INTERNATIONAL SUMMER SCHOOL

# SELECTED ISSUES OF SAFETY ENGINEERING AND EXPLOITATION OF NUCLEAR POWER PLANTS IN THE CONTEXT OF EU ENERGY POLICY

PROCEEDINGS

*Trnava, September 1–12, 2011*

Oficyna Wydawnicza Politechniki Wrocławskiej
Wrocław 2011

**Address of the Organizers**

Faculty of Mechanical and Power Engineering,
Wrocław University of Technology,
Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland



OFICYNA WYDAWNICZA POLITECHNIKI WROCŁAWSKIEJ
Wybrzeże Wyspiańskiego 27, 50-370 Wrocław
http://www.oficyna.pwr.wroc.pl
e-mail: oficwyd@pwr.wroc.pl
zamawianie.ksiazek@pwr.wroc.pl

ISBN 978-83-7493-654-5

Drukarnia Oficyny Wydawniczej Politechniki Wrocławskiej. Zam. nr 1220/2011.

# CONTENTS

# SUMMARY OF THE MAIN GOALS OF THE INTERNATIONAL SUMMER SCHOOL ’11

The first eddition of the intensive program entitled “*Selected issues of safety engineering and exploitation of nuclear power plants in the context of EU energy policy*” took place in Trnava (Slovakia) between 1st–12th of September 2011. The main aims of the intensive program (called International Summer School) were: an integration of European academic centers in order to discuss current problems of nuclear power engineering sector, exchanging experiences from fields of new power engineering technologies and safety engineering issues connected with exploitation of modern nuclear power plants as well as enhancing qualifications of graduates. The timetable of the project consisted of ten-day cycle of teaching activities including lectures, laboratories, projects for a group of 30 students from the partner universities. During the School organizers also have arranged two workshops which took places in Jaslovskie-Bohunice and Mochovce nuclear power plants.

Additional goal of the project has focused on an invitation to cooperation representatives of enterprises from a nuclear power engineering sector like AREVA, EDF or WANO Paris Centre. Invited lectures were devoted to exchange of personal experiences of speakers from a field of design and exploitation of nuclear reactors.

The leading subject matter of the project was devoted to exploitation of modern nuclear power plants with a particular emphasis on the problem of safety engineering and procedures because development of these sources of energy is strongly connected with necessity of reduction of $CO_2$ emission – one of current priorities of the EU Energy Policy.

**Partner institutions**

– Faculty of Mechanical and Power Engineering, Wrocław University of Technology, Poland;
– Department of Power Engineering, Faculty of Mechanical Engineering, VŠB-Technical University Ostrava, Czech Republic;
– Institute of Safety and Environmental Engineering, Faculty of Materials Science and Technology in Trnava, Slovak University of Technology Bratislava, Slovak Republic.

# PODSUMOWANIE GŁÓWNYCH PRIORYTETÓW MIĘDZYNARODOWEJ SZKOŁY LETNIEJ ’11

Realizując założenia podpisanej przez Politechnikę Wrocławską Karty Erasmusa, Wydział Mechaniczno-Energetyczny podjął się koordynacji i współrealizowania pierwszej edycji kursu intensywnego – Międzynarodowej Szkoły Letniej – współfinansowego w ramach programu LLP/Erasmus.

Program kursu intensywnego pt.: *Selected issues of safety engineering and exploitation of nuclear power plants in the context of EU energy policy* został opracowany we współpracy Politechniki Wrocławskiej z Politechnikami w Ostrawie (Czechy) i Bratysławie – Wydział Materiałoznawstwa i Technologii Materiałowych z siedzibą w Trnavie (Słowacja). Nadrzędnym celem kursu była integracja europejskich środowisk akademickich prowadząca do wymiany doświadczeń z zakresu nowych technologii i procedur bezpieczeństwa stosowanych w nowoczesnych elektrowniach jądrowych jak również podnoszenie kwalifikacji zawodowych absolwentów uczelni technicznych. Plan kursu obejmował 10-dniowy cykl zajęć dydaktycznych prowadzonych dla międzynarodowej grupy studentów z uczelni partnerskich obejmujący: wykłady, projekty w pięcioosobowych grupach, zajęcia laboratoryjne bazujące na symulatorach różnego typu reaktorów jądrowych, warsztaty praktyczne w elektrowniach jądrowych: Jaslovskie Bohunice i Mochovce (Słowacja). Dodatkowym atutem kursu były wykłady przedstawicieli branży energetyki jądrowej: EDF Polska, AREVA oraz WANO Paris Centre. Urozmaicony program kursu intensywnego pozwalał jego uczestnikom nie tylko pozyskać wiedzę teoretyczną z zakresu projektowania i eksploatacji reaktorów jądrowych, ale również umożliwił konfrontację tej wiedzy z praktycznymi doświadczeniami związanymi ze stosowaniem procedur bezpieczeństwa składowania, użytkowania i utylizacji paliwa jądrowego oraz odpadów radioaktywnych.

Wiodącą tematykę kursu stanowiły zagadnienia inżynierii bezpieczeństwa w projektowaniu i użytkowaniu nowoczesnych reaktorów i elektrowni jądrowych, których rozwój i rozbudowa wynikają z poszukiwania alternatywnych źródeł energii w celu redukcji emisji $CO_2$ produkowanego przez elektrownie bazujące na konwencjonalnych paliwach kopalnych co stanowi jeden z podstawowych priorytetów polityki energetycznej Unii Europejskiej do roku 2020 (Dyrektywa Unii Europejskiej o redukcji o 20% emisji $CO_2$ oraz dokument Rady Europejskiej dot. polityki energetycznej z marca 2007).

**Lecture no. 1**

# FUNDAMENTALS OF NUCLEAR ENERGY

**Pavel Kolat**

VŠB-Technical University Ostrava, Faculty of Mechanical Engineering,
Department of Power Engineering, Czech Republic, e-mail: Pavel.Kolat@vsb.cz

## Abstract

The primary emphasis of this lecture is to provide the basic knowledge associated with nuclear processes for energy generation. Fundamentals of radiation and nuclear power will be taught. These include: nuclear models, nuclear reactions and building a theoretical understanding of issues related to nuclear energy. Emphasis will be placed on learning the specialized language used by nuclear engineers and health physicists and basic mathematical relationships used to quantify radioactivity. Students will be taught how radiation affects human health and discuss ongoing epidemiology studies. Other applications of radioactivity that affects the economy and standard of living will be discussed. Listeners get tools to make informed decisions regarding legislation, public policy, risks and benefits of nuclear technology. This knowledge is utilized not only in nuclear industries, nuclear power stations but also related branches like nuclear materials' handling for health care, and/or medical research.

**Time of presentation:** 2 hours

**Lecture no. 2**

# NUCLEAR POWER PLANTS

**Pavel Kolat**

VŠB-Technical University Ostrava, Faculty of Mechanical Engineering,
Department of Power Engineering, Czech Republic, e-mail: Pavel.Kolat@vsb.cz

## Abstract

A nuclear power is a necessity to meet the global need for power. The U.S. and EU has fallen behind in state of the art power generation, distribution and reliability. The lecture is

designed to familiarize the listener with nuclear power plants. Power generation begins with either a fission or fusion reaction. The thermal energy from the nuclear reaction is used to generate electricity. The thermal energy that captured the electricity is generated identically to more traditional forms of power plants: coal, natural gas, wood. The lecture focuses on systems and procedures unique to nuclear power plants, types of nuclear power plants including the gen. IV reactors, fuel loading, coolant, loss of coolant, severe accidents, reprocessing and spent fuel.

The main items of the lecture focuses on:

- Physical principles of nuclear energy, radioactive decay, neutron nuclear reactions, the balance of neutrons in a nuclear reactor.
- Fundamentals of dosimetry. Calculation of nuclear reactor physics, neutron diffusion, the critical equation of a nuclear reactor neutron flux. The kinetics of nuclear fission.
- Operating and transient regimes. Development and dissipation of heat in a nuclear reactor, the distribution of heat flow, temperature field inside fuel elements.
- Operation and management of a nuclear reactor, the reactivity compensation, poisoning of the reactor, reactor dynamics in the supercritical state, compensation devices and power control. Compensation in the primary circuit coolant. Pressurizers.
- Mathematical model, transition and operational processes. Thermal and hydraulic calculation KO VVER 440 and 1000.
- Basic types of nuclear power reactors, light water, heavy water, high, fast, and gas-cooled. Component of a nuclear reactor. Equipment for fueling. Nuclear power plants. Thermal diagrams of nuclear power, thermal efficiency and ways of its improvement. Material of reactors.
- Physico-technical aspects of nuclear reactor safety, nuclear safety. Reactors with higher inherent and passive safety III. + generation. Promising types of nuclear power plants IV generation. Thermonuclear reactors and power plants.

**Time of presentation:** 2 hours

**Lecture no. 3**

# FUEL AND FUEL CELL PRODUCTION

**Paweł Regucki**

Wrocław University of Techology, Faculty of Mechanical and Power Engineering,
Poland, e-mail: Pawel.Regucki@pwr.wroc.pl

## Abstract

The lecture focuses on different aspects of production, utilization and recycling of nuclear fuel. Economical and physical reasons are considerated showing that the uranium is the best material for production of fuel pellets.

During the lecture there are discussed:

– Chemical and physical processes utilized to separate the pure uranium from uranium ore;
– Adventages and disadvantages of utilization of natural and enriched uranium in nuclear reactors;
– Different types of equipment used to enriched uraminum;
– Arrangement of fuel modules, rods and pellets in different types of reactors;
– Recycling of spent fuel and MOX fuel.

**Time of presentation:** 2 hours

**Lecture no. 4**

# STORAGE AND DISPOSAL OF NUCLEAR WASTE

**Andrzej Tatrek**

Wrocław University of Techology, Faculty of Mechanical and Power Engineering,
Institute of Thermal Engineering and Fluid Mechanics, Poland,
e-mail: Andrzej.Tatarek@pwr.wroc.pl

## Abstract

The lecture focuses on low and intermediate level radioactive waste which are produced during nuclear fuel cycle, technical, scientific as well as medical applications. The presentation touches problem of waste classification by radioactivity, its transportation and utilization. During the lecture will be also discussed selected aspects of safety procedures of medium and low radioactive waste storage.

**Time of presentation:** 2 hours

**Lecture no. 5**

# ADVANCED NUCLEAR REACTORS OF III & IV GENERATION

**Pavel Kolat**

VŠB-Technical University Ostrava, Faculty of Mechanical Engineering,
Department of Power Engineering, Czech Republic, e-mail: Pavel.Kolat@vsb.cz

## Abstract

The lecture deals with the analysis of possibilities for use of III and IV generation of nuclear reactors for the Czech Republic, Slovakia and Poland. Introduction deals with basic principles of nuclear energetics and fuel cycle which is closely associated with the issue and its development and application in practice will have a significant effect both for choice of future

types of nuclear reactors of IV generation and the matter of settlement with spent nuclear fuel. In other parts the lecture deals with the present state of nuclear energetics compares concrete chosen types of nuclear power plants of III generation and generally describes nuclear reactors and power plants of IV generation. Final part of the work is focused on questions concerning the possibility of construction of new blocks of nuclear power plants in the Czech Republic, Poland and Slovakia and presents concrete recommendation from author's point of view.
Nuclear reactors are often classified in terms of their reactor generation, or stage of reactor technology development:

– Generation I: these reactors were prototypes and first commercial plants developed in the 1950s and 60s of which very few still operate;
– Generation II: these are commercial reactors built around the world in the 1970s;
– Generation III/III+: Gen III reactors were developed in the 1990s and feature advances in safety and cost compared to Gen II reactors. Gen III+ reactors are the most recently developed reactor designs and have additional evolutionary design improvements. Only a few Gen III/III+ reactors have been built, but currently planned reactors in the United States are of this type;
– Generation IV: refers to the advanced reactor designs anticipated for commercial deployment by 2030 and expected to have revolutionary improvements in safety, cost, and proliferation resistance as well as the ability to support a nuclear fuel cycle that produces less waste.

**Time of presentation:** 2 hours

## Lecture no. 6

# SAFETY ASPECT OF PRODUCTS USED IN NUCLEAR POWER PLANTS

**Karol Balog**

Slovak University of Technology Bratislava, Faculty of Materials Science
and Technology in Trnava, Institute of Safety and Environmental Engineering,
Slovak Republic, e-mail: Karol.Balog@stuba.sk

## Abstract

The lecture presents requirements concerning quality of materials and products used to construct and utilization of nuclear power plants and reactors, its utilization, storage and future

potential recycling. Physical and chemical properties of materials are especially important in the context of possible failures or breakdown of different parts of power unit including fire, leakage of steam or contaminated water. Safety procedures are discussed including special fire brigade units which are trained to work in such special conditions like area of nuclear power plants.

**Time of presentation:** 2 hours

## Lecture no. 7

# HAZARD AND RISK ASSESSMENT IN NUCLEAR POWER PLANT – SAFETY PROCEDURES

**Karol Balog**

Slovak University of Technology Bratislava, Faculty of Materials Science and Technology in Trnava, Institute of Safety and Environmental Engineering, Slovak Republic, e-mail: Karol.Balog@stuba.sk

## Abstract

The lecture presents changes in safety procedures in nuclear power plants during last tens years. The special emphasis is putted on changes in legal control in nuclear power plants and hazard and risk assessment after large catastrophes like Three Miles Island or Czarnobyl. The lecture provides also the modern engineering tools used to assess the potencial risk and safety standards introduced to nuclear power plants in order to minimize the possibility of failure or breakdown.

**Time of presentation:** 2 hours

**Lecture no. 8**

# ENGINEERING TOOLS
# USED TO RISK ASSESSMENT IN NPP

**Karol Balog, Ivan Hrušovský**

Slovak University of Technology Bratislava, Faculty of Materials Science
and Technology in Trnava, Institute of Safety and Environmental Engineering,
Slovak Republic, e-mail: Karol.Balog@stuba.sk, Ivan.Hrusovsky@stuba.sk

## Abstract

Risk assessment is an important part of risk magement. Through the history of it's development people used different tools for making the assessment easier. However, there is no universal solution for risk assessment, because of the different varieties of industrial operations and processes. Tools can only help us to orient in the process of risk assessment. Many tools have been developed, but only few are appropriate for complex systems like those used in NPP.

