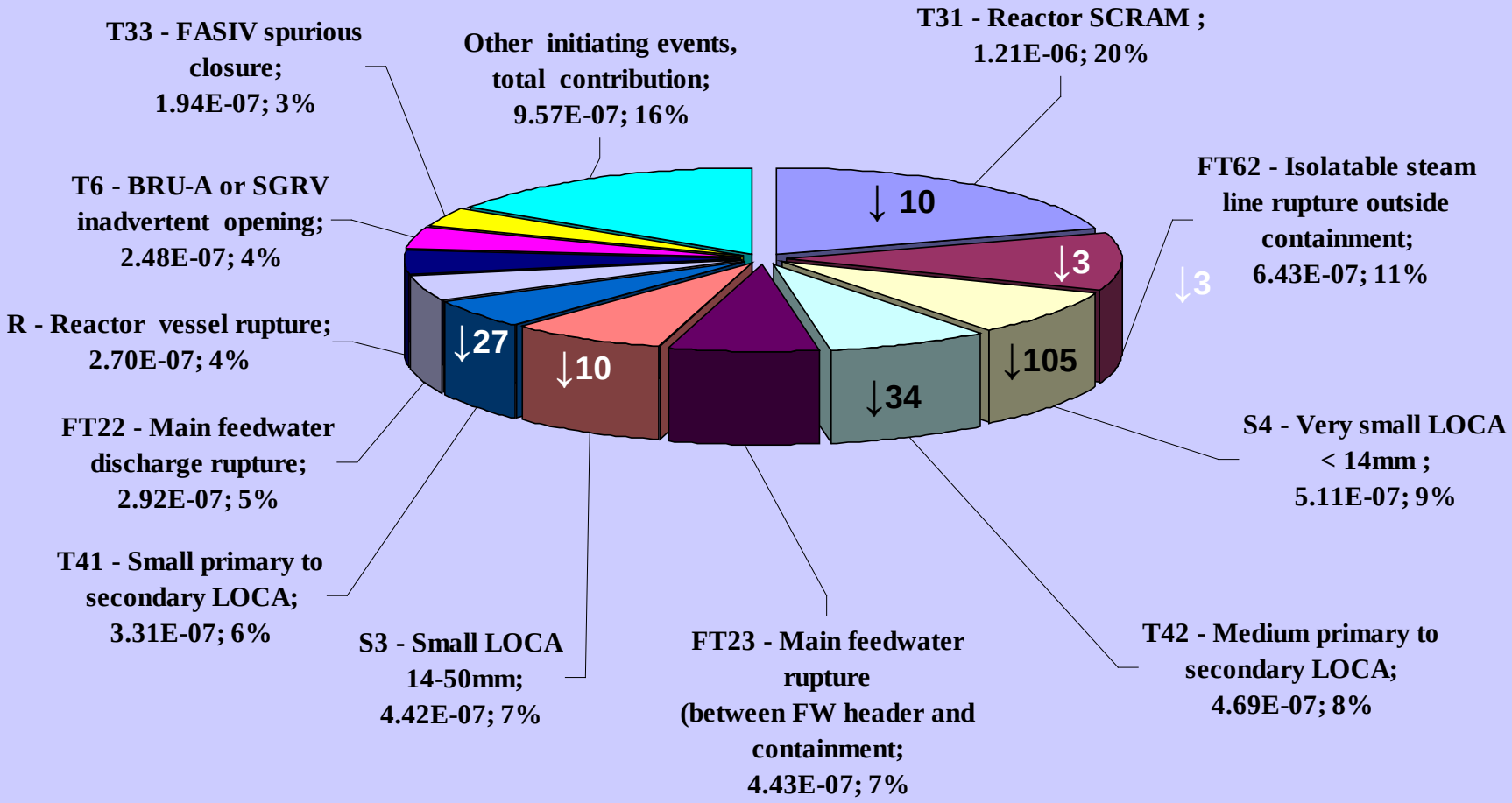
Total Core Damage Frequency =1,5*10-4 1/year



SUNPP-1 PSA Level 1 for internal IE at nominal power (2009)

