Nuclear Safety Research in Germany

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RIC 2011

Background (1)

German Atomic Energy Act

„§1 Purpose of the Act

The purpose of this Act is

1. *to phase out the use of nuclear energy for the commercial generation of electricity in controlled manner, and to ensure orderly operation up until the date of termination,*
2. *…"*

Background (2)

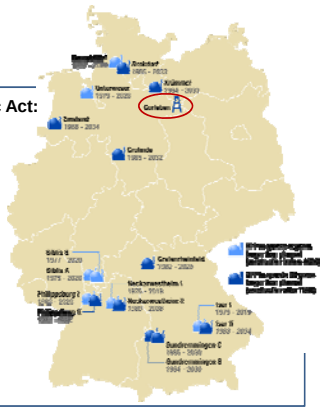
German Atomic Energy Act

2010 Amendment of the Atomic Act:

- Moderate extension of operational lifetimes to gain time until renewables are mature for the market **(32 + 8) or (32 + 14) FPYs**

2009 coalition decision:

- Termination of exploration moratorium of the Gorleben rock salt site
- Completion of exploration and objective assessment of results



Problems & Chances

Phase out and missing of a large national nuclear energy project impedes

- Maintain experimental infrastructures
- Maintain competence, recruit young engineers and scientists

But

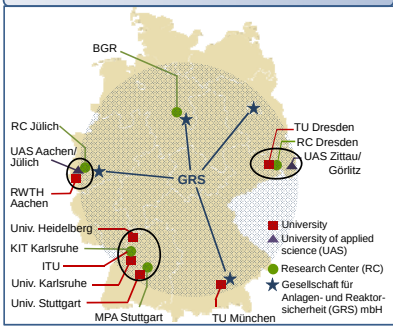
- Promotes involvement of German research institutions into international collaborations
  - Sustainable Nuclear Energy Technology Platform (SNETP)
  - Implementing Geological Disposal Technology Platform (IGDTP)
  - EURATOM framework programs

General Objectives

- Provide state of the art methods and codes to assess, maintain and further enhance the safety of German nuclear power plants
- Create the know-how needed to analyze and influence the safety of new technologies and reactor concepts developed worldwide (GEN-III, III+, IV and P&T)
- Make available tools and methods for the safety performance assessment of geological radioactive waste repositories

Involved Institutions and Framework

Competence Alliance on Nuclear Technology



4 clusters centered around:

- KIT Karlsruhe
- RC Jülich
- RC Dresden-Rossendorf
- GRS

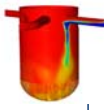
Role of GRS:

- Identification of LWR safety research priorities
- Implementation of results into validated methods and codes for safety assessment
- Application in regulatory process

Public Funding of Nuclear Safety Research

		2010 approx.
BMBF Federal Ministry of Education and Research	• Institutional funding (Research Centers) • Promotion of young academics in nuclear safety research	50 Mio €
BMWi Federal Ministry of Economics and Technology	Project grants for • Reactor safety research • Final repository research	33 Mio €
BMU Federal Ministry for the Environment, Nature Conservation & Nuclear Safety	Generic safety issues • Regulatory context	31 Mio €
European Commission	• Radioactive waste disposal • Nuclear technology and reactor safety • Radiation protection	6 Mio € (2009)
		120 Mio €

Current Main Topics



- **LWR thermal hydraulics**
- **Reactor physics and fuel behavior**

} multi-scale, multi-physics simulation

- **Sensitivity and uncertainty analysis**
- Stress/strain limits of materials and components
- **Ageing of reactor components, incl. irradiation induced degradation effects**
- Nondestructive material description and testing
- **Severe accident research**
  - **in-vessel core degradation and in-vessel melt retention**
  - **containment phenomena**
    - **ex-vessel melt behavior**
    - steam explosion phenomena
    - **fission product behavior**
    - **hydrogen distribution, combustion and countermeasures**
- **PSA and human factors**
- Digital I&C
- Long term operation
- **New reactor concepts (GEN III+, GEN IV, P&T)**

Figure: Lucas, D. HZDR (2009), GRS-A-3432

LWR Thermal Hydraulics

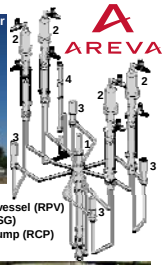
PKL Integral Test Facility Simulation of a 1300 MW PWR

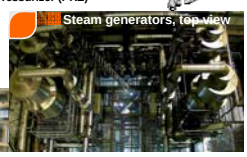
Main Design Features

- 4-Loop configuration: prim. and sec. side
- All relevant safety and operational systems
- Elevations 1:1, diameter 1:12 (volume and power scale 1:145)
- Extensive instrumentation with about 1500 measuring locations (incl. boron concentration measurements)

General Objectives

- Thermal hydraulic system behavior under accident situations
- Efficiency of countermeasures, demonstration of safety margins
- Data base for code validation
- Solving of actual PWR safety issues

