DISCLAIMER

Overview of Radiation Emergencies

Emergencies at Research Reactors

Lecture

Introduction

- First research reactor (RR) began operation in 1942
  - Over 651 research reactors have operated world-wide
  - Approximately 268 are currently in operation
- Total number of operating years for RRs in operation and shut down is in excess of 12,000 reactor years

Introduction (1)

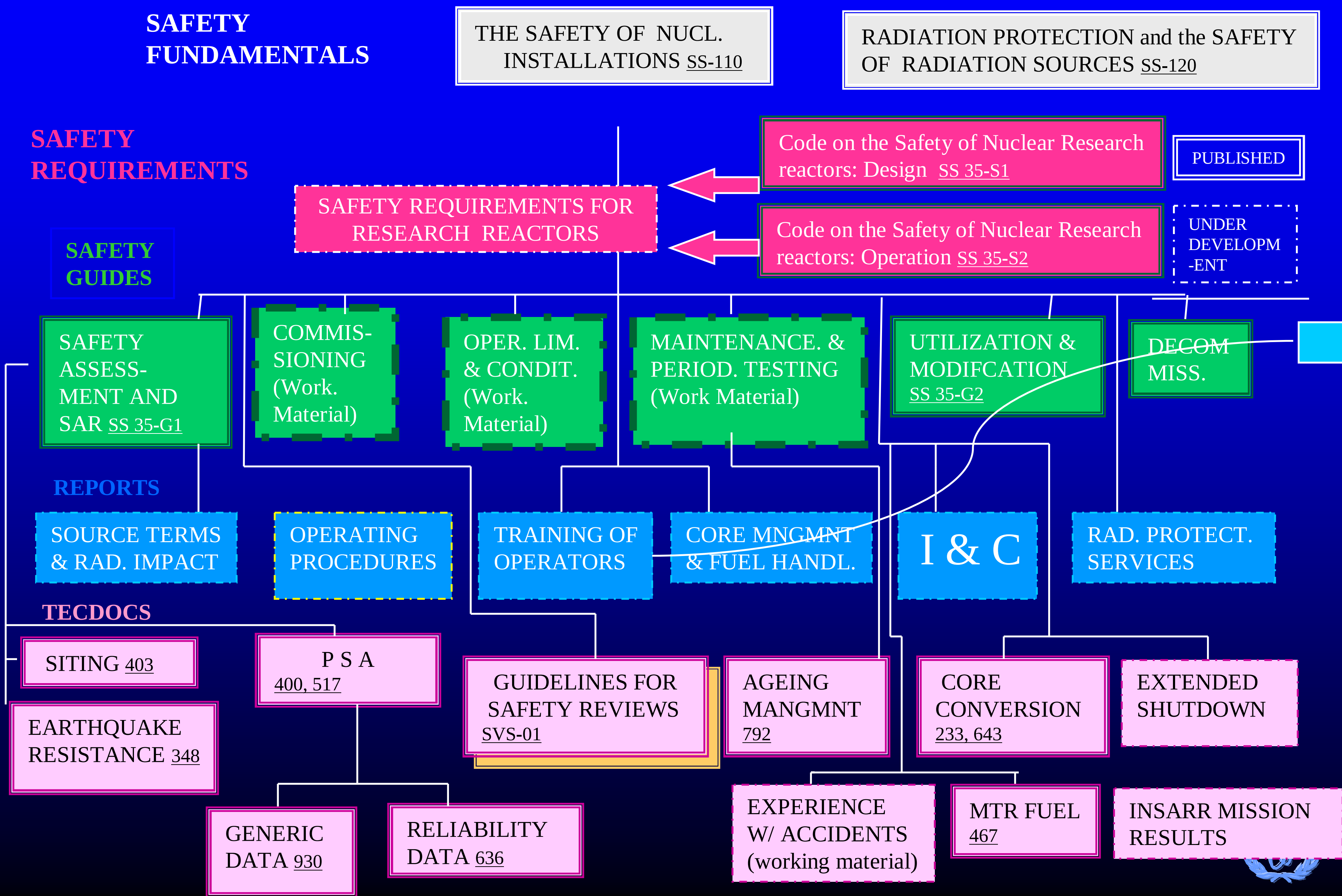
- Emergencies at RRs have occurred
  - Very few may be considered serious emergencies
  - None of them had significant consequences outside reactor building