**Time of presentation:** 2 hours

**Lecture no. 9**

# NUCLEAR POWER PLANT
# SIMULATION MODEL VVER 1000

**Zbyszek Szeliga**

VŠB-Technical University Ostrava, Faculty of Mechanical Engineering,
Department of Power Engineering, Czech Republic, e-mail: Zbyszek.Szeliga@vsb.cz

## Abstract

The lecture deals with construction and principles of operations VVER 1000 nuclear reactor presentating of basic features of VVER1000 simulator. The first part of presentation is

devoted attention to the basic description of the major process equipment operating VVER nuclear power plants including basic description of the technological equipments that are important in the service of the VVER NPP. The second part of the lecture is focused on the analysis of transients, a transient step change of basic operating parameters of system components of VVER nuclear power plants, possible failure of basic technological components.

**Time of presentation:** 2 hours

**Lecture no. 10**

# SELECTED ISSUES CONCERNING SAFETY DESIGN AND OPERATION OF NUCLEAR REACTORS

**Wojciech Zacharczuk**

Wrocław University of Techology, Faculty of Mechanical and Power Engineering,
Institute of Thermal Engineering and Fluid Mechanics, Poland,
e-mail: Wojciech.Zacharczuk@pwr.wroc.pl

## Abstract

Selected issues concerning safety design and operation of nuclear reactors are presented on an example of CANDU reactor. The CANDU is a Canadian-invented, pressurized heavy water reactor. It was first developed and designed in the late 1950s by a consortium of Canadian government and private industry including Atomic Energy of Canada Limited (AECL). The lecture provides a general information about CANDU reactor. It discusses the reactor design and operation principles. Answers a question why a CANDU, in contrary to the Light Waster Reactros, can be fuelled by natural uranium. Explains reasons, a CANDU reactor core comprises a small diameter fuel channels instead of one large pressure vessel. It also reviews the most important reactor systems including moderator and heat transport systems. The second part of the presentation focuses on the unit power control. It reviews two modes of CANDU plants operation, i.e. normal and alternate mode. Topics to be covered also include reactivity control systems – reactor regulating and protecting systems.

The last part of the lecture discuss the major features of the ACR (Advanced Candu Reactor), that is considered to be a III generation reactor.

**Time of presentation:** 2 hours

# FUNDAMENTALS OF NUCLEAR ENERGY

**Pavel Kolat**

VŠB-Technical University Ostrava, Faculty of Mechanical Engineering,
Department of Power Engineering, Czech Republic

**Key words:** *radioactivity, uranium, plutonium, nuclear energy*

**Fundamental concepts.** Atomic and nuclear phenomena, kinematics, crosssections, and energy. Essential topics in atomic and nuclear theory, radioactive decay, interaction of radiation with matter, neutron physics, neutron transport, nuclear reaction.

**Foundations of nuclear science.** Nuclear models and properties, nuclear energy, radioactivity, radiation, detection and measurement, nuclear structure, elementary quantum theory, nuclear forces, shell structure of the nucleus, alpha, beta, and gamma radioactive decays, interactions of nuclear radiations (charged particles, gammas, and neutrons) with matter, nuclear reactions, fission and fusion, nuclear energy, and principles of nuclear power.

**Introduction to nuclear fission energy technologies.** Principles of fission reactors, the fission process, the controlled chain reaction and the critical arrangement, principles of a nuclear reactor, cross-sections, neutron flux and reaction rates, neutron spectrum, diffusion of neutrons, slowing down of neutrons, and reactor equations and critical reactors, neutron balance and heat production in the core, some aspects of reactor physics, burn-up of fissile materials and build-up of higher isotopes, reactivity coefficients, etc.

**Nuclear fuel and fuel cycle.** Nuclear fuel cycle, fissile and fertile materiále procurement regulation, uranium and thorium, plutonium, uranium enrichment, enrichment technologies, gaseous diffusion, ultra centrifugation, and laser isotopic separation.

**Nuclear power plants.** Overview of reactor types, plant overview, components of the core, components of the primary system, reactor containment, reactor safety systems, auxiliary systems, steam turbine plants, thermo-hydraulic aspects of the core and of the fuel elements, loss of coolant, break of steam generator pipes, core melt incidents in light water reactors, consequences of core melt accidents, and new topics in nuclear reactor design, III and III+ generation of Nuclear reactors, IV generation and their requirements.

**Controlled nuclear fusion: general aspects.** Magnetic confinement fusion, stellarator, tokamak, laser and heavy ion inertial confinement fusion, and radioisotope thermoelectric power generation.

**Nuclear chemistry.** An overview of chemical and radiochemical dynamics. Principles of chemical and physical separation processes. Technologies for the production of nuclear fuel, moderator, and structural materials. Management of radioactive wastes and spent fuel, including chemical processing and disposal. Safety and nuclear safeguards. Chemistry of fission products and actinides.

**Radiation protection.** Internal and external radiation dosimetry and protection including radiation quantities and units, legal guidelines and regulations, derivations of external dosimetry calculations, source and facility shielding, pathways and bioassays, and contamination control.

**Health physics.** Definition of dosimetry and introduces the student to the complexities of determining radiation dose to a human from measured quantities. The measured quantities are found using a variety of dosimeters, biomarkers, and detectors. The students will be taught the basics of some of the detectors and dosimeters.

**Outcomes.** The following competencies should be imparted to the students:
1. Gain understanding of fundamentals of nucrear processes.
2. Gain comprehensive knowledge nuclear energy conversion.
3. Learn nuclear matrial handeling, environmental effect, and safety.
4. Learn methods of radiation detection, measurement , and singal processing.
5. Study the new approaches in unclear energy development.

## Literature


1. J. Bečvář et al., *Jaderné elektrárny*, SNTL/ALFA Praha, 1988, 634.
2. F. Dubšek, *Jaderná energetika*, VUT Brno, 1994, ISBN 80-214-0833-2, 216.
3. J. Ambrož, *Jaderné elektrárny*, ČVUT Praha, 1985, 252.
4. F. Klik, *Jaderná energetika*, ČVUT Praha, 1995, ISBN 80-01-01280-8, 189.
5. R. Hejzlar, *Stroje a zařízení jaderných elektráren*, ČVUT Praha, 1994, ISBN 80-01-00164-4, 166.
6. http://www.fs.vsb.cz/KE

7. *Nuclear Energy*, published June 1999, ISBN 0-85403-526-5, 1999, The Royal Society, 1999, The Royal Academy of Engineering, Printed by Holbrooks Printers Ltd., Norway Road Hilsea Portsmouth Hants PO3.
8. R. Murray, *Nuclear Energy, Fifth Edition: An Introduction to the Concepts, Systems, and Applications of Nuclear Processes*, Amazon.com
9. E.P. Wigner, *Nuclear Energy*, Alvin M. Weinberg (Ed.), Amazon.com
10. I. Hore-Lacy, *Nuclear Energy in the 21st Century: World Nuclear*, University Press.
11. A.M. Herbst, G.W. Hopley, *Nuclear Energy Now*, Amazon.com

# NUCLEAR POWER PLANTS

**Pavel Kolat**

VŠB-Technical University Ostrava, Faculty of Mechanical Engineering,
Department of Power Engineering, Czech Republic

**Key words:** *radioactivity, uranium, plutonium, nuclear energy*

**Classification of the nuclear power plants.** Types, operative experience and power facilities in the World. Light water power plants. Heavy water power plants. Graphite-gas power plants. Advanced design power plants. Other power stations.

**Power plants design criteria.** Risk concept. Probabilistic Risk Assessment (ARS). Design Basic Accidents (ABS). Main system reliability and availability. Security Criteria in the site, project and operation of the nuclear power plants. Norms and Codes. Security studies. Defense-in-Depth. Criteria on redundancy and physical separation. The passive security.

**Nuclear Reactors.** Thermal power generation in the reactor. Nuclear and Residual power. Core power distribution. Stability. Reactors transfer heat rate. Residual power of radioactive products.

**Reactors Technology.** Reactors materials and internal components. Nuclear steam supply system. Nuclear and Thermal limits. Radiation effects in the nuclear components.

**Energy conversion systems.** Thermodynamic cycles. Main components of the conversion system: Steam turbines and condensers. Feed water system. Cooling systems in opened, closed or mixed cycle.

**Operation principles and the reactors and power plant control system.** Operation states. Reactivity control systems. Reactors nuclear instrumentation. Protection systems. Data processing.

**Thermal hydraulic analysis in nuclear systems.** Core heat transport. Coolant transient. Loss of Coolant Accident. TMI2, Fucushima accident.

**Electric production system.** Nuclear power station. Electrical system. One-line diagram. Emergency electrical system. Electrical consumptions balance of a power plant in operation and standby.

**Auxiliary systems and security systems.** Main Auxiliary systems: Service Water System. Intermediate Cooling System. Residual Heat Removal System. Main Security systems: Emergency Core Cooling System. Emergency Feed Water System. Residual Heat Removal System. The Containment and the Engineering Saveguards.

**Buildings location in the plant.** Areas classification. Construction norms. Reactor building: containment and penetrations. Fuelbuilding, auxiliary building, electrical building, turbines building, control building. Other buildings and structures.

**Plants operation management.** Radiological safety management. Maintenance. External Inspection. Quality assurance. Fuel cycle associated to the power plant. Fuel and reload necessities. Operating procedures. The energy costs.

**Disscusions**

– Licensing requirements in Spanish nuclear power plants;
– Environmental impact;
– Reactors reactivity balances;
– Fuelling and Operating strategy;
– Water Chemistry in Nuclear Power Plants;
– Plants maintenance and work conditions;
– Nuclear fuel irradiation study;
– Operation radioactive waste production. Low and medium level waste;
– Design modifications of nuclear power plants in operation;
– Nuclear power plant ageing management program;
– Nuclear power plants decommissioning.

## Literature

1. http://www.fs.vsb.cz/KE
2. *Nuclear Energy*, published June 1999, ISBN 0-85403-526-5, 1999, The Royal Society, 1999, The Royal Academy of Engineering, Printed by Holbrooks Printers Ltd., Norway Road Hilsea Portsmouth Hants PO3.
3. R. Murray, *Nuclear Energy, Fifth Edition: An Introduction to the Concepts, Systems, and Applications of Nuclear Processes*, Amazon.com
4. E.P. Wigner, *Nuclear Energy*, Alvin M. Weinberg (Ed.), Amazon.com
5. I. Hore-Lacy, *Nuclear Energy in the 21st Century: World Nuclear*, University Press.
6. M. Herbst, G.W. Hopley, *Nuclear Energy Now*, Amazon.com

# FUEL AND FUEL CELL PRODUCTION

**Paweł Regucki**

Wrocław University of Techology, Faculty of Mechanical and Power Engineering,
Poland, e-mail: Pawel.Regucki@pwr.wroc.pl

**Key words:** *uranium, isotopes, fuel cycle, nuclear fuel pellets*

Total amount of uranium in the natural environment is order of $10^{14}$ tons (in oceans and seas approx. $4 \cdot 10^9$ tons). Due to the fact of low concentration of uranium in rocks only $10^8$ tons are useful for technological processes (it means that the world sources of uranium would be utilized by approx. 100 years). From energetical point of view 1 kg of natural uranium is equivalent to 20 000 kg of hard coal.

Natural uranium cosists of four isotopes but only one 235-U is utilized as a fuel of nuclear reactors. Below there are listed isotopes together with information about its concentration in natural environment and half life:

- 238-U – 99,27%; T 1/2 – $4,468 \cdot 10^9$ years
- **235-U – 0,72%; T 1/2 – $7,838 \cdot 10^8$ years**
- 234-U – 0,0054%; T 1/2– $2,446 \cdot 10^5$ years
- 233-U – produced in nuclear reactors

From the economical point of view the profitable concentration is above 0,03% of pure uranium in the ore (>0,3 kg U/t) but nowadays utilized ores have average value at the level of 0,05% (for 0,05% concentration $\rightarrow$ 5 t Uranium from $10^4$ t of ore).

Fuel cycle usually cosists of six stages:

1. Uranium ore mining;
2. Concentrated uranium production $UO_2$;
3. Fuel element production;
4. Utilization of fuel pellets in nuclear reactor;
5. Utilization of spent fuel (recycling is optional solution MOX fuel production);
6. Radioactive waste dump.

Production of nuclear fuel from first to fourth stage takes approximately 5 years and requires advanced technology. In order to reduce economical costs and shorten the time of production most of reactors work on the natural fuel with 0.7% uranium concentration. The enrichment process extend the time of utilization of the nuclear fuel but also is time and power consuming. Nowadays the technological and economical analysis indicates that the cost optimum is reached for enriched uranium at the level of 2–4%. Due to the fact that isotopes have the same chemical properties the enrichment process can be realized only by mechanical of physical processes. Physical processes utilized e.g. difussion through porous media (difusion chambres), electromagnetic forces; mechanical processes mainly based on centrifugal forces (centrifuge).

Difussion process deals with $UF_6$ gass and bases on the different masses of uranium isotopes ($^{235}UF_6$ moves 1,0043 times faster then $^{238}UF_6$). Besides its simplicity diffusion process is high energy consuming (thousands of diffusion chambers – cascads) requires special porous material and high pressures in order to force the process. It is worth to notice that cascade demand increases drastically if we would like to produce more enriched fuel.

In mechanical processes the centrifugal forces are utilized and its efficiency depends on the mass difference of uranium isotopes. Coefficient of separation in singular centrifuge depends of its rotational speed and is usually at the level of $a$ = 1,02. It means that in the enrichment process must be involved thousand of centrifuges with high rotational speed (more then thousands of rpm).

The spent fuel could be recycle in order to obtain new type of nuclear fuel – MOX fuel – mixture of 239-Pu + 238-U.

In the technological process of nuclear fuel production a special emphasis is put on a quality of material used to prepare fuel rod wall (zircaloy):

- thickness of the rod wall – approx. 0.5–1.0 mm
- very high coefficient of heat transfer (temperature gradient approx. 1500 C),
- very high durability (high thermal tensions),
- very high pressure inside rod (up to 20 MPa).

Also arrangement of fuel rods in the core of reactor must be secected in order to optimize an access of coolant (heat transfer) and access of moderator (reactivity) to the fuel rods.

In the process of fission for enriched fuel (3.2% 235-U) for PWR reactor usually approx. 70–90% 235-U is “burnout” and 239Pu + 241Pu are produced. For example 1000 MWe PWR reactor produces annually approx. 25 t of spent fuel including 290 kg of Pu.

## Literature

1. Z. Celiński, *Energetyka jądrowa*, PWN, Warszawa 1991,
2. J. Kubowski, *Nowoczesne elektrownie jądrowe*, WNT, Warszawa 2010.