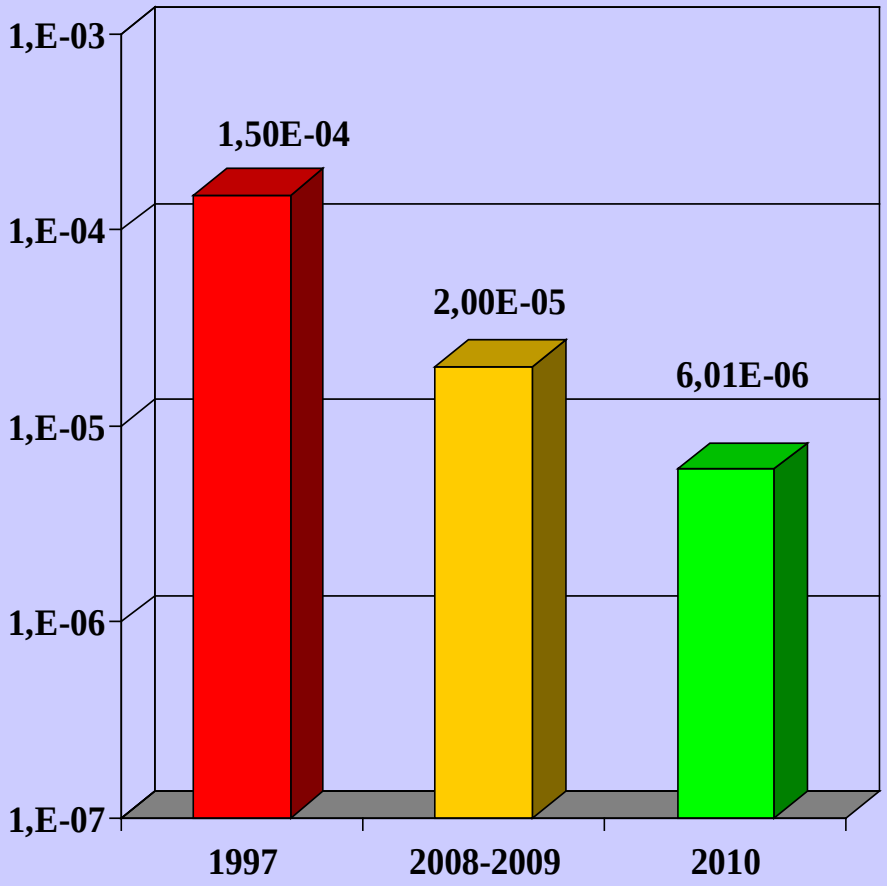
Total CDF =6,01*10^{-6} 1/ year

25 times decrease of CDF (vs 1998)



Safety Upgrade Activities

SUNPP-1 CDF decrease



SUNPP-1 Safety improvement (example for selected IE)