- The objective of this lecture is to present and explain safety requirements, major emergency initiating events at RRs and lessons learned from past experiences

Content

- Safety fundamentals and requirements
- Major emergency initiating events at RRs
- Accident/incident history at RR facilities
- Lessons learned
- Summary

IAEA RESEARCH REACTOR SAFETY PUBLICATIONS (April 2002)



Safety Objectives

- **Overall safety objectives**
  - **To protect individuals, society and environment from harm by establishing and maintaining in nuclear installations effective defences against radiological hazards**
- **Radiation Protection Objectives**
  - **To keep doses below prescribed radiation exposure limits and as low as reasonably achievable**
  - **To ensure mitigation of radiological consequences of radiation emergency**

Safety Objectives (1)

- **Technical safety objectives**
  - **To take all reasonably practicable measures**
  - **To ensure high level of confidence**
  - **To ensure that likelihood of accidents with serious radiological consequences is extremely low**

Achievement of Safety Objectives

The 3 columns

Government	Regulatory Body	Operating Organization
Legislation establishing the prime responsibility of Safety on OO and Regulatory Body for licensing, regulatory control and enforcement	•To set SS •To license and inspect •To monitor and enforce licence conditions •To monitor corrective actions	•Prime responsibility for safety (design, construction and operation) •Implement safety policies •Clear responsibilities, lines of authority and communications •Staff: sufficient, education and training •Develop procedures •Review, monitor and audit all safety matters

Levels of Defence in Depth

- FIRST: to prevent deviations from normal operation
- SECOND: to prevent system failures and to control deviations from operational states
- THIRD: to provide engineering safety features that are capable of leading reactor facility first to a controlled state, and subsequently to safe shutdown state, and maintaining at least one barrier for confinement of radioactive material
- FOURTH: to address situations in which design basis may be exceeded and to ensure that radioactive releases are kept as low as practicable
- FIFTH: to mitigate radiological consequences of potential releases of radioactive materials

Concepts and Definitions

- **Design Basis**
  - **Range of conditions and events taken explicitly into account in design of facility, according to established criteria**
- **Operational States**
  - **Range of parameters and specified support features**
- **Design Basis Accidents**
  - **Accident conditions against which RR facility is designed according to established design criteria, and for which damage to fuel and release of radioactive material are kept within authorized limits**

Concepts and Definitions (1)

- **Postulated initiating event**
  - **Event identified during design as capable of leading to anticipated operational occurrences or accident conditions**
- **Anticipated operational occurrences**
  - **All operational processes deviating from normal operation which are expected to occur at least once during the operating lifetime of reactor**
- **Beyond design basis accidents**
  - **Accident conditions more severe than design basis accident**
- **Source term**
  - **Amount and isotopic composition of material released or release, used in modelling releases of material to environment**

Emergency Glossary

- **Emergency response**
  - **Actions to mitigate the impact of an emergency**
- **Emergency preparedness**
  - **The capability to promptly take actions that will effectively mitigate the impact of an emergency**
- **Emergency procedures**
  - **A set of documents describing the detailed actions to be taken**

Design Features for Emergencies Planning

- **Depending on potential hazard specific design features for emergency planning shall be considered**
- **Accidents beyond design basis should be considered for purposes of emergency planning and accident management**
- **Provide sufficient technical capability and competence**
- **Meet relevant international requirements**

The ABC…for Ecy. Readiness

- **Emergency procedures**
- **Periodical reviews, lessons learned incorporated**
- **Actions taken by operational personnel and on site services with up to date knowledge**
- **Instruction, training and retraining**
- **Exercises, Exercises, Exercises, Exercises…**
- **Facilities, equipment, tools, documentation, communication always ready**

Safety Requirements on EP for RR

- Emergency plans for research reactor shall be prepared to cover all activities planned to be carried out in event of emergency

- Emergency plans shall be prepared by operating organization, in accordance with requirements of regulatory body, and in cooperation with appropriate governmental and local authorities or other bodies

Safety Requirements on EP for RR (1)