# STORAGE AND DISPOSAL OF NUCLEAR WASTE

**Andrzej Tatarek**

Wrocław University of Techology, Faculty of Mechanical and Power Engineering,
Institute of Thermal Engineering and Fluid Mechanics, Poland,
e-mail: Andrzej.Tatarek@pwr.wroc.pl

**Key words:** *radioactivity, radioactive waste, waste classification*

## 1. Introduction [1]

### 1.1. Generation of Radioactive Waste

- Nuclear Fuel Cycle:
  - Uranium Mining,
  - Ore Processing and Uranium Enrichment,
  - Fuel Fabrication,
  - Operation of Nuclear Reactors,
  - Reprocessing of Spent Nuclear Fuel,
  - Decommissioning of Nuclear Facilities,
  - Nuclear Research and Development;
- Technical and Scientific Application;
- Medical Application.

### 1.2. Waste Classification by Radioactivity

a)
- High level radioactive waste,
- Intermediate level radioactive waste,
- Low level radioactive waste;

b)
- Short lived waste,
- Long lived waste;

c)
- Heat generating waste,
- Waste with negligible heat generation;

d)
- Natural occurring radioactive material.

## 2. Low and intermediate level radioactive waste [2]

### 2.1. Operational Classification of Radioactive Waste in France

<table>
<tr><td>Half-life<br>Activity</td><td>Very short half-life<br>(<100 days)</td><td>Short lived<br>(≤31 years)</td><td>Long lived<br>(>31 years)</td></tr>
<tr><td>Very Low Level<br>(VLL)</td><td rowspan="4">Decay storage followed by controlled release</td><td colspan="2">Surface disposal (CSTFA)</td></tr>
<tr><td>Low Level (LL)</td><td rowspan="2">Surface disposal<br>(CSFMA)</td><td>Dedicated near surface facility under siting</td></tr>
<tr><td>Intermediate Level<br>(IL)</td><td>Under investigation<br>(Underground Research Laboratory<br>in geological clay formation)</td></tr>
<tr><td>High Level (HL)</td><td colspan="2"></td></tr>
</table>

### 2.2. Disposal of LILW in France

Two repositories dedicated to LILW disposal
- CENTRE de la MANCHE:
  - Status: closed and monitored,
  - Operated from 1969 to 1994,
  - 527,000 $m^3$ of waste disposed;
- CENTRE de l'AUBE:
  - In operation since 1992. Total licensed capacity: 1,000,000 $m^3$,
  - Volume of waste delivered: 220,000 $m^3$ (end of 2008),
  - Current annual delivery: 12,000 $m^3$,
  - Expected operational lifetime: 50–60 years.

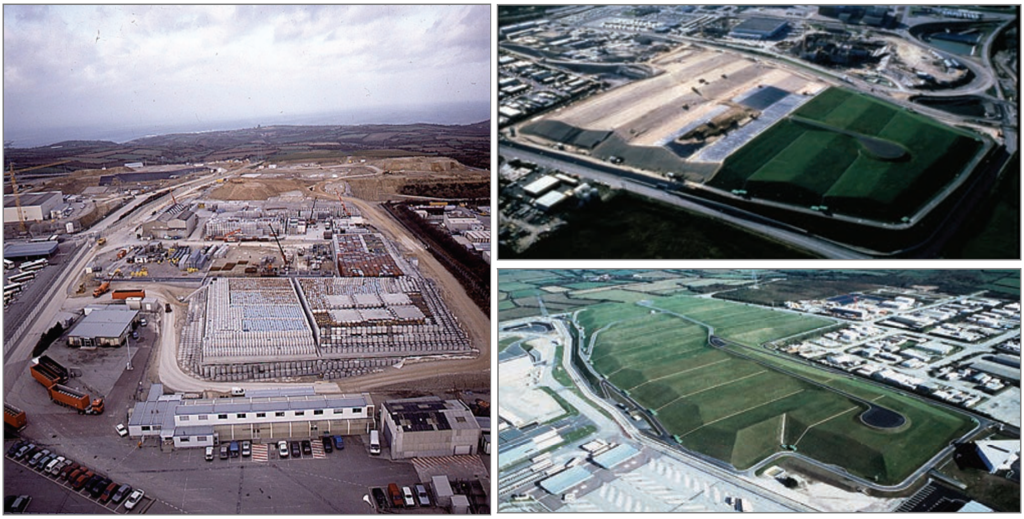


Fig. 1. CENTRE de la MANCHE LILW repository Construction of capping system [2]

## 3. Transport and storage of irradiated fuel [3, 4]

### 3.1.Transport and Storage Casks for HLW in Germany

- Dual-purpose operation for transport and storage;
- Monolithic cask body made of ductile cast iron, cast in one piece;
- Different cask types available, i. e. for PWR, BWR, HTR, MTR fuel;
- Dimensions:
  - Length: 4.0–6.0 m,
  - Diameter: 1.5–2.5 m,
  - Wall thickness: 0.25–0.45 m;
- Cylindrical holes filled with polyethylene as moderator in cask side wall;
- Double lid with monitored leak-tightness control (by means of a pressure gauge).

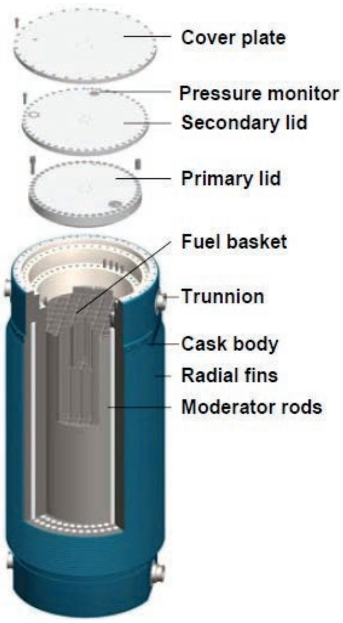



Fig. 2. Design features of CASTOR® casks [3]

## 3.2. Transport casks for transportation of SF in Slovakia

Fig. 3. Transport of casks TK C-30 [4]

# Literature

1. W. Brewitz, *Classifications of radioactive waste*, ISaR Training Courses 2010/11, T. 5: Nuclear Fuel Cycle (3–5 Nov. 2010).
2. L. Schacherer, *Overview of ANDRA's Disposal Facilities for LIL & VLL Waste*, ANDRA, Centres de l'Aube, 23 November 2009.
3. H. Geiser, *Transport and storage of irradiated fuel*, ISaR Training Courses 2010/11, T. 5: Nuclear Fuel Cycle (3–5 Nov. 2010).
4. Jadrova a vyraďovacia spoločnosť, a.s., homepage www.javys.sk

# ADVANCED NUCLEAR REACTORS OF III & IV GENERATION

**Pavel Kolat**

VŠB-Technical University Ostrava, Faculty of Mechanical Engineering,
Department of Power Engineering, Czech Republic

**Key words:** *reactor, III generation reactor, IV generation reactor*

Several generations of reactors are commonly distinguished. Generation I. reactors were developed in 1950–1960s, and outside the UK none are still running today. Generation II. reactors are typified by the present US and French fleets and most in operation elsewhere. Generation III (and 3+) are the Advanced Reactors discussed in this paper. The first are in operation in Japan and others are under construction or ready to be ordered. Generation IV. designs are still on the drawing board and will not be operational before 2020 at the earliest.

Third-generation reactors have:

- a standardised design for each type to expedite licensing, reduce capital cost and reduce construction time;
- a simpler and more rugged design, making them easier to operate and less vulnerable to operational upsets;
- higher availability and longer operating life – typically 60 years;
- further reduced possibility of core melt accidents;
- resistance to serious damage that would allow radiological release from an aircraft impact;
- higher burn-up to reduce fuel use and the amount of waste;
- burnable absorbers (“poisons”) to extend fuel life.

However, certification of designs is on a national basis, and is safety-based. In Europe there are moves towards harmonised requirements for licensing. In Europe, reactors may also be certified according to compliance with European Utilities Requirements (EUR) of 12 generating companies, which have stringent safety criteria. The EUR are basically a utilities’ wish list of some 5000 items needed for new nuclear plants. Plants certified as complying with EUR include Westinghouse AP1000, Gidropress’ AES-92, Areva’s EPR, GE’s ABWR, Areva’s Kerena, and Westinghouse BWR 90.

European regulators are increasingly requiring large new reactors to have some kind of core catcher or similar device, so that in a full core-melt accident there is enhanced provision for cooling the bottom of the reactor pressure vessel or simply catching any material that might melt through it. The EPR and VVER-1200 have core-catchers under the pressure vessel, the AP1000 and APWR have provision for enhanced water cooling.

In the USA a number of reactor types have received Design Certification (see below) and others are in process: ESBWR from GE-Hitachi, US EPR from Areva and US-APWR from Mitsubishi. The ESBWR is on track to receive certification about September 2011, and the US EPR in mid 2012. Early in 2008 the NRC said that beyond these three, six pre-application reviews could possibly get underway by about 2010. These included: ACR from Atomic Energy of Canada Ltd (AECL), IRIS from Westinghouse, PBMR from Eskom and 4S from Toshiba as well as General Atomics' GT-MHR apparently. However, for various reasons these seem to be inactive.

Generation IV International Forum (GIF) is a US-led grouping set up in 2001 which has identified six reactor concepts for further investigation with a view to commercial deployment by 2030. At the commercial level, by the end of 2006 three major Western-Japanese alliances had formed to dominate much of the world reactor supply market:

- **Areva** with **Mitsubishi Heavy Industries** (MHI) in a major project and subsequently in fuel fabrication,
- **General Electric** with **Hitachi** as a close relationship: **GE Hitachi Nuclear Energy** (GEH)*,
- **Westinghouse** had become a 77% owned subsidiary of **Toshiba** (with **Shaw** group 20%).

## Literature

1. J. Bečvář et al.: *Jaderné elektrárny*, SNTL/ALFA Praha, 1988, 634.
2. F. Dubšek, *Jaderná energetika*, VUT Brno, 1994, ISBN 80-214-0833-2, 216.
3. J. Ambrož, *Jaderné elektrárny*, ČVUT Praha, 1985, 252.
4. F. Klik, *Jaderná energetika*, ČVUT Praha, 1995, ISBN 80-01-01280-8, 189.
5. R. Hejzlar, *Stroje a zařízení jaderných elektráren*, ČVUT Praha, 1994, ISBN 80-01-00164-4, 166.
6. http://www.fs.vsb.cz/KE
7. *Nuclear Energy*, published June 1999, ISBN 0-85403-526-5, 1999, The Royal Society, 1999 The Royal Academy of Engineering, Printed by Holbrooks Printers Ltd., Norway Road Hilsea Portsmouth Hants PO3.

8. R. Murray, *Nuclear Energy, Fifth Edition: An Introduction to the Concepts, Systems, and Applications of Nuclear Processes*, Amazon.com
9. E.P. Wigner,: *Nuclear Energy*, Alvin M. Weinberg (Ed.), Amazon.com
10. Hore-Lacy, *Nuclear Energy in the 21st Century: World Nuclear*, University Press.
11. M. Herbst, G.W. Hopley, *Nuclear Energy Now*, Amazon.com

# ENGINEERING TOOLS USED TO RISK ASSESSMENT IN NUCLEAR POWER PLANTS

**Karol Balog, Ivan Hrušovský**

Slovak University of Technology Bratislava, Faculty of Materials Science and Technology in Trnava, Institute of Safety and Environmental Engineering, Slovak Republic

**Key words:** *risk assessment*, *hazard*, *risk*,

Risk assessment is an important part of risk magement. Through the history of it's development people used different tools for making the assessment easier. However, there is no universal solution for risk assessment, because of the different varieties of industrial operations and processes. The tools can only help us to orient in the process of risk assessment. Many tools have been developed, but only few are appropriate for complex systems like those used in NPP.

## HAZOP

A Hazard and Operability (HAZOP) study is a structured and systematic examination of a planned or existing process or operation in order to identify and evaluate potential hazards and operability problems. Or to ensure the ability of equipments in accordance with the design intent. HAZOP is based on a theory that assumes risk events are caused by deviations from design or operating intentions. Identification of such deviations is facilitated by using sets of "guide words" as a systematic list of deviation perspectives. This approach is a unique feature of the HAZOP methodology that helps stimulate the imagination of team members when exploring potential deviations.

| | |
|---|---|
| ▪ **No or not** | ▪ **Other than** |
| ▪ **More** | ▪ **Early** |
| ▪ **Less** | ▪ **Late** |
| ▪ **As well as** | ▪ **Before** |
| ▪ **Part of** | ▪ **After** |
| ▪ **Reverse (of intent)** | ▪ **Others can be crafted as needed…** |

Fig. 1. Guide words for HAZOP analysis

<table>
<tr><td colspan="7">Study title:</td><td colspan="3">Page: of</td></tr>
<tr><td colspan="3">Drawing no.:</td><td colspan="4">Rev no.:</td><td colspan="3">Date:</td></tr>
<tr><td colspan="7">HAZOP team:</td><td colspan="3">Meeting date:</td></tr>
<tr><td colspan="10">Part considered:</td></tr>
<tr><td colspan="3">Design intent:</td><td colspan="7">Material: Activity:<br>Source: Destination:</td></tr>
<tr><td>No.</td><td>Guide-word</td><td>Element</td><td>Deviation</td><td>Possible causes</td><td>Conse-quences</td><td>Safeguards</td><td>Comments</td><td>Actions required</td><td>Action allocated to</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Fig. 2. Typical HAZOP worksheet

## FMEA/FMECA

Failure modes, effects, and criticality analysis (FMECA) is a methodology to identify and analyze:

– All potential failure modes of the various parts of a system;
– The effects of these failures on the system;
– How to avoid the failures, and/or mitigate the effects of the failures on the system.

<table>
<tr><td colspan="7">Study title:</td><td colspan="3">Page: of</td></tr>
<tr><td colspan="3">Drawing no.:</td><td colspan="4">Rev no.:</td><td colspan="3">Date:</td></tr>
<tr><td colspan="7">HAZOP team:</td><td colspan="3">Meeting date:</td></tr>
<tr><td colspan="10">Part considered:</td></tr>
<tr><td colspan="3">Design intent:</td><td colspan="7">Material: Activity:<br>Source: Destination:</td></tr>
<tr><td>No.</td><td>Guide-word</td><td>Element</td><td>Deviation</td><td>Possible causes</td><td>Conse-quences</td><td>Safeguards</td><td>Comments</td><td>Actions required</td><td>Action allocated to</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Fig. 3. Typical FMECA worksheet

Initially, the FMECA was called FMEA (Failure modes and effects analysis). The C in FMECA indicates that the criticality (or severity) of the various failure effects are considered and ranked.

The main procedure steps are:

1. FMECA prerequisites;
2. System structure analysis;
3. Failure analysis and preparation of FMECA worksheets;
4. Team review;
5. Corrective actions.