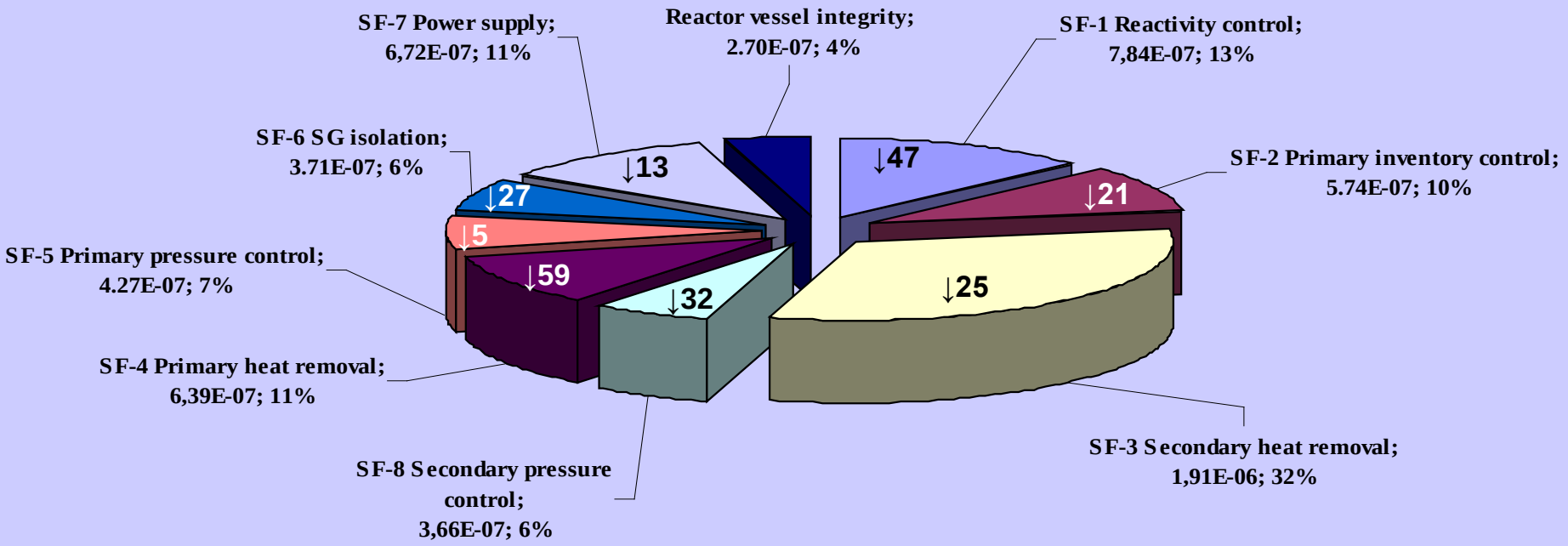
Very small LOCA

- Modernization of systems and components (HPIS, LPIS, Secondary systems)
- Improved human reliability (Full-scope simulator, EOP improvement)
  - Strategies for mitigation of the LOCA were evaluated using PSA results. Areas for improvement include:
    - IE identification
    - Secondary cool down (e.g., excessive requirements on SG feeding and boron injection preclude early cooldown)
    - Primary pressure control (does not provided in EOP)
    - Maintain long term cold shutdown state (does not provided in EOP)
  - Proposed strategy was evaluated by thermal hydraulic analyses and validated on full-scope simulator:
    - realistic time window,
    - number of available equipment,
    - order of human actions, etc.
- As a result, CDF for very small LOCA was decreased by 105 times.

SUNPP-1 Safety improvement (example for selected IE)

- Medium primary to secondary LOCA
  - Preventive measures to decrease LOCA possibility (100% nondestructive control, adequate water-chemical mode, etc)
  - Improved human reliability (full-scope simulator, EOP improvement)
  - Modernization of systems and components
    - improve diagnostics of the LOCA and affected SG;
    - ensure operability of BRU-A, SG RV on water/steam mixtures;
    - provide emergency make-up of the containment sump using spent fuel pool
    - implementation of new automatic algorithm to prevent releases through BRU-A of affected SG
  - As a result, CDF for the IE was decreased by 34 times.

SUNPP-1 CDF due to unavailability of safety functions (PSA 2009 vs PSA 1998)



Improve reliability of safety functions for SUNPP-1

- **Primary heat removal** (59 times enhancement)
  - Installation of PORV qualified for water/steam mixtures
  - Introduction of feed&bleed mode
  - Modernization of ECCS sump filters
  - Replacement of thermal insulation on primary circuit
  - Installation of high pressure ECCS discharge control valves and ensuring make-up pumps operation via ECCS sumps
  - Ensuring HPIS operation on primary circuit at primary pressure < 40 bar
- **Reactivity control** (47 times enhancement)
  - Modernization of reactor protection system (two-sets scram, new signals for scram actuation)
  - Automatic supply of boric acid to make-up pumps during reactor scram
  - Ensuring HPIS boron pumps operation on primary circuit at primary pressure up to 180 bar
- **Secondary pressure control** (32 times enhancement)
  - Modernization of SGRV and BRU-A to ensure their operation on water/steam mixtures
  - Modernizations of safeguards for control of primary to secondary LOCA (automatic algorithm to prevent releases through BRU-A of affected SG)