- **Shall be implemented by emergency procedures in form of documents and instructions**
- **Action shall be taken by operating personnel**
- **Emergency response team shall include persons with up to date knowledge of reactor operations and normally should be headed by reactor manager or deputy manager**

Potential Emergency Initiating Events at RR

- **Loss of electrical power supplies**
- **Insertion of excess reactivity**
- **Loss of flow**

Potential Emergency Initiating Events at RR (1)

- Loss of coolant
- Erroneous handling or malfunction of equipment or components
- Special internal events
- External events
- Human errors

Accident History and Statistics

- **Criticalities: 16 events**
  - **9 on critical assemblies**
- **Loss of flow accident: 11 events**
- **LOCA: 6 events**
- **Erroneous handling/failure of equipment: 25**
- **Special events (external or internal): 2**

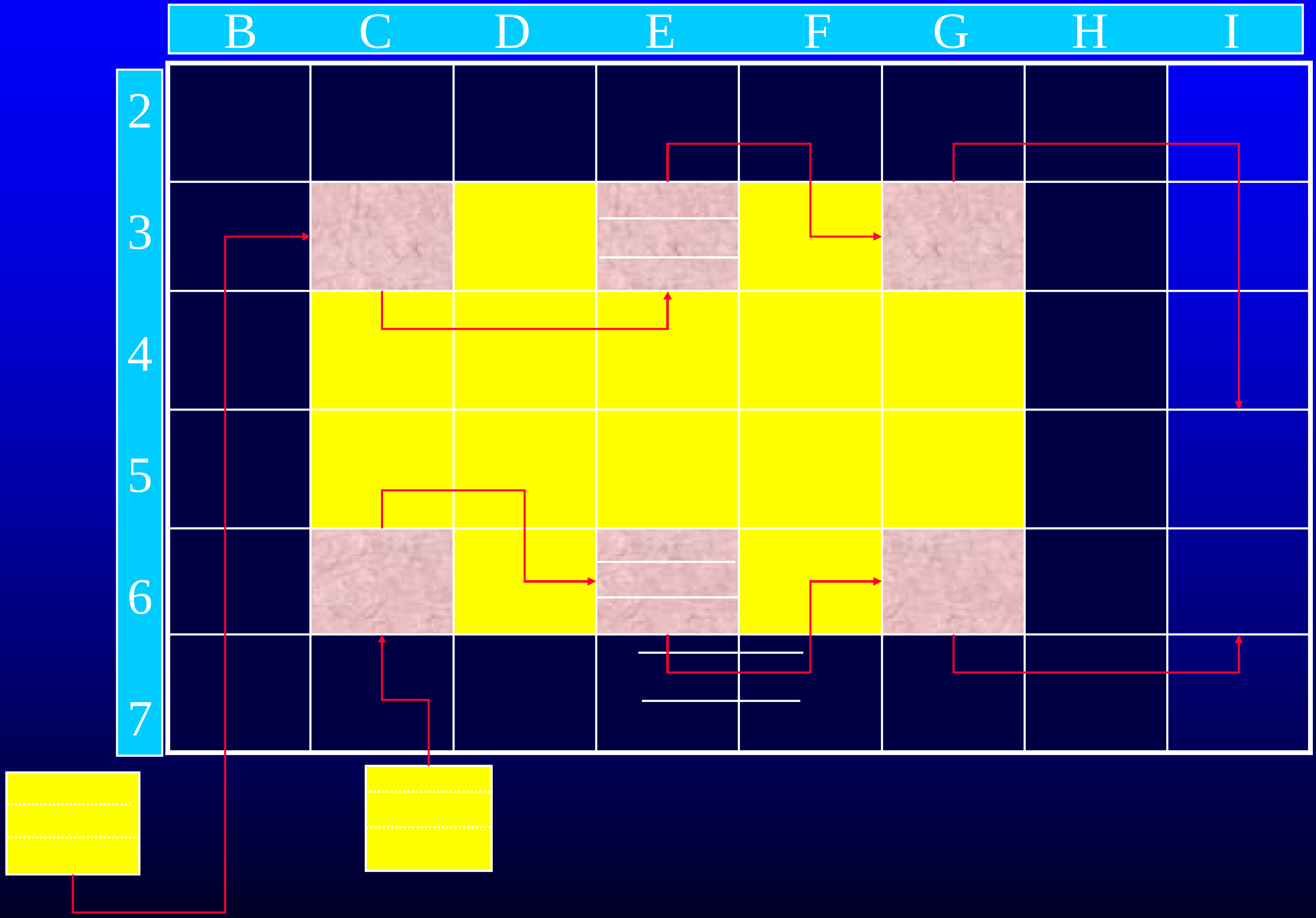
- **Number of fatalities reported: 12**

RA-2 Criticality Excursion

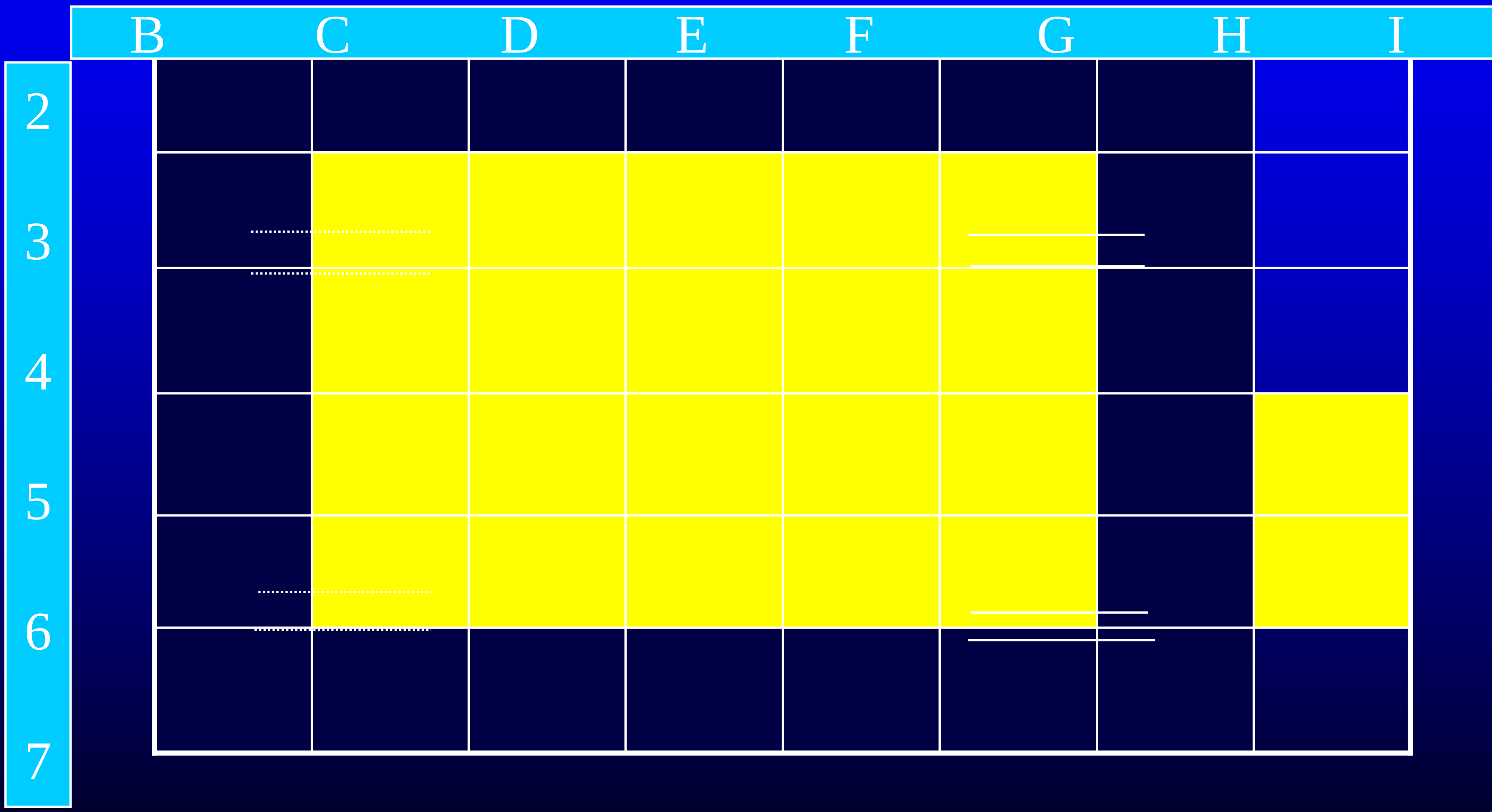
- **Argentina, 1983/09/23, RA-2, 0.1 Watt, Critical Assembly**