## ETA

An event tree analysis (ETA) is an inductive procedure that shows all possible outcomes resulting from an accidental (initiating) event, taking into account whether installed safety barriers are functioning or not, and additional events and factors.

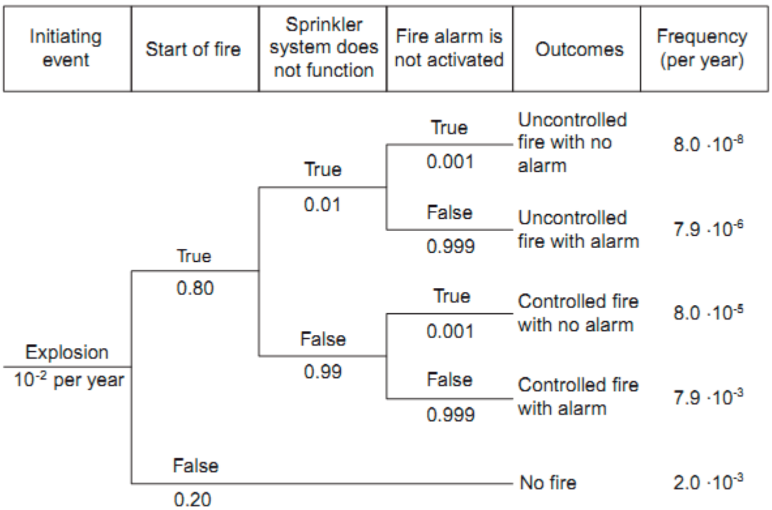



Fig. 4. Graphical representation of ETA

By studying all relevant accidental events (that have been identified by a preliminary hazard analysis, a HAZOP, or some other technique), the ETA can be used to identify all potential accident scenarios and sequences in a complex system.

## FTA

Fault tree analysis (FTA) is a top down, deductive failure analysis in which an undesired state of a system is analyzed using boolean logic to combine a series of lower-level events.

The fault tree is a logic diagram based on the principle of multi-causality, which traces all branches of events which could contribute to an accident or failure. It uses sets of symbols, labels and identifiers.

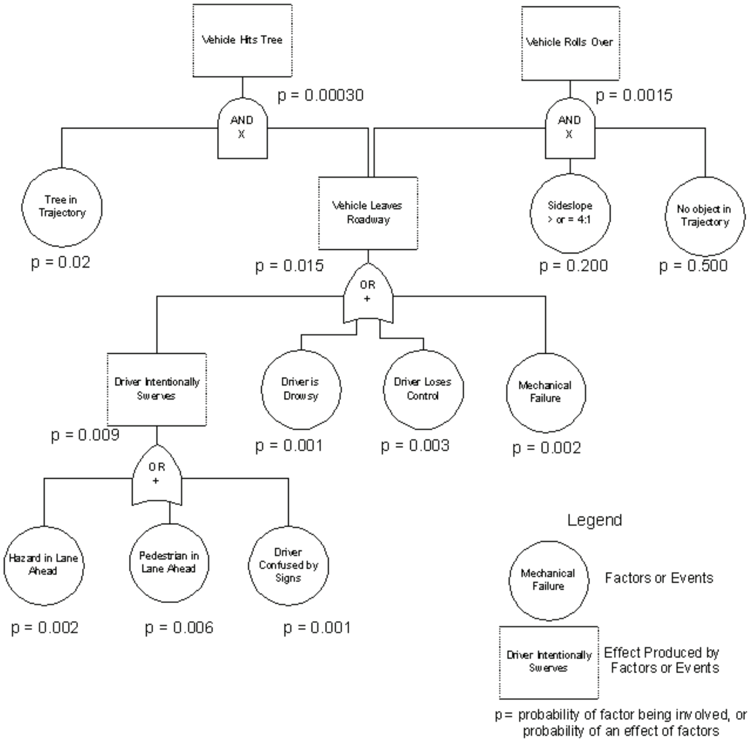



Fig. 5. FTA graphical representation

## Literature


1. www.ntnu.no
2. P.L. Celmens, *Event Tree analysis* (www.faoult-tree.net)
3. P.L. Celmens, *Fault Tree analysis* (www.faoult-tree.net), Hazard Analysis Techniques for System Safety, by Clifton A. Ericson, II, John Wiley & Sons, Inc., 2005.
4. *Fault tree analysis*, by Clifton A. Ericson, II, John Wiley & Sons, Inc., 2005.
5. NEBOSH National Diploma – Unit A, Managing Health and Safety, Element A3, Identifying Hazards, Assessing and Evaluating Risks.

# NUCLEAR POWER PLANT SIMULATION MODEL VVER 1000

**Zbyszek Szeliga**

VŠB-Technical University Ostrava, Faculty of Mechanical Engineering,
Department of Power Engineering, Czech Republic,
e-mail: Zbyszek.Szeliga@vsb.cz

Key words: *reactor, VVER 1000, simulator software*

The lecture deals with nuclear power plant simulation model VVER 1000. The first part is devoted attention to the basic description of the major process equipment operating VVER nuclear power plants. In the this part is given attention at the basic description of the technological equipments that are important in the service of the VVER nuclear power plants. The lecture provides general information about VVER 1000 reactor. It discusses the reactor design and operation principles.

The second part of the lecture is focused on the analysis of transients, a transient step change of the basic operating parameters of system components of VVR nuclear power plants, possible failure of basic technological components.

For the actual simulation is used simulator, the “Simulator Nuclear Power” Author: © 2006–2007, Jiří Punčochář. Here then are simulated emergency conditions in the primary, secondary and tertiary circuit of nuclear power plants. Students are acquainted with the control software, based on theoretical knowledge of technological units of simulated emergency conditions. On the simulator are monitored responses of the management and regulation system. On the basis of pre-defined tasks students solve various regulatory interventions and interpret the response system.

In the last phase then solve the problematic transition states in the hand-operated, the manual mode.

The lesson is finished interpretation of the data, discussion on the seriousness of the accident, and secure solution to their consequences, discussion on security measures in primary and secondary area.

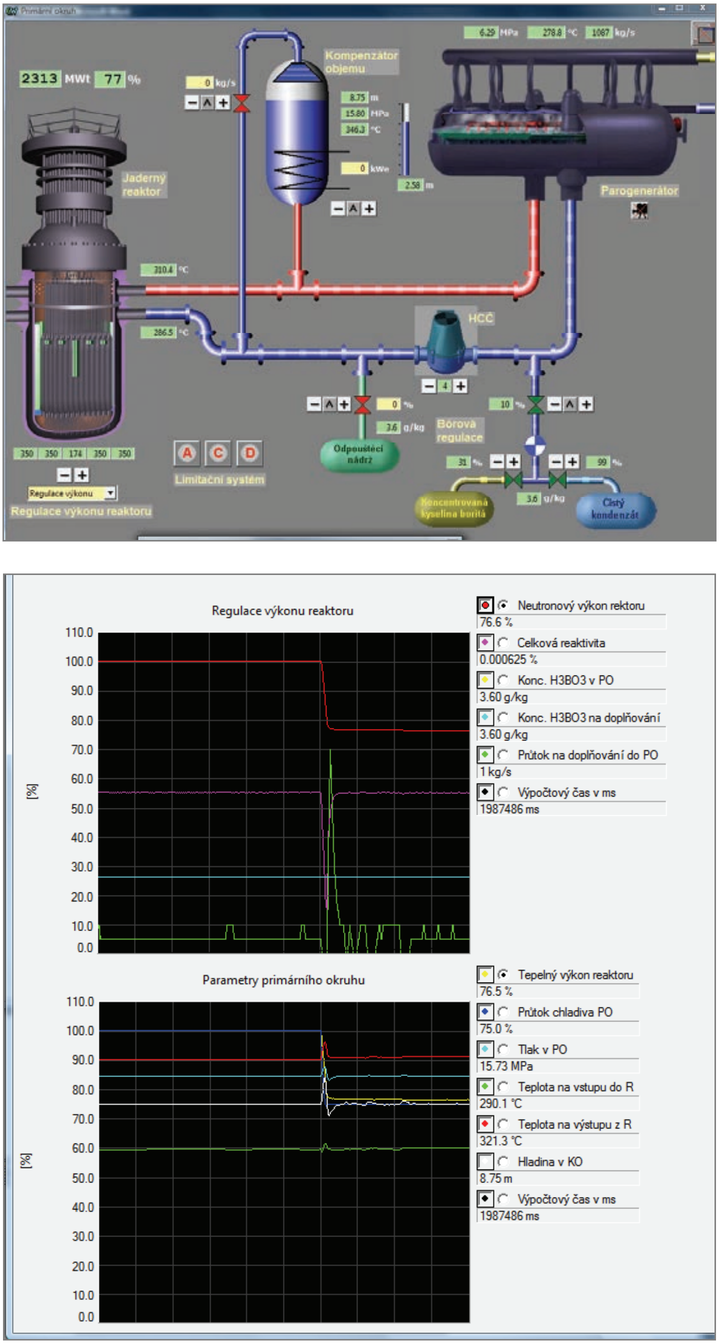



Fig. 1. Primary circuit simulation – failure of the main circulation pump

# SELECTED ISSUES CONCERNING SAFETY DESIGN AND OPERATION OF NUCLEAR REACTORS

**Wojciech Zacharczuk**

Wrocław University of Technology,
Faculty of Mechanical and Power Engineering,
Institute of Thermal Engineering and Fluid Mechanics, Poland.

Key words: *CANDU, design, operation, reactivity control*

Selected issues concerning safety design and operation of nuclear reactors are presented on an example of CANDU reactor.The CANDU (stands for Canada Deuterium Uranium) is a Canadian-invented, pressurized heavy water reactor. It was developed and designed in the late 1950s by a consortium of Canadian government and private industry including Atomic Energy of Canada Limited (AECL).

CANDU is found to be a third most popular commercial nuclear power reactor. Conceptually, it is similar to the Pressurized Water Reactor, although differs in the details.

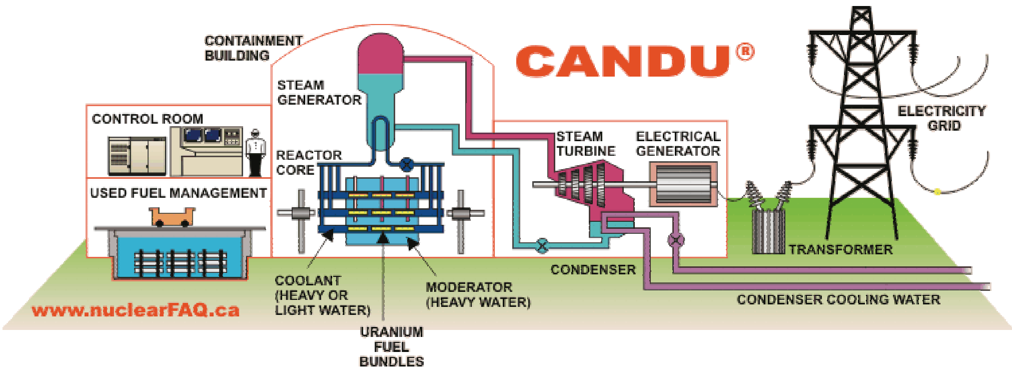



Fig. 1. Diagram of the CANDU based nuclear power plant

CANDU based nuclear power plant employs two major, separated systems. In the **primary system** (heat transport system), the heat generated in the fuel by nuclear fission is removed by the coolant, flowing through the reactor core under high pressure, and then carried to steam generators, where it is transferred to water of the secondary system to produce steam. The coolant then returns to the inlet of reactor core while the steam is delivered by the **secondary system** (feedwater and steam generator system) to the main turbine generator, to produce electricity. After passing through the low pressure turbine, the steam is routed to the main condenser where it is cooled down (condensed) by external water and then pumped back to the steam generator for reuse.

In typical CANDU reactors, a heavy water as a coolant and moderator is applied that assures higher neutron economy in the core, so the chain reaction (criticality) is possible with natural uranium fuel. The use of natural uranium results in some benefits e.g. widens the source of supply, reduces investment and operating costs as expensive to build and operate, uranium enrichment facilities are not required, allows the core to be fuelled with a number of other low-fissile content fuels, including spent fuel from light water reactors.

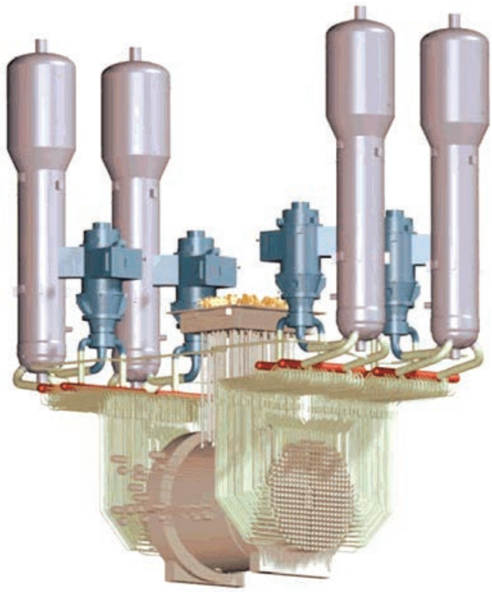


Fig. 2. CANDU core design

Another unique feature is a pressure tube core design. Instead of one large pressure vessel (LWR's), the CANDU reactor core comprises a low-pressure horizontal cylindrical tank called Calandria, with hundreds of small diameter high-pressure fuel channels, running completely through it from one side to the other. It results, the moderator and coolant are separate systems.

Such core design brings some benefits e.g. allows on-power refueling, that increases a capability factor as well as assures a maximum fuel burn-up in the core.