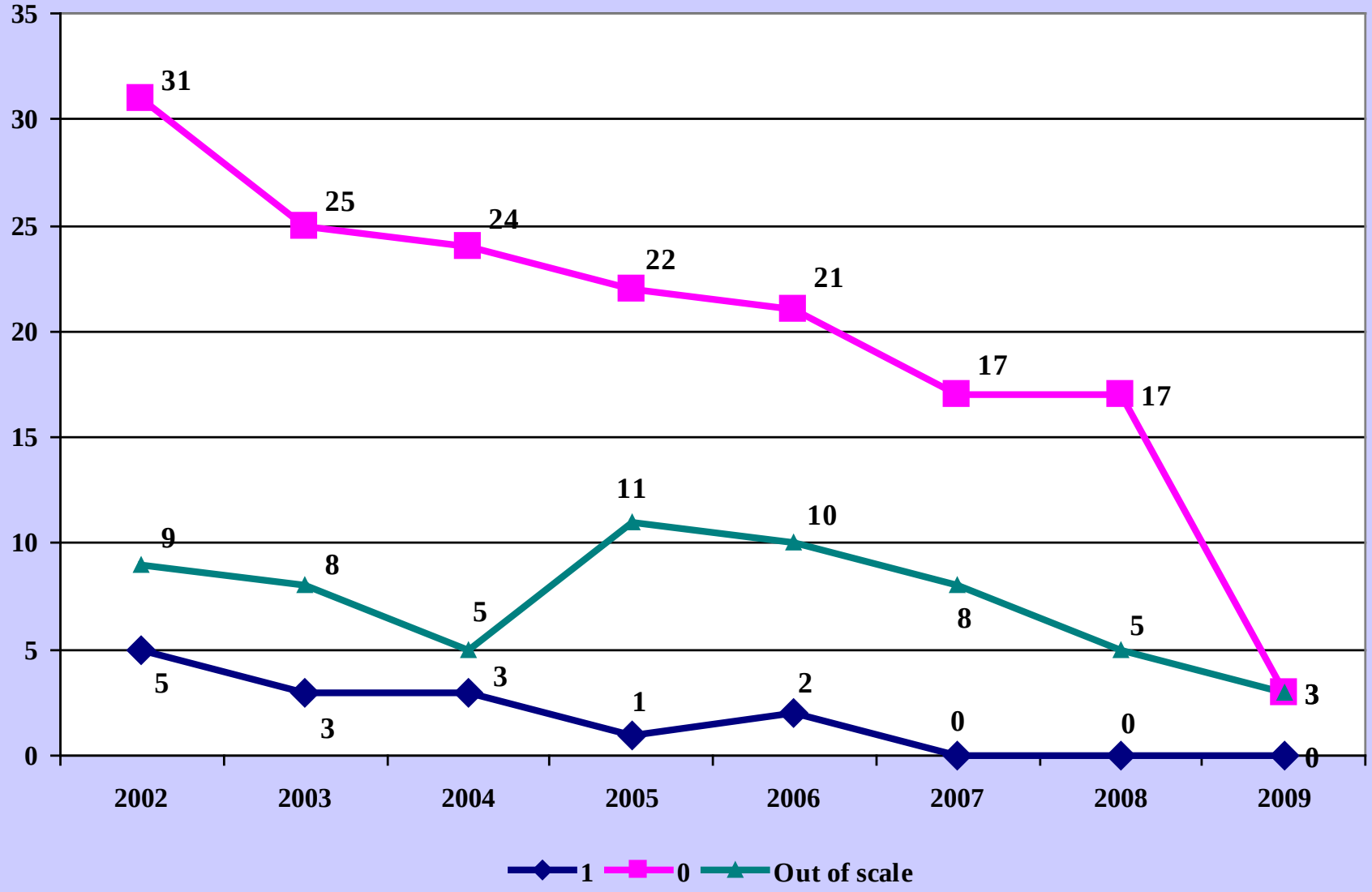
Improve reliability of safety functions for SUNPP-1 (cont.)