- **What happened**
  - **Due to operator's error and violation of safety rule, assembly became supercritical on prompt neutrons (reactivity insertion of 1170 PCM)**
  - **Energy released was 10 MW sec with peak of 200 MW**

RA-2 – Sequence of Fuel Movements



RA-2 – "Final" Configuration



RA-2 ….. (1)

- Operator received dose of 21 Gy gamma and 22 Gy neutrons and died after 48 hours

- Other people received doses between 0.006 to 0.25 Gy

- Several fuel elements were damaged with no release of fission products

RA-2 ….. (2)

- **Root causes and corrective actions**
  - **One operator alone performed operation**
  - **Fuel manipulation while moderator not completely dumped**
  - **Decision to change core configuration taken by an operator, without having an approved plan for this activity**

RA-2 ….. (3)

- **Poor planning of the core re-arrangement:**
  - **Sequence of operations not appropriate**
  - **Storing 2 fuel elements, taken out of the core, next to reflector**
  - **Introduction of 2 special control fuel elements without absorber blades into the core**

RA-2 ….. (4)

- **Lessons learned**
  - **More attentions should be paid to development of safety culture and training of operators in critical assemblies**
  - **Fuel management and particularly changes to core configuration should be approved by reactor manager**
  - **Management and assignment of responsibilities should be defined clearly**

Prevention of accidents

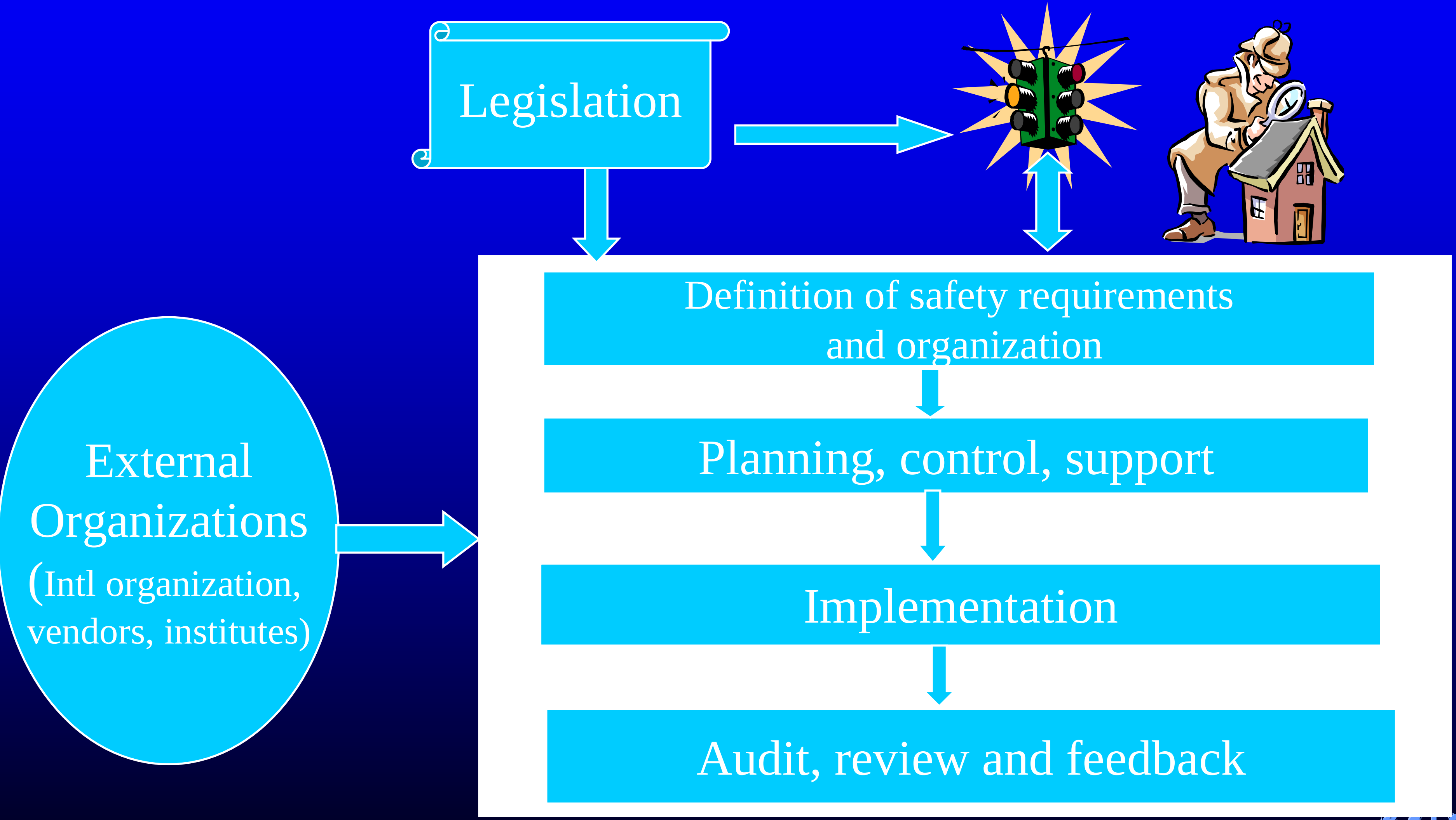
- **Good Engineering, construction and maintenance**