## Literature

1. J. Tabak, *Nuclear Energy*, 2009.
2. R. Hantula, *Nuclear Power*, 2010.

**Technology and experience of**

AREVA

**for the Polish Nuclear Energy Programme**

Adam Rozwadowski

Trnava 12 September 2011

# An energy mix that meets our customers' requirements


- **World leader in nuclear power**
  - A unique integrated model, from uranium mining to reactor design and related services to used nuclear fuel recycling
- **A major player in renewable energies**
  - A portfolio of diversified operations: offshore wind, bioenergies, concentrating solar power, hydrogen and energy storage

**Nuclear and renewables: contributing to a reliable, economical, carbon-free energy mix**



AREVA

# AREVA provides New Renewable Energy solutions

**Renewable Energies**

- Development of wind energy, bio-energy, solar power and hydrogen power solutions

**#1 in Bio-energy**
**Off-shore wind turbine of the highest power rating (5MW) currently in operation**

- **€168M sales (2009)**
  **1% of AREVA sales**
- **892 people (2008)**
  **1% of AREVA workforce**
- **€1.1Bn backlog in 2009**
  **X14 over 2006-09**

*Itacoatiara biomass plant (Brazil)*

*Off-shore wind turbine*

# EPRTM the best from French and German technology

**KONVOI**

(~1300 MWe)

- Neckar 2
- Emsland
- Isar 2

- Chooz 1&2
- Civaux 1&2

(~1450 MWe)

**N4**

EPR™ by AREVA

**The EPR™ provides more safety and better economics with the certainty of a proven and evolutionary technology**

# Generation III safety requirements integrate the feedback of 3 major events

**A**

**Three Miles Island (1979) : Accident with core melting**

Reduce the probability of a severe accident with core melting

**B**

**Tchernobyl (1986) : Radioactive dispersal**

Reduce the impact on the population in case of severe accident

**C**

**9/11 (2001) : Terrorist attack with commercial airplane**

Reinforce the resistance to any external attack (commercial airplanes)

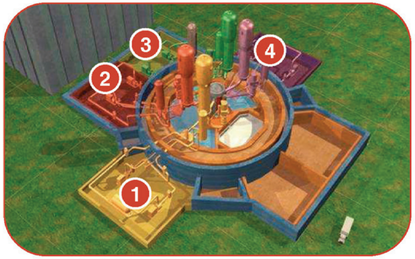
# AREVA has choosen 3 main technical options to address these new objectives

| | | AREVA technical options |
|---|---|---|
| A | Reduce the probability of a severe accident with core melting | Physical separation, Redundancy of critical components for maintenance and diversity |
| B | Reduce the impact on the population in case of severe accident | Core catcher<br>Annulus and filtration |
| C | Reinforce the resistance to any external attack (commercial airplanes) | APC resistant containement (double schell + liner) |

**Whatever happens inside or outside the nuclear power plant, no impact on the surroundings***

*no emergency evacuation beyond the industrial site, and no long-term relocation

# Reduce the probability of a severe accident with core melting



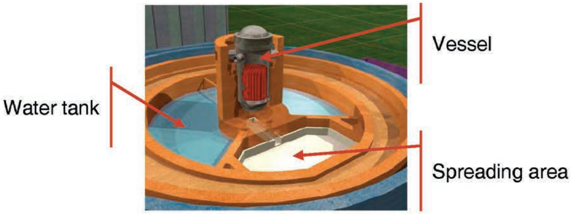

Four Train concept
and physical separation

**Physical separation, diversity of safety systems, and redundancy for critical maintenance components**

- **Redundancy of critical maintenance components** (diesels, exchangers…)
  - Safety Level is kept in cas of « on line » maintenance
- **Physical separation of redundant safety systems**
  - Security against internal hazards such as flooding, fire, …)

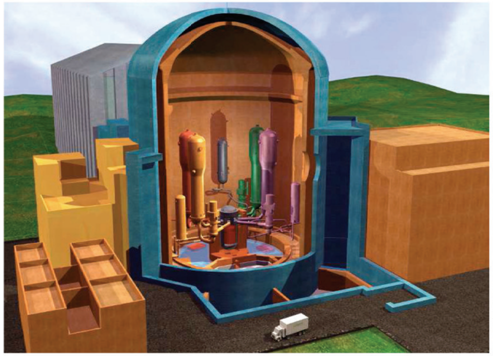
# Reduce the impact on the population in case of severe accident

## Core catcher




- **Design of a cooling / spreading area + corium colling systems**
  - In case of leak, the corium is spread through « passive » phenomenom
  - Cooling bottom up to ease a quick stabilization
  - Dedicated cooling system for long term management.
- **Reinforcement of reactor building containment in order to adress such severe accident.**

## Annulus and filtration

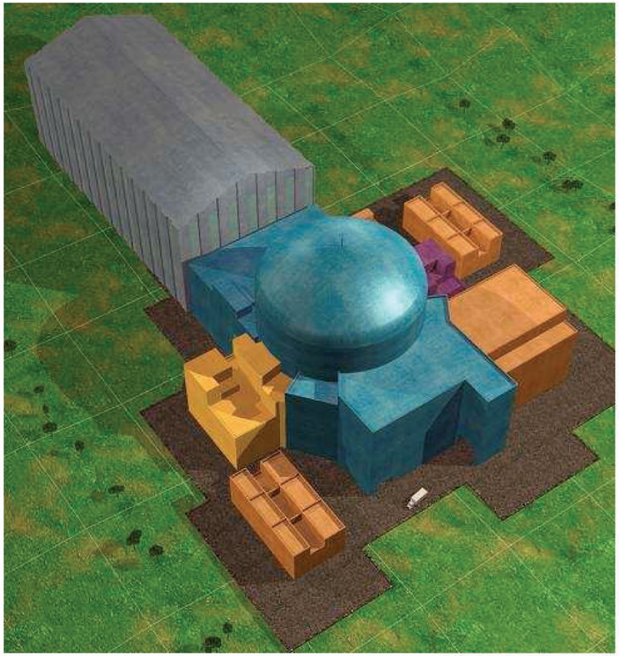


- **Double wall containment**
- **Annulus inside double-wall containment is maintained at a negative pressure**
- **All leakages are collected in the annulus and a reduction of radioactive aerosols is achieved by filtration prior to the release via the stack**



AREVA

# Reinforce the resistance to any external **attack** (commercial airplanes)

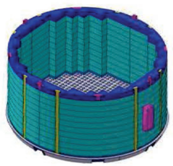


**Specific adapted design to adress any external attack**

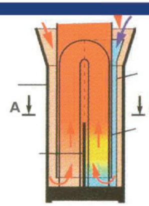
- **A thick highly reinforced concrete shell protects the inner walls and structures from direct impact and resulting vibrations**
- **Protection is provided for the reactor, fuel and safeguard buildings 2 and 3 (housing the Main Control Room)**
- **This improves also the resistance to other type of attacks**

# The EPR™ reactor has been designed to minimize its environmental footprint

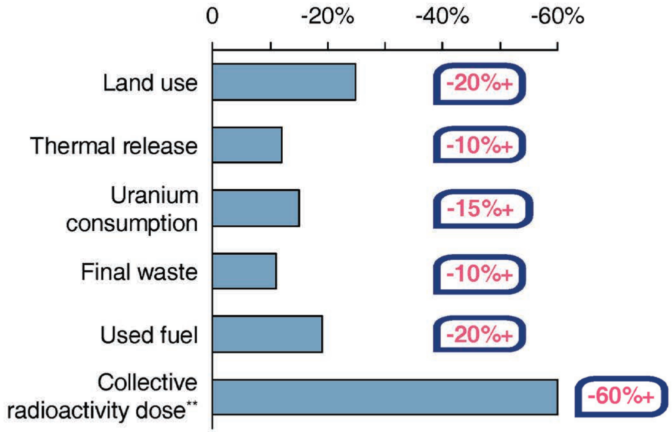
**Heavy neutron reflector**



**Steam generator with economizer**




**Comparison of environmental footprints EPR versus Gen 2 reactors**




Source: AREVA
* 900 MW, CPY reactor ; ** per reactor x year for operating and maintenance workers



AREVA

# Polish Nuclear Energy Programme

Ministry of Economy
Governement Commissioner for Nuclear Energy
November 2010

- **Experience suggests that it may be not sufficient to rely on theoretically disigned safety features to achieve actual safety.**
- **AREVA:**
- **4 EPR based NPPs in construction**

# AREVA's Experience

**100+** **AREVA reactors around the world**

**30%** **of worldwide installed nuclear capacity**

**84** **PWR in operation**
**6** **BWR in operation**
**1** **PHWR in operation**
**7** **Shutdown reactors**

**+**

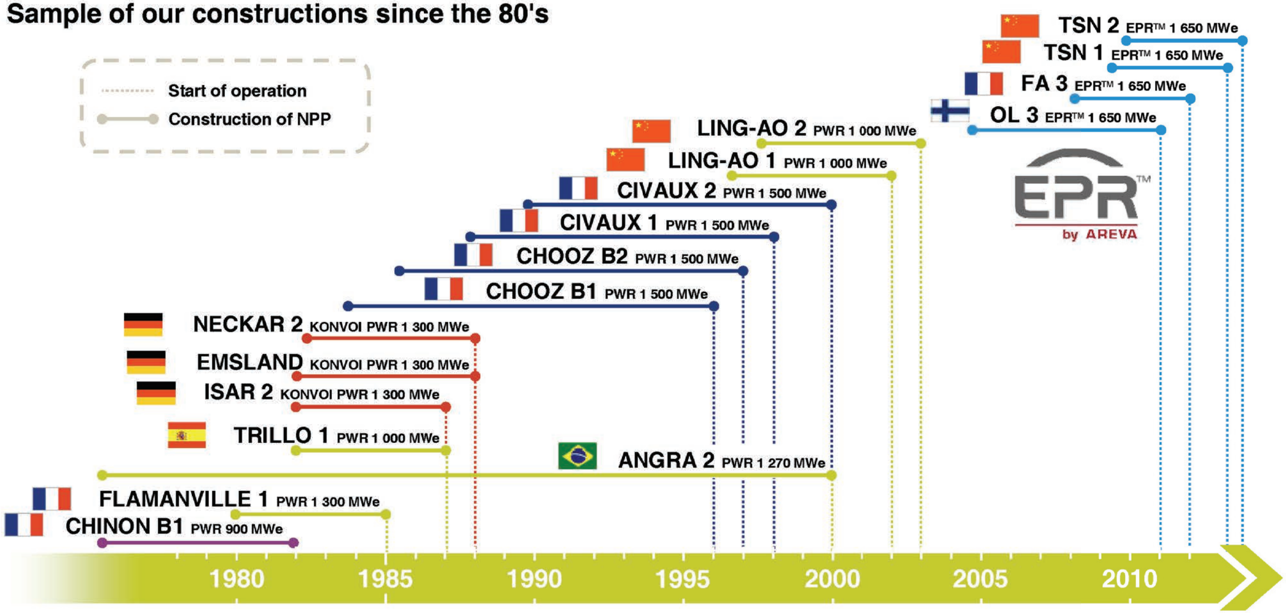
**4 EPR™ by AREVA**

**Under construction**

Source: World Nuclear Association – August 2009

# AREVA never stopped designing and building

**Sample of our constructions since the 80's**






AREVA

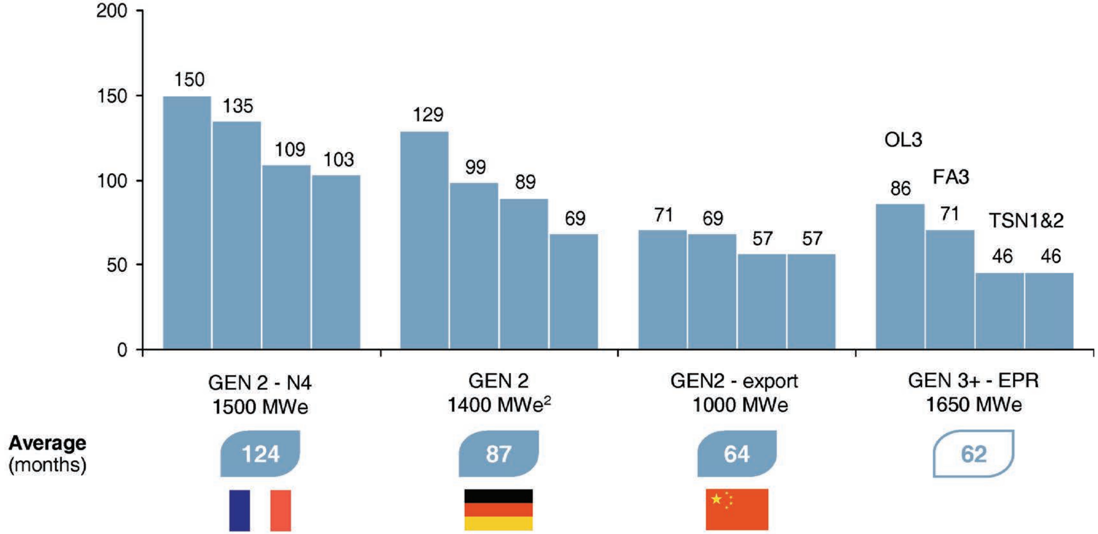
# 4 EPR™ Units Under Construction


**The World's First Gen III+ Fleet to be deployed**

# AREVA is achieving with the EPR a series effect for faster project delivery

## Illustration: Evolution of construction schedule

**Construction duration: 1st concrete to first criticality[1]**
(# months)

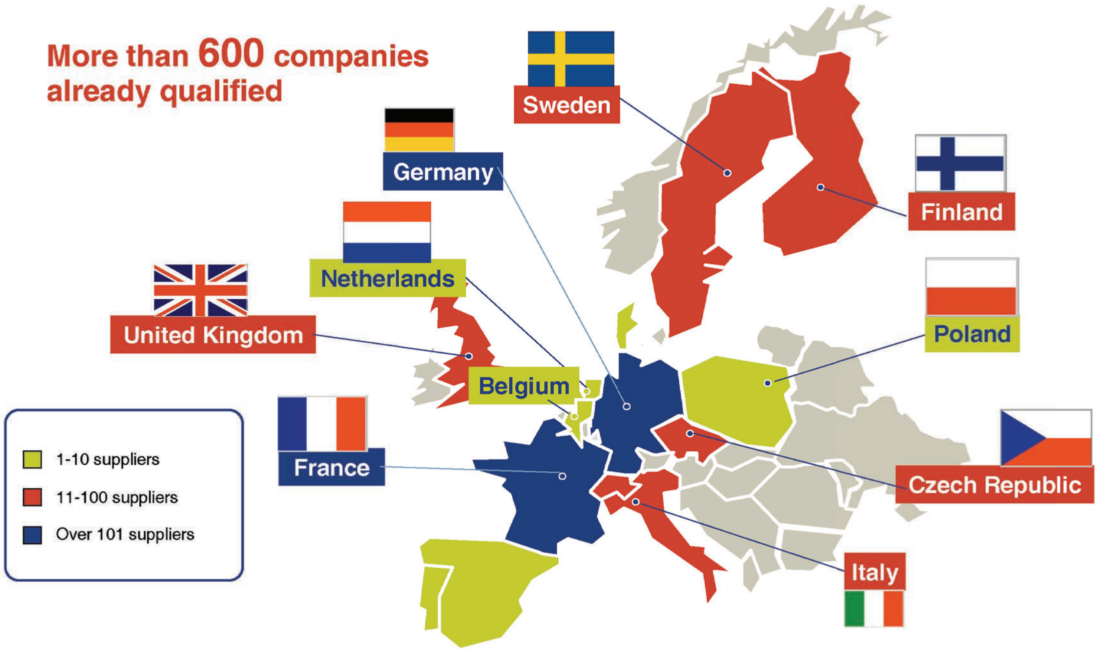



1. First four units per technological steps
2. First 3 plants are pre-KONVOI designs (Brokdorf, Grohnde, Philippsburg 2) and fourth plant refer to the average of the 3 KONVOI units started simultaneously