- **SG isolation** (27 times enhancement)
  - Modernization of FASIVs to ensure their operation on water / steam mixtures
  - Monitoring of primary to secondary leaks by nitrogen 16
  - Modernizations of safeguards for control of primary to secondary LOCA (automatic algorithm to prevent releases through BRU-A of affected SG)
  - Automatic isolation of emergency feedwater during uncontrolled overcooling
- **Secondary heat removal** (25 times enhancement)
  - Modernization of SGRV and BRU-A to ensure their operation on water / steam mixtures
  - Ensuring power supply of demineralized water pumps from diesel generators
  - Separation and water insulation of emergency feedwater compartments
  - Emergency SG feeding by fire water
- **All safety functions**
  - Using full scope simulator to improve qualification and reliability of operators
  - Symptom based EOP
  - Implementation of measures on additional power supply during blackout

Examples of safety issues resolved

- presurizer safety and relief valves' qualification for water flow
- steam generator safety and relief valves' qualification for water flow
- control of primary coolant loss into secondary loop
- ECCS sump screen blocking
- primary circuit cold overpressure protection
- mitigation of dependent and common cause failures
- improvement of decay heat removal via secondary system
- elaboration of emergency operating procedures
- emergency battery discharge time

Decreasing number of events



Implementation of safety improvement measures/ Further steps

United NPP Safety Upgrade Program
to be implemented since 2010

Outcomes of Joint IAEA-EU-Ukraine project:
- severe accidents considerations;
- seismic design basis re-evaluation

Outcomes of implementation of Upgrade Package and K2R4 Modernization Program

Strengthening of requirements of national regulations as introduced during 2005-09

United NPP Safety Upgrade Program

- Scope:
  - VVER-1000/320 – 90 measures
  - VVER-1000/302,338 – 61 measures
  - VVER-1000/213 – 62 measures
- List of safety measures was reviewed and agreed by Riskaudit
- Implementation Period: 2010/2011-2017

United NPP Safety Upgrade Program (2)

- 0 General:
  - equipment qualification
- 1 Reactor core and fuel treatment:
  - neutron – physics reactor core characteristics
  - reactor core
  - fuel treatment
- 2 Component integrity:
  - primary circuit
  - pressures safety system
  - reactor (incl. vessel)
  - other

United NPP Safety Upgrade Program (3)

- 3 System:
  - reactivity control
  - heat removal
  - pressure control
  - essential system
- 4 Instrumentation and Control System
- 5 Power Supplying
- 6 Containment system:
  - interfacing LOCA (bypass of containment)
  - containment integrity

United NPP Safety Upgrade Program (4)

- 7 Internal hazards:
  - fire
  - flooding
  - missiles
- 8 External hazards:
  - Seismic hazards
  - Natural external hazards
  - Man made external hazards
- 9 Accident Analysis:
  - Safety analysis
  - Accident management

Independent Safety Evaluation of existing NPPs /Joint IAEA-EU-Ukraine project

December 1, 2005 – Memorandum of Understanding on Cooperation in the Field of Energy between EU and Ukraine signed, providing that safety evaluation of existing NPPs is to be conducted

March 2007 – ToR of Joint IAEA-EU-Ukraine project on safety evaluation of existing NPPs agreed, including 4 Tasks to be implemented on the basis of IAEA safety review services:

- Task 1 – Design Safety – DSR;
- Task 2 – Operational Safety – OSART;
- Task 3 – Waste Safety – especially designed missions;
- Task 4 – Regulatory Issues – IRRS.

June 2008 – first IAEA mission under project came to Ukraine (IRRS)

April 2009 – reporting approach agreed

July 2009 – interim project report to be prepared

December 2009 – final project report to be prepared

Joint IAEA-EU-Ukraine project/ Design Safety (1/4)

Main milestones:

- Endorsement of the IAEA technical guidelines for design safety review adopted for the project – *completed;*
- Self-assessment – *completed;*
- Full Scope Design Safety Review missions to pilot units (Khmelnitsky-2, Rovno-1, SouthUkraine-1) – *completed;*
- Design Safety Review missions to all other units, due consideration being given to pilot units results, - *completed;*
- Preparation of an interim task report – *completed;*
- Preparation of a final task report – *end 2009.*

Joint IAEA-EU-Ukraine project/ Design Safety (2/4)