- **Enough resources**

- **Training and qualification**

- **Organizational and cultural issues**

Prevention of Accidents
Safety Management (INSAG-13)



Homework for Participants

- Describe shortly one typical RR in your country (no more than 10 lines)
  - One you are operating or one you are supervising
- Identify main hazards of that facility
  - Internal
  - External
- List operational aspects that require particular attention in QA programme in RR and say why
- Have you ever participate in an exercise of an emergency situation in that facility? If yes, say when was last occasion

Summary

- **Current status of research reactors**
- **Safety requirements and elements of EP for RR**
- **Emergency experience and lessons learned from past emergencies**

Where to Get More Information

- **Safety Series 35, S1 and S2**
- **IRSRR (Incident Reporting System for RR)**

Appendix

More Cases of Emergency at RR

Criticality Excursion Due to Manual Withdrawal of Control Rods

- USA, 1949/12, Water Boiler (Hypo), 6kW
- Homogenous: Uranyl nitrate/Graphite reflected
- Start of operation: 1944
- Abstract
  - Two control rods were manually lifted from core, while reactor was shut down and control panel was shut off
  - Reactivity insertion was 0.86% -K/K to a period of 0.16 sec

Criticality Excursion … (1)

- **Power excursion was estimated to be 3 - 4 x 10E16 fissions and lasted 1.5 sec**
- **Excursion was not detected immediately**
- **Reactor was shut down by negative temperature coefficient**
- **Operator received 25 mSv (2.5 rem) gamma radiation**
- **Reactor was not damaged**

Criticality Excursion … (2)

- **Root causes and corrective actions**
  - **Root cause of this accident was the possibility to manually lift the control rods**
  - **As result of this accident, enclosure at top of reactor was provided with lock which was accessible only to senior members of group**

Criticality Excursion … (3)

- **Lessons learned**
  - **Reactors should be designed so that it is very difficult or impossible to raise control rods by hand, unless special criteria are met and adequate procedures are followed. (e.g.. partial unloading of core)**
  - **No employee should be allowed to work alone or isolated in any dangerous operation**
  - **Operations involving reactivity changes shall be carried out**

SL-1 Power Excursion Due to Manual Withdrawal of Central Control Rod

- **USA, 1961/1/3, SL-1, 3 MW, BWR, 1958**
- **What happened**
  - **Manual withdrawal of central control rod gave rise to transient with peak power of 1.9 ± 0.4 x 104 MW, total energy release of about 133 MW sec. and temperature about 10000 C in centre of fuel meat**
  - **Reactivity insertion of 2.4% -K/K caused power rise on period of 4-5 msec**

SL-1 …. (1)

- **Formation of steam void terminated transient**
- **Pressure wave lifted pressure vessel 3 meters up**
- **Kinetic energy released caused serious mechanical damage**
- **Flying debris and radiation release caused death of 3 operators**