Source: IAEA; AREVA; EDF; CGNPC

# Ramping up capacities: European Supply Chain up and running

**More than 600 companies already qualified**






AREVA

# Securing Uranium Supply

**▶ Canada**
- Development (Shea Creek, Kiggavik etc.)
- Exploration since 1964
- Cigar Lake production to start after 2012 (+2,600 tU)

**▶ Kazakhstan**
- Mining & global fuel agreement signed
- Katco production ramp-up / license for 4,000 tU obtained
- Exploration

**▶ Mongolia**
- Sainshand
- Exploration

**▶ Morocco**
- Agreement signed with Office Chérifien des Phosphates

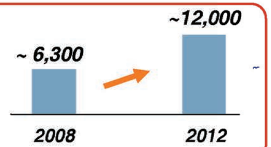
**▶ Niger**
- Somaïr & Cominak mines
- Imouraren mining license obtained - Start up 2013-14 (+ 5,000 tU)

**▶ Democratic Republic of Congo**
- Mining partnership

**▶ AREVA Resources Southern Africa**
- Namibia - Trekkopje: mining permit obtained / 1st production expected in 2010
  +3,000 tU production expected
- Central African Republic -Bakouma: government agreement obtained
  +2,000 tU production expected
- South Africa – Ryst Kuil
- Exploration

**▶ Australia**
- Exploration since 1969

*Production (metric tons of U)*



# Polish Energy Strategy until 2030

Ministry of Economy, October 2009

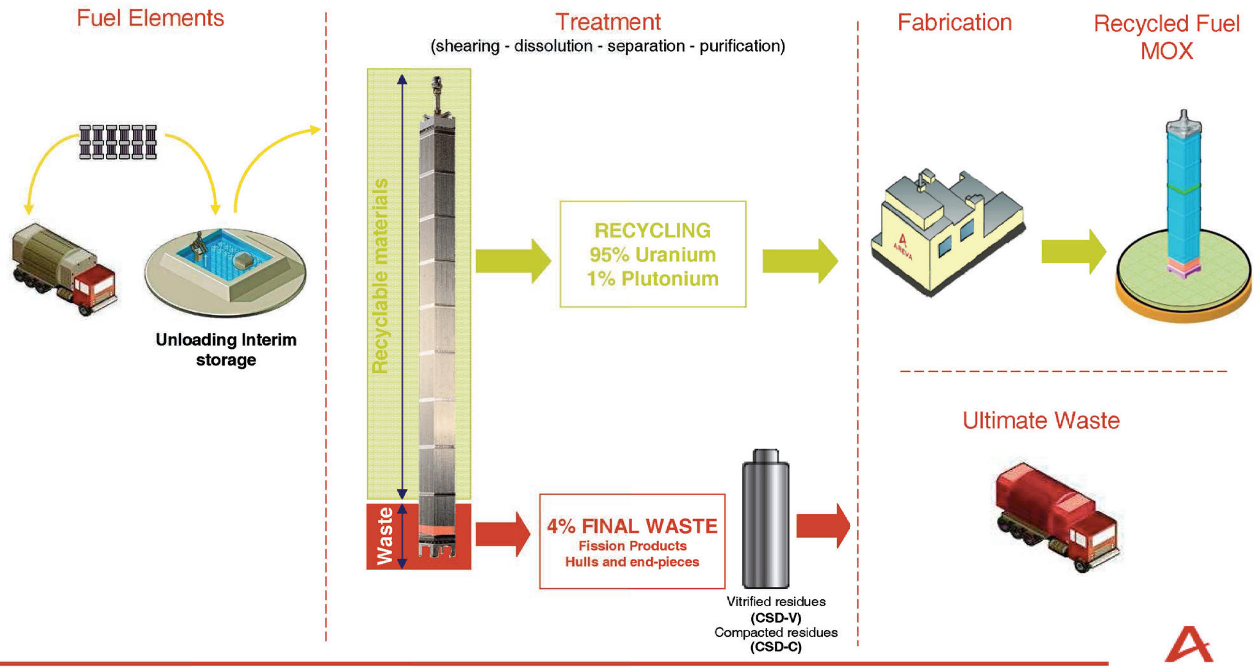
- It is necessary to ensure Poland's permanent access to all stages of fuel cycle
- (..) recycling of burnt fuel and disposal of highly radioactive nuclear waste



AREVA

# 96% of used Nuclear fuel is recyclable

## Main stages in recycling



# Conclusion : Excellence in delivery

- **AREVA brings:**
  - **The EPR™ design, the European reference for the new generation of nuclear power plants**
  - **An unparalleled international construction experience**
  - **A unique company wide continuous improvement process to build on it**
- **Project execution progress is captured to benefit both AREVA and our customers**

**Project execution**
**=**
**Customer satisfaction**



AREVA

# Technical and human accidents in Nuclear Power Plants occurred in the last 50 years

Trnava, 12 Sept 2011

# Summary

1. Presentation of WANO
2. Events that shaped the industry
3. How to learn from our mistakes

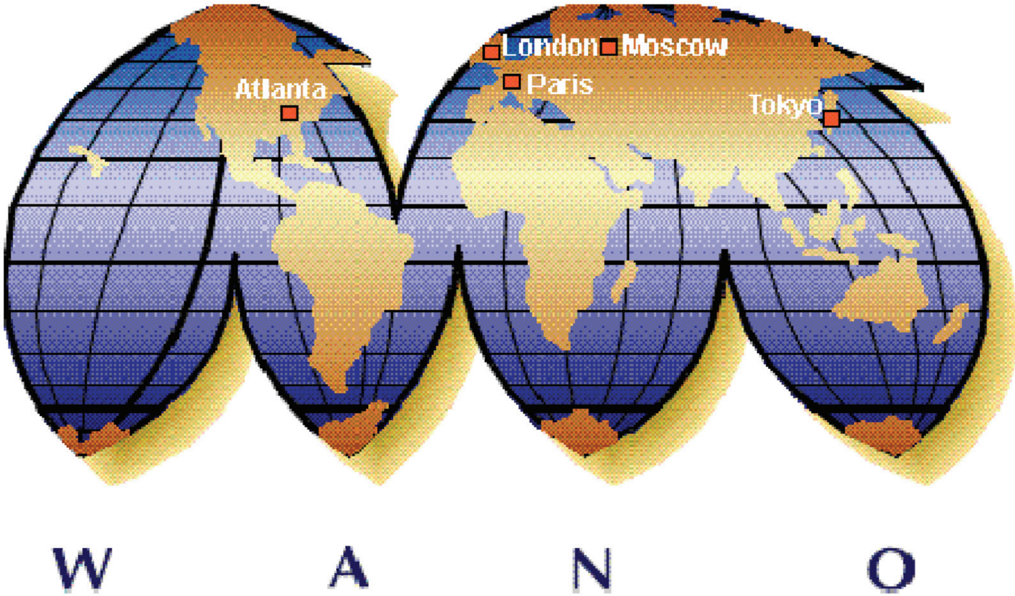
# 1. Presentation of WANO

# Why WANO exists?

After the 1986 Chernobyl accident, the world's nuclear operators realised that an event at ***one*** plant impacted ***every*** plant and that international cooperation was needed to ensure such an accident could never happen again.

WANO was formed in 1989.
Today, every nuclear operator in the world is a member.

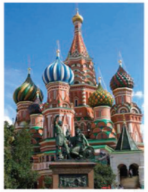
# World Association of Nuclear Operators

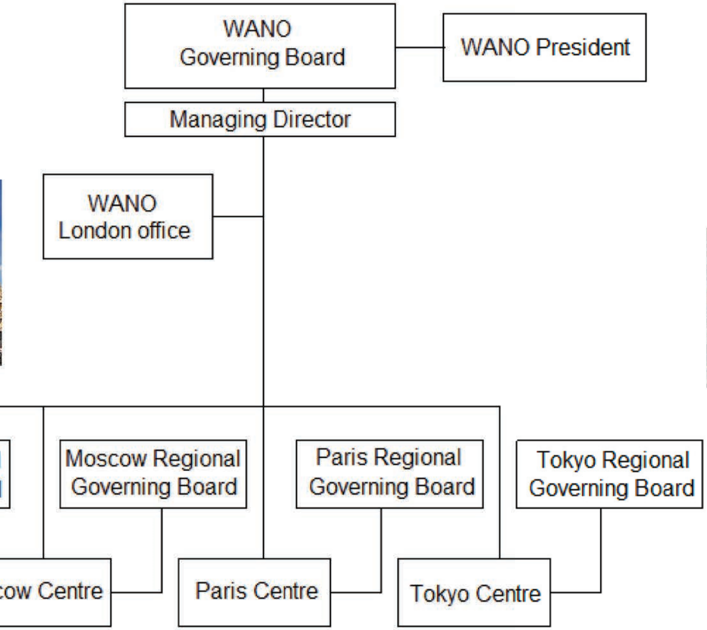


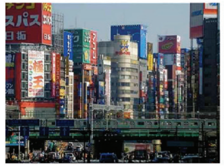
# Mission of WANO

**To maximise the safety and reliability of nuclear power plants worldwide by working together to assess, benchmark and improve performance through mutual support, exchange of information, and emulation of best practices.**

# WANO Organisation

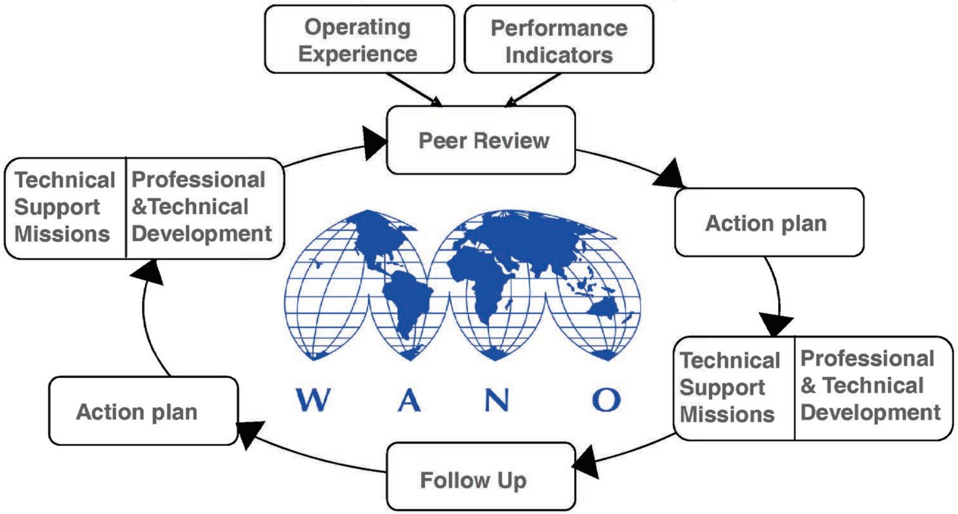




# WANO Paris Centre Programmes

The programmes work together to drive continuous performance improvement



# Operating Experience Programme

Use of Operating Experience :

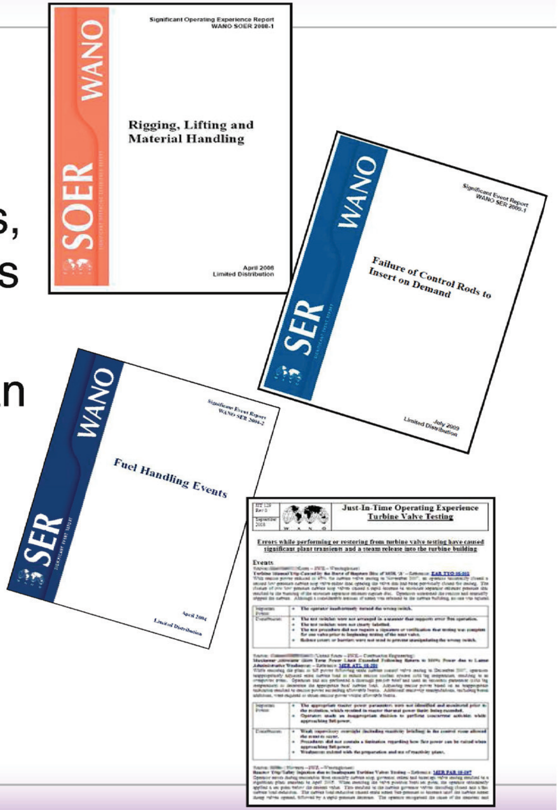
to improve plant performance by applying the applicable lessons learned from past events.

The objectives are to:

- encourage members to report events promptly with a plant analysis valuable to its members.
- alert members to events which could enable them to take actions to prevent similar events on their own plants.

# OE documents

- Significant Operating Experience Reports (SOER) are written to address significant events or trends, including required corrective actions for WANO members.
- Significant Event Report (SER) is an analysis of significant events to identify and communicate the lessons learned.
- Just-in-Time (JIT) briefings help planners, workers and supervisors apply lessons learned.



# WANO Peer Reviews

The purpose of a Peer Review is to compare the operational performance of a Station to best international practice through an in-depth, objective review by an independent team.

A Peer Review pushes all stations to continuous improvement.

# Corporate Peer Reviews

Safety at a plant depends strongly on the interaction between the plant and its corporate organisation.

How corporate

- sets vision, goals and objectives
- provides resources, including human, financial, engineering, etc.
- exercises nuclear oversight.

A Corporate Peer Review takes a critical look at these interactions and how they impact performance and reliability.

# Pre-start-up Peer Reviews

Pre-start-up Peer Reviews

- look at everything needed to operate safely at the beginning of commercial operation
- bring new plants into the international nuclear community, establishing lines of communication
- support the new plant during the transition from a construction culture to an operating culture.

# WANO Technical Support Missions (TSMs)

TSMs provide a method for assisting WANO members to identify solutions to known problems at the plant that the plant has been unable to solve itself.

The objective is to improve station safety and reliability.