- **Unit information:**
  - Khmelnitsky 2 – VVER 1000/320 (commissioned - August 2004);
  - Modernization Program under implementation
- **Mission information:**
  - 13-24 October 2008
  - Review Team: Gary Johnson/Peter Kelm + 8 experts
- **Main findings:**
  - Full compliance with most NS-R-1 requirements;
  - Non full compliance but good progress in areas of:
    - Equipment qualification
    - Consideration of severe accidents
    - Control of containment hydrogen concentration
    - Waste storage
  - Non compliance as for seismic design margin

Joint IAEA-EU-Ukraine project/ Design Safety (3/4)

- **Unit information:**
  - Rovno 1 – VVER 440/213 (commissioned - December 1980);
  - Upgrade Package under implementation (near completion);
  - Preparation for lifetime extension
- **Mission information:**
  - 12-23 January 2009
  - Review Team: John Preston/Peter Kelm + 8 experts
- **Main findings:**
  - Full compliance with most NS-R-1 requirements;
  - Non full compliance but good progress in areas of:
    - Equipment qualification
    - Consideration of severe accidents
    - Seismic design margin
    - Demonstration of plant safety characteristics

Joint IAEA-EU-Ukraine project/ Design Safety (4/4)

- **Unit information:**
  - South Ukraine 1 – VVER 1000/302 (commissioned - December 1982);
  - Upgrade Package under implementation;
  - Preparation for lifetime extension
- **Mission information:**
  - 2-11 February 2009
  - Review Team: Gary Johnson/Ervin Liska + 8 experts
- **Main findings**:
  - Full compliance with most NS-R-1 requirements;
  - Non full compliance but good progress in areas of:
    - Equipment qualification
    - Consideration of severe accidents
    - Protection against internal events and common cause failures
    - Probabilistic risk assessment
    - Seismic design margin

Joint IAEA-EU-Ukraine project/ Operational Safety

- OSART missions, including follow ups:
  - on schedule
  - last mission planned for November 2009
- Conclusions as presented by IAEA Task Leader at April 2009 Steering Committee meeting:
  - There are no issues at any of the plants which have been determined to have “insufficient progress to date”
  - Results indicate good alignment of actions taken with other plants worldwide
  - High degree of cooperation between plant personnel and OSART/EM teams

Joint IAEA-EU-Ukraine project/ Waste and Decommissioning

- Specially designed review approach:
  - Considering separate NPPs but not separate units;
  - Self-assessment completed;
  - Missions to SUNPP, KhNPP, RNPP, ZhNPP completed.
- Conclusions as presented by IAEA Task Leader at April 2009 Steering Committee meeting:
  - The review team found that all requirements are complied with
  - It was noted that particular attention over the next years should be paid to:
    - Clearance criteria;
    - Waste acceptance criteria;
    - Refinement of end-point criteria for decommissioning;
    - Interdependencies between units in operation and under decommissioning

Joint IAEA-EU-Ukraine project/ IRRS Mission (1/2)

- Mission information:
  - 8-20 June 2008;
  - IRRS Review Team: 13 senior regulatory experts from 9 Member States, 1 representative from the EC Joint Research Centre, 1 observer from Japan, 5 IAEA staff members;
  - Scope: Full scope mission;
  - Policy issues: 1) application of risk informed decision making in the regulatory process; 2) the regulatory process for authorizing new build NPPs;
- Results:
  - 20 recommendations, 34 suggestions and underlined 14 good practices

Joint IAEA-EU-Ukraine project/ IRRS Mission (2/2)

- Key findings (examples):
  - SNRCU is effectively regulating nuclear safety and areas of radiation safety within its responsibility;
  - Comprehensive legal infrastructure that addresses international requirements and includes all the relevant international conventions is in force;
  - SNRCU is de facto an effectively independent regulatory body, however, to strengthen its de
  - jure independence its status should be established in law.

- Recommendations and Suggestions high priority for implementation (examples):
  - The Government of Ukraine should define and guarantee the statute of the SNRCU in law.
  - At the earliest opportunity the Government should approve the “National Programme on Radioactive Waste Management” and the funding mechanism necessary to guarantee its implementation.
  - The Government should consider enacting legislation that assigns responsibility to SNRCU for the authorization of the siting and design of new reactor units.