SL-1 …. (2)

- **Root causes and corrective actions**
  - **SL-1 accident involves design errors, inadequate organisation and human mistakes**
  - **Principal design error was use of control rod mechanism design which required that rod itself be raised by hand during assembly and disassembly**
  - **This, coupled with the fact that single rod withdrawal could make rector critical placed entire responsibility in hands of human operator**
  - **In this case, positive mechanical limit could have prevented accident**

SL-1 …. (3)

- Second important design error was use of burnable poison in form of Boron-Aluminium strips, uncladded and spot welded to fuel

- This design resulted in too rapid burn-up of Boron, that, coupled with corrosion and disintegration of these plates, caused reactivity gain over core life period and reduction of shutdown margin

SL-1 …. (4)

- **Lessons learned**
  - **Reactor should have enough control rods, thus reducing the reactivity worth per rod**
  - **It should be impossible for reactor to be made critical in its most disadvantageous situation by withdrawal of single rod**
  - **Design of safety related systems should not be influenced by pressure on personnel or tight time schedules**

SL-1 …. (5)

- Untested materials should not be used in core
- Manipulation of core components should be carried out only when control instrumentation is activated and operator is communicating with control room
- Importance of emergency planning was demonstrated in this case: remote and accessible emergency depot, adequate equipment and procedures

Partial Fuel Meltdown Accident in SILOE Reactor

- **France, 1967/11/7, SILOE, 30 MW, Pool type**
- **What happened**
  - **During overpower testing fuel element partially melted, either due to coolant flow redistribution or foreign object blocking coolant flow**

SILOE Reactor …. (1)

- **Meltdown of 6 fuel plates of overall weight equal to 36.8 grams of uranium, of which 18 grams was uranium U-235, led to release of 55,000 Ci of fission products to reactor water pool and 2,000 Ci, most of which were noble gases, were released through stack within two days after accident**

- **There was no personnel irradiation and releases to environment were insignificant**

SILOE Reactor …. (2)

- **Sequence of Accident**
  - **At 15:02 (t_0) reactor power dropped by 7MW, then more slowly to 20 MW**
  - **t_0 +20s: Reactor power auto-stabilized at 20MW**
  - **t_0 +26s: Reactor scram by safety rod drop**
  - **t_0 +45s: Rapid increase of gamma activity measured by underwater monitors; high radiation alarm and evacuation**
  - **t_0 +50s: Ventilation system switched over to emergency mode**

SILOE Reactor …. (3)

- t_0 +144s: Primary Coolant Pump stopped
- t_0 +several min: Maximum dose rate
- t_0 +47hr: Return to normal environment
- t_0 +70hr: Core dismantling started, remove molten fuel plate
- t_0 +160hr: Reactor restarted

SILOE Reactor …. (4)

- **Root causes and corrective actions**
  - **Coolant flow redistribution could have happened at 35.5 MW if all uncertainties were algebraically added at hot spot or at 51.5 MW if uncertainty coefficients were statistically added**
  - **Probability for this to be reason is very low**
  - **Foreign object, which could have blocked several flow channels in fuel assembly, and disappeared later on during accident**

SILOE Reactor …. (5)

- **Such foreign object could have been piece of dry paint that peeled off reactor pool walls**
- **In order to avoid recurrence of accident, power of Silo reactor was limited in normal operation to 30 MW and maximum overpower during tests was limited to 39 MW**
- **Paint was removed from all reactor structures above reactor pool**

SILOE Reactor …. (6)

- **Lessons learned**
  - **All possibilities of foreign objects falling into core must be eliminated**

25

  - **After accident appropriate instructions were given to personnel regarding this matter**
  - **These instructions became part of operating procedures**

SILOE Reactor …. (7)

- **Experience with this accident showed that melting of fuel of low burn up is much less hazardous than previously thought**

- **Although 18 grams of molten uranium were transferred to primary cooling circuit during accident, they did not contaminate entire system, but remained in delay tank and were removed without much trouble one year later**

SILOE Reactor …. (8)

- **Number of improvements in Siloe systems were introduced after accident in order to provide remote control of purification system, improve efficiency of ventilation system, and provide better shielding of filters**