# WANO Professional and Technical Development

This programme includes:

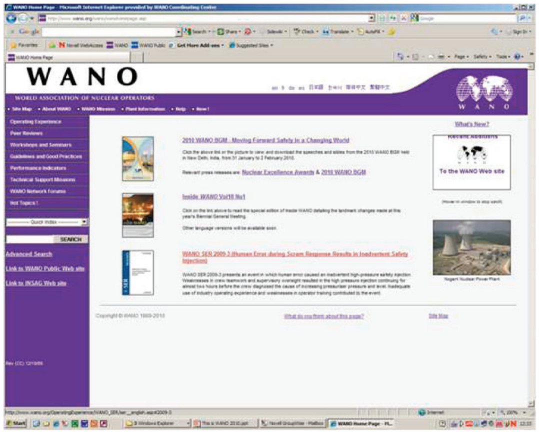
- Seminars and Workshops
- Guidelines and Good practices
- Database of Good examples
- Communication.

# WANO Communication tools

## WANO Web sites

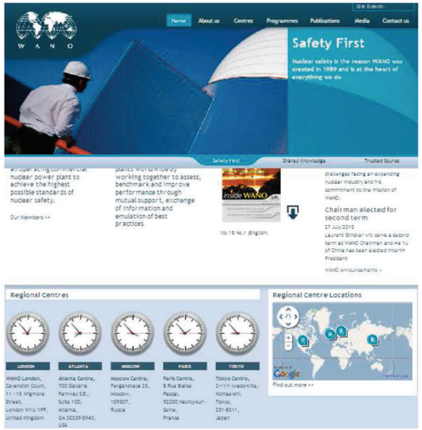
For Members

www.wano.org




Public

www.wano.info

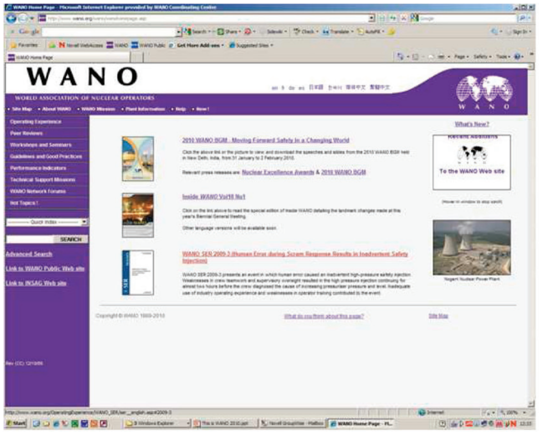


# WANO Communication tools

## WANO Web sites

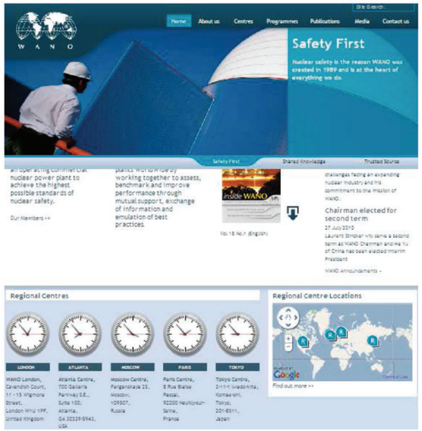
For Members

www.wano.org

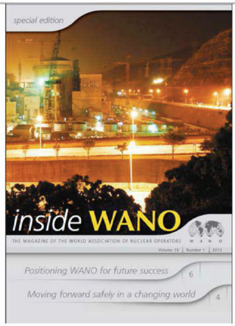



Public

www.wano.info



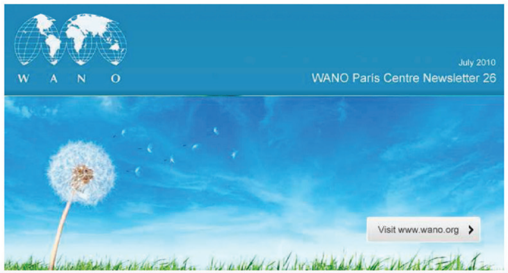
# WANO Communication tools




Inside WANO publication

WANO Paris Centre Newsletter

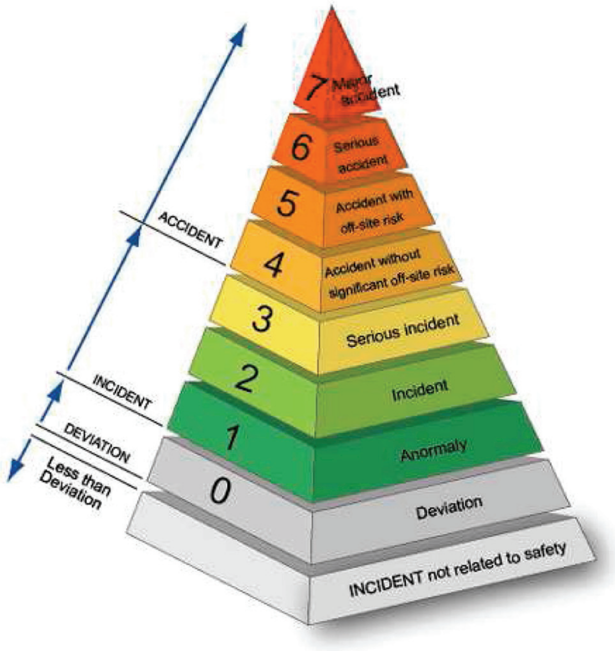
- e-version
- English, French, German, and Spanish



# 2 – Events that shaped the nuclear industry

# The INES scale

- A worldwide tool for communicating to the public in a consistent way the safety significance of nuclear and radiological events.
- The severity of an event is about ten times greater for each increase in level on the scale



W A N O

# Examples of events at Nuclear Facilities

*(Source: IAEA)*

| | People and Environment | Radiological Barriers and Control | Defence-in-Depth |
|---|---|---|---|
| 7 | Chernobyl, 1986 — Widespread health and environmental effects. External release of a significant fraction of reactor core inventory. | | |
| 6 | Kyshtym, Russia, 1957 — Significant release of radioactive material to the environment from explosion of a high activity waste tank. | | |
| 5 | Windscale Pile, UK, 1957 — Release of radioactive material to the environment following a fire in a reactor core. | Three Mile Island, USA, 1979 — Severe damage to the reactor core. | |
| 4 | Tokaimura, Japan, 1999 — Fatal overexposures of workers following a criticality event at a nuclear facility | Saint Laurent des Eaux, France, 1980 — Melting of one channel of fuel in the reactor with no release outside the site. | |
| 3 | No example available | Sellafield, UK, 2005 — Release of large quantity of radioactive material, contained within the installation. | Vandellos, Spain, 1989 — Near accident caused by fire resulting in loss of safety systems at the nuclear power station. |
| 2 | Atucha, Argentina, 2005 — Overexposure of a worker at a power reactor exceeding the annual limit. | Cadarache, France, 1993 — Spread of contamination to an area not expected by design. | Forsmark, Sweden, 2006 — Degraded safety functions for common cause failure in the emergency power supply system at nuclear power plant. |
| 1 | | | Breach of operating limits at a nuclear facility. |

# Events the shaped the industry

Three Mile Island (USA): 28 March 1979 - Ines 5
Event: Partial Melt Down of Reactor Core (Unit 2) – only small off-site releases of radioactivity.

Root Causes:
- Equipment malfunctions
- Worker errors
- Design related problems

Creation of INPO (Institute of Nuclear Power Operations) to promote excellence in operations and to provide for sharing of lessons.

# Events the shaped the industry

Chernobyl: 26 April 1986 - Ines 7
Event: Core Melt Down - affects of radioactivity felt across Europe

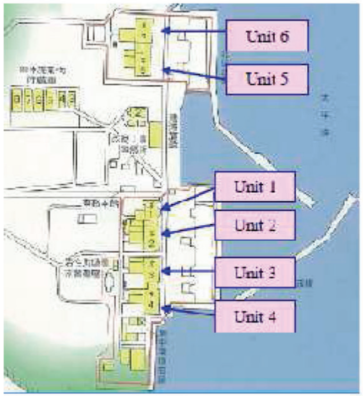
Root Causes:

- Worker Error
- Safety Systems Overridden

As a result of this accident, the need for international collaboration in setting and implementing high standards for operating nuclear facilities was recognized. The World Association of Nuclear Operators (WANO) was formed as a result.

# Events the shaped the industry

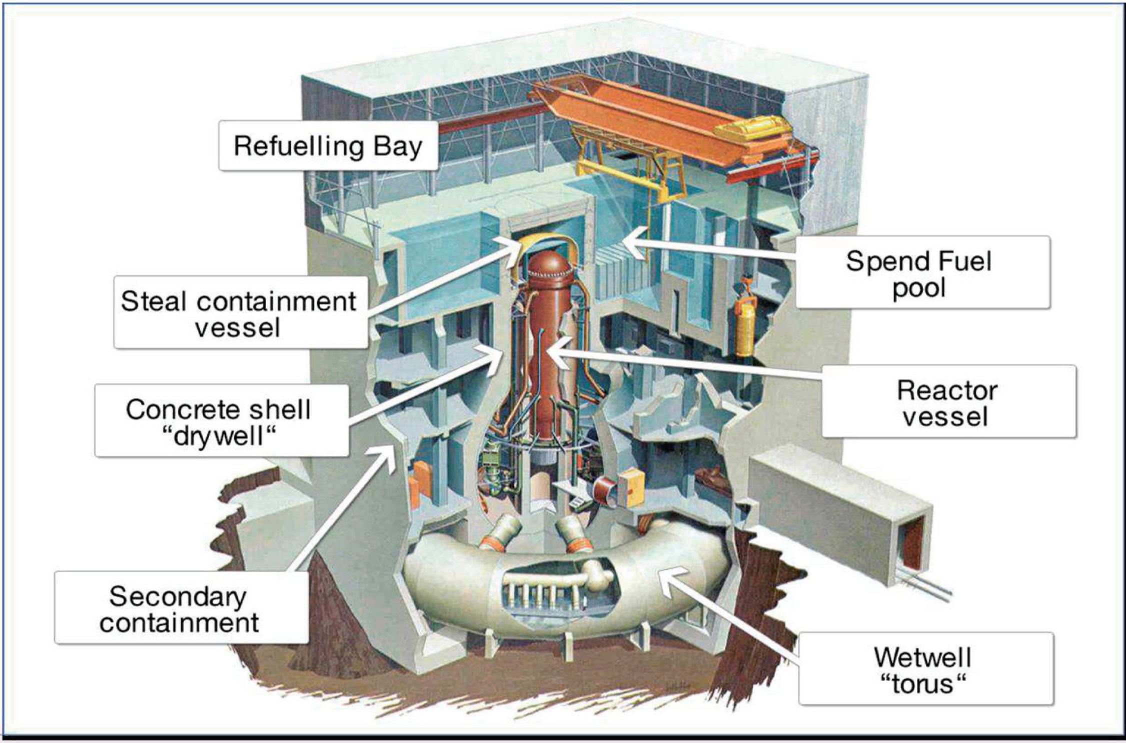
## Fukushima Daichi




| | Unit 1 | Unit 2 | Unit 3 | Unit 4 | Unit 5 | Unit 6 |
|---|---|---|---|---|---|---|
| Electric output (MWe) | 460 | 784 | 784 | 784 | 784 | 1100 |
| Commercial operation | 1971/3 | 1974/7 | 1976/3 | 1978/10 | 1978/4 | 1979/10 |
| Reactor model | BWR3 | BWR4 | | | BWR5 | |
| PCV model | Mark-1 | | | | | Mark-2 |
| Number of fuel assemblies in the core | 400 | 548 | 548 | 548 | 548 | 764 |

Source: Report of the Japanese Government to the IAEA Ministerial Conference on Nuclear Safety - The Accident at TEPCO's Fukushima Nuclear Power Stations - June 2011

# Events the shaped the industry




*Boiling water reactor layout. Source: GE*

# Events the shaped the industry

11 March 2011 – INES Level 7

- Analysis not completed
- Earthquake magnitude: 9.0
 & tsunami
- Inundation height: 15m
- Unit status before the tsunami:
  - Unit1, 2, 3: under operation
  - Units 4,5,6: periodical inspection

In “Report of the Japanese Government to the IAEA Ministerial Conference on Nuclear Safety - The Accident at TEPCO’s Fukushima Nuclear Power Stations” - June 2011:

Lessons learned so far:
1 - Strengthen preventive measures against a severe accident
2 - Enhancement of response measures against severe accidents
3 - Enhancement of nuclear emergency responses
4 - Reinforcement of safety infrastructure
5 - Thoroughly instill a safety culture

# 3 - How to learn from our mistakes?

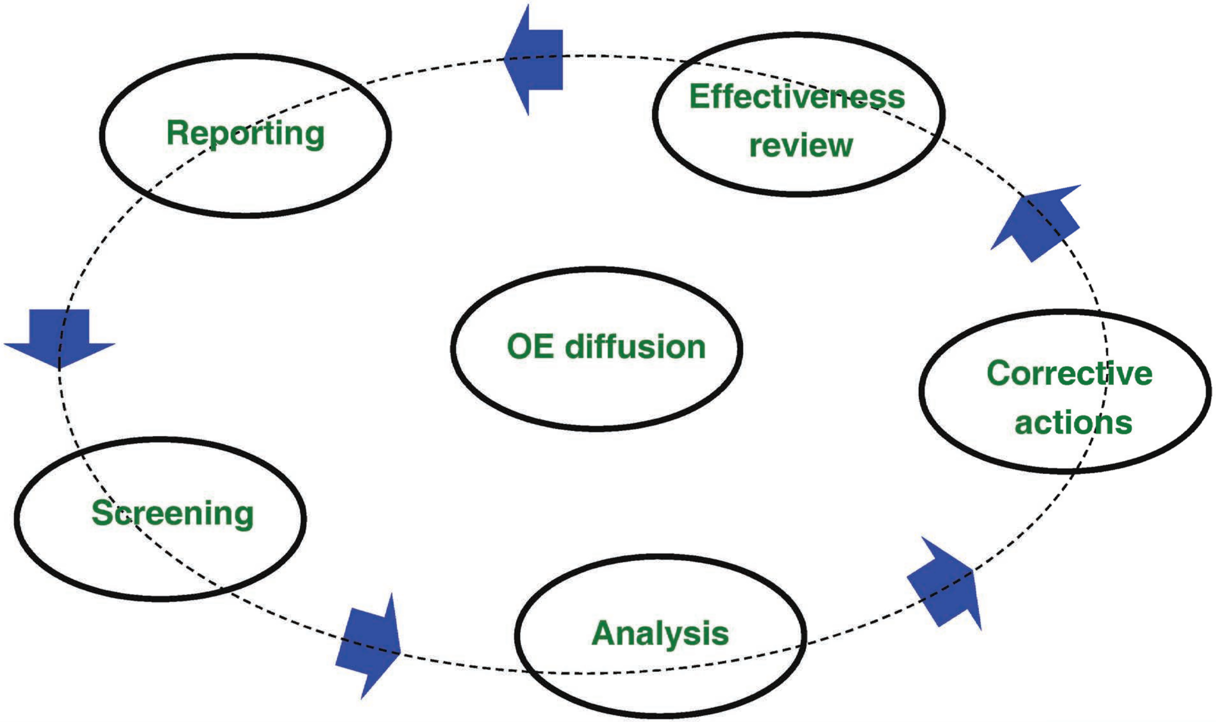
# WANO OE Programme

Experience shows that many events could have been prevented if lessons had been learned from previous incidents.

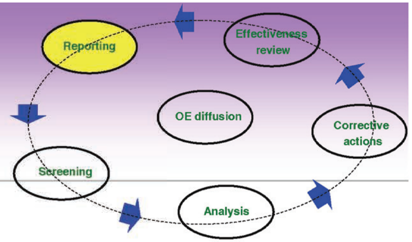
Basic principle underlying WANO:

- It is better to learn from someone else's mistakes than from your own.
- It is also better to benefit from someone else's good ideas rather than work in isolation without perhaps improving the results.

# The Operating Experience loop



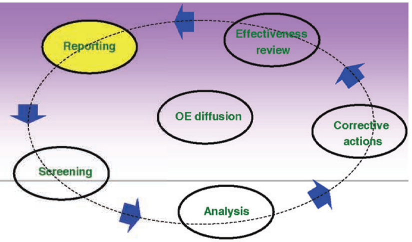
# Reporting - Principles



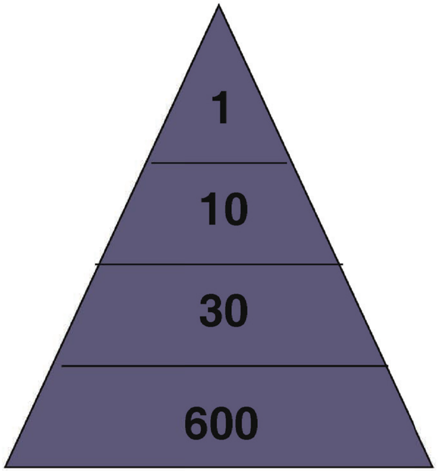

Plant events and human performance problems often result from weaknesses or breakdowns in plant processes, practices, procedures, training and system or component design that were not previously recognised or corrected.

Communicating these weaknesses both internally within the plant organisation and externally to other operators are an important part of the operating experience programme.

# Reporting: Event correlation




*Bird triangle (1969)*



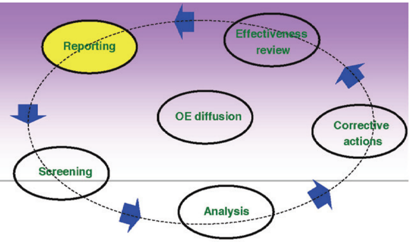

**Serious or Disabling Injury**

**Minor injuries**

**Property damage incidents**

**Incidents with No Visible Injury or Damage**

***A correlation exists between minor non consequential incidents and serious accidents***

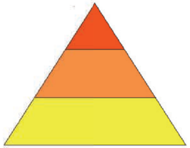


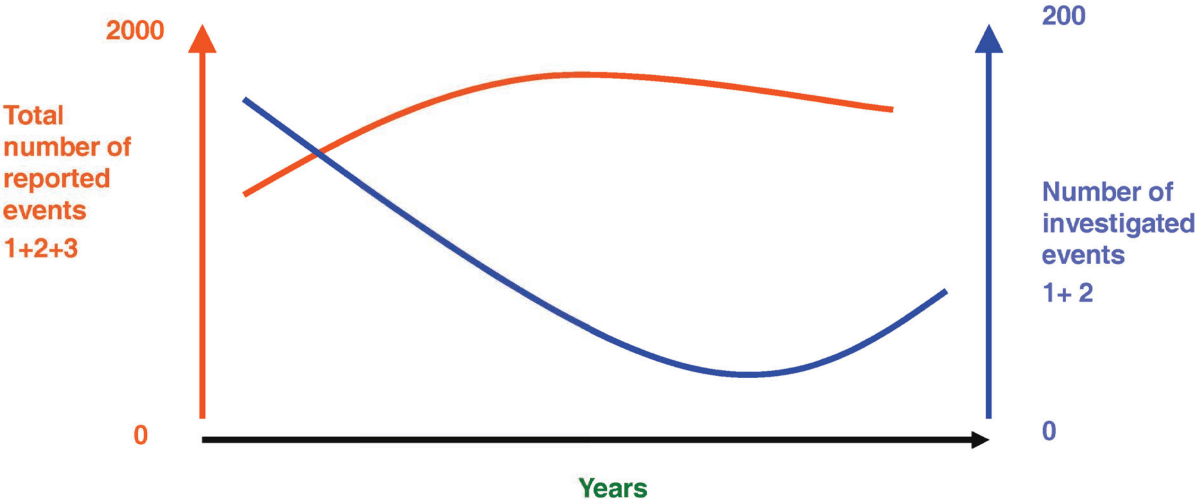

# Why volume of reported events matters

1 Externally reportable events

2 Internally investigated events

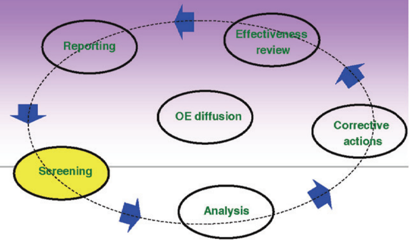
3 Minor events

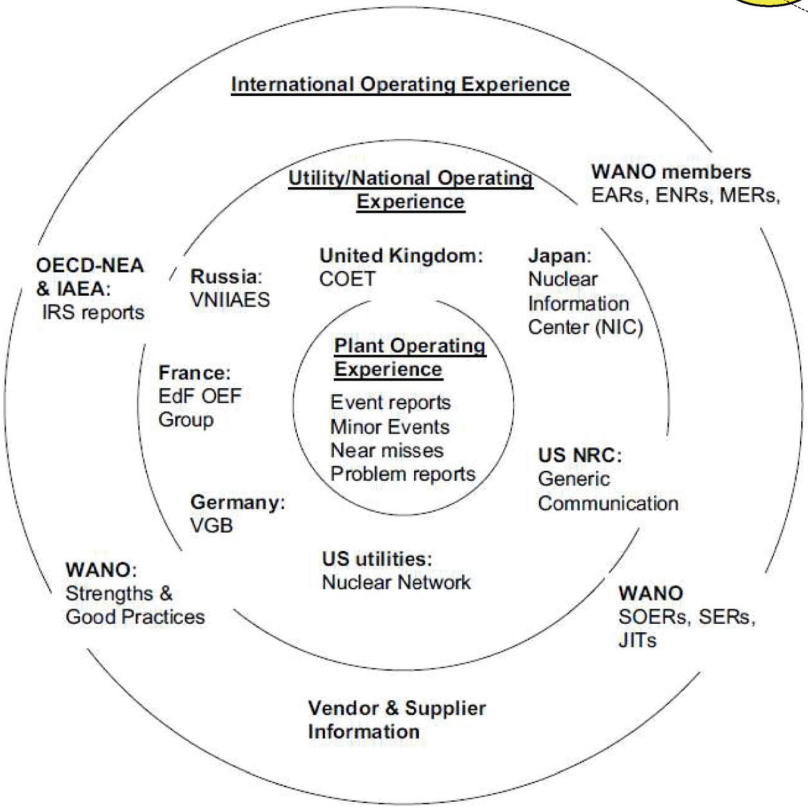




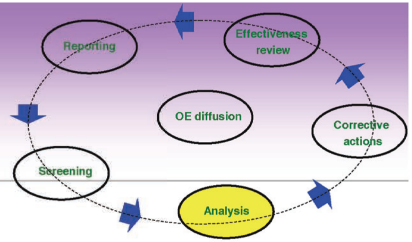

*Source: Magnox North*

# Sources of information



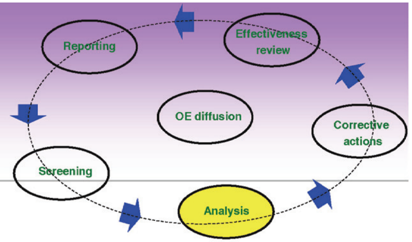



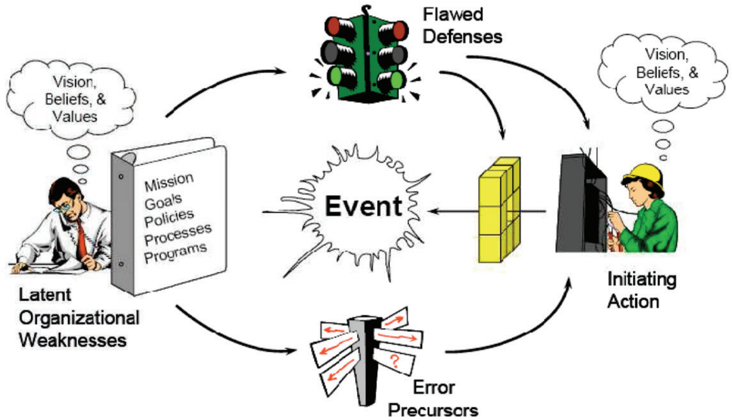
# Analysis




- Events are analysed to identify the causes, causal factors and corrective actions that address identified weaknesses.
- Near misses and minor events are analysed to reduce the occurrence of similar, more significant events.
- Equipment failures are monitored and failure analyses are performed if an adverse trend develops.

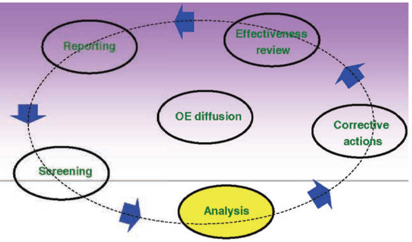
# Anatomy of an event



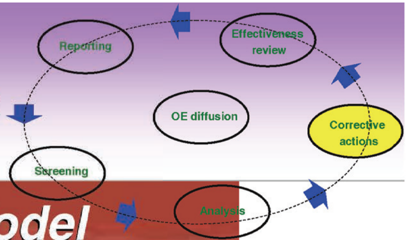

An effective event investigation should identify:
- The specific consequences
- Initiating actions (active errors) and error precursors that provoked the active errors
- Flawed defenses either that failed to prevent the active errors or failed to prevent or mitigate the event consequences
- The organizational weaknesses that contributed to every factor just mentioned and their link to the consequences.

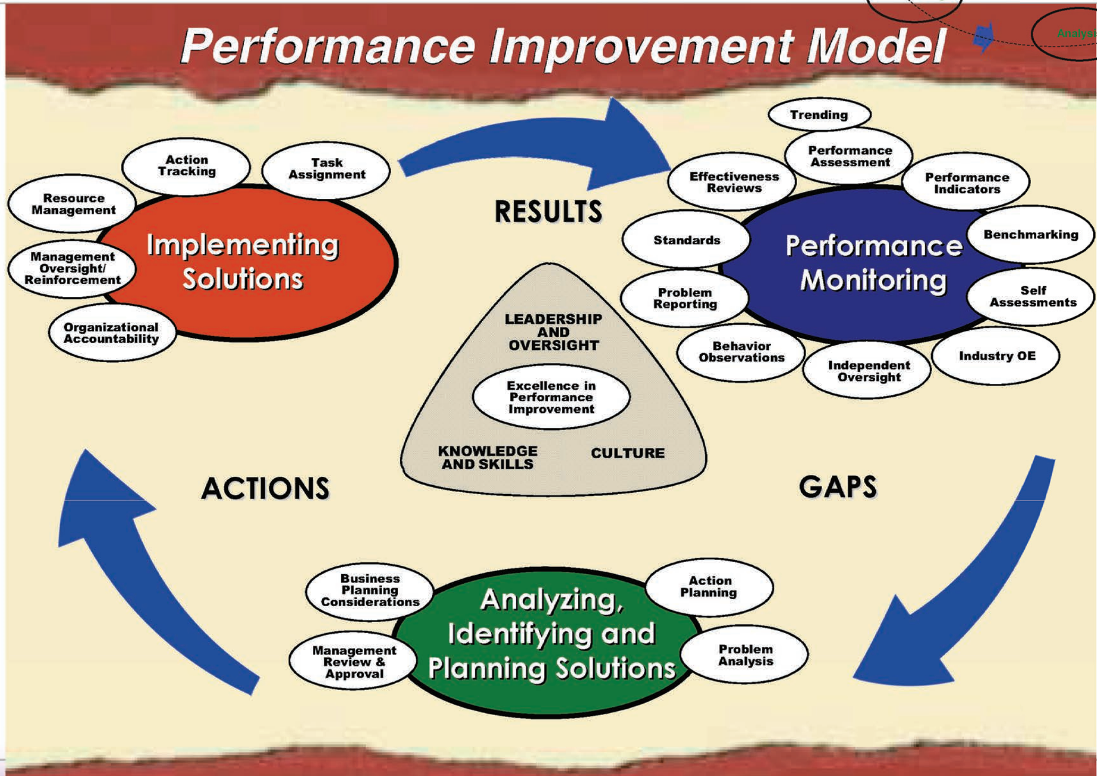
# Analysis methods




- Numerous methods of problem-solving exist, e.g.:
  - Event cause analysis
  - Yellow sticky exercise
  - Stream analysis…
- In the nuclear industry, Event investigation methods and techniques are proposed by: IAEA, INPO, WANO, vendors (Taproot®, Kepner-Tregoe®)…
- Most companies have defined their own process for gap identification and investigation, including roles and responsibilities, procedures to follow and tools to use, depending on event significance.
- Gap identification/investigation is a component of the WANO model of Performance Improvement (Find, Analyse, Fix Gaps).

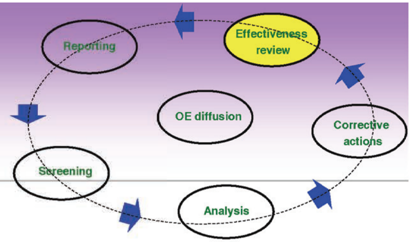
# Corrective Action Programme




1

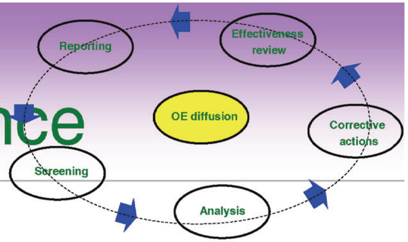
# Effectiveness review




Assess how effectively operating experience information is used.

Review Plant procedures, training documentation, action item tracking logs or databases and interviews.

# Diffusion of Operating Experience




Incorporate OE into:

- Daily Work Activities
- Training Programmes
- Operational Decision Making

# Any questions?