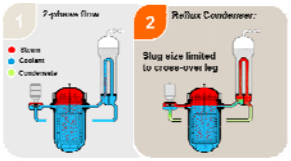




LWR Thermal Hydraulics

PKL Tests

- **More than 150 integral tests at AREVA NP in Germany on:**
  - LB / SB-LOCA, SG tube rupture, MSL-break, loss of feed water transients, SBO etc.
  - efficiency of counter-measures (e.g. cool down, bleed-and-feed)
- **International OECD-Programs since 2001: 25 organizations from 15 countries,** US (NRC), Japan, Korea and 12 EU countries
- **Major topics in recent years:**
  - accidents under cold shutdown conditions (failure of RHRS)
  - boron dilution following SB-LOCA: limitation of the size of a single boron-depleted slug to the cross-over leg
    - complemented by mixing tests at the Rossendorf **ROCOM** facility

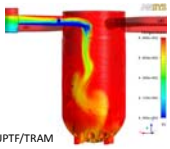


LWR Thermal Hydraulics

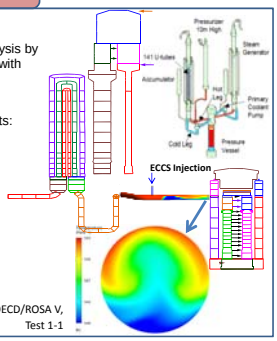
Validation of 3D CFD for One-phase Flows and Coupling to System Codes

ATHLET - ANSYS CFX

- Objective: Improvement of 1D system code analysis by 3D CFD simulation of selected areas with complex flow behavior (downcomer, ECC injection, etc.)
- Example 1: Validation of CFX against mixing tests: ROCOM, UPTF/TRAM
- Example 2: Validation of ATHLET-CFX on OECD/ROSA V, Test 1-1



UPTF/TRAM



OECD/ROSA V, Test 1-1

LWR Thermal Hydraulics

CFD Models for Multi-phase Flows

Development and validation of CFD models for transient two-phase flows

TOPFLOW:

- Based on experiments at the TOPFLOW large scale facility
- Reference experiment of the German CFD-Association in reactor safety
- Vertical pipe flows
- Stratified flows up to CCFL
- PTS-phenomena (EdF, CEA, PSI,..)

Parameters:

- water-air-vapor-mixtures
- p_{max} = 7 MPa, T_{max} = 286°C
- $\dot{M}_{vap}$ = 2 kg/s (with N_{max} = 4 MW)
- $\dot{M}_{water}$ = 50 kg/s
- industry relevant scale

- **Unique parameters and innovative measuring technologies**

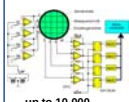
Transient Two-Phase Flow Test Facility at RC Dresden

LWR Thermal Hydraulics

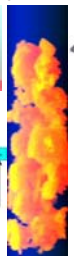
CFD Models for Multi-phase Flows

Advanced Two-phase Flow Instrumentation

Ø 200mm
64x64 meas. points

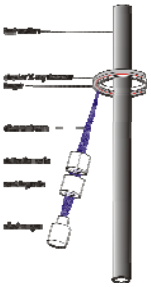


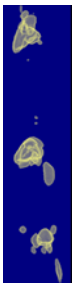
up to 10 000
frames/sec



High-pressure
wire-mesh
sensor
70 bar, 286°C

Measurement
even at high gas
volume fraction
possible





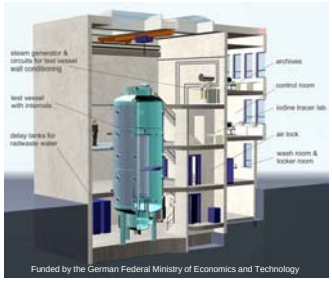
Wire-mesh sensors (intrusive)

Spatial resolution: sub-mm
Time resolution: sub-ms

Ultra fast X-ray tomo-graphy (non-intrusive)

Severe Accident Research

Containment Phenomena: Test Facility THAI



Funded by the German Federal Ministry of Economics and Technology

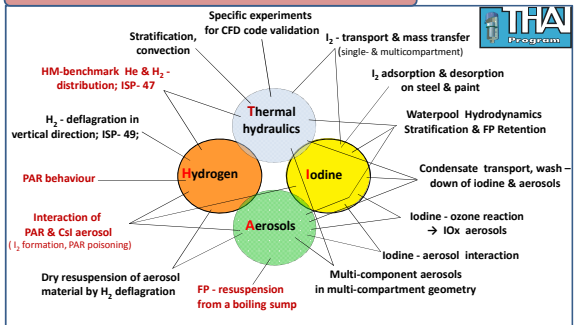
Technical scale facility to perform separate/coupled effect experiments in the areas of:

Thermal Hydraulics - **H**ydrogen - **A**erosols - **I**odine

- **Dimensions:** V= 60 m³, H= 9.2 m, D= 3.2 m
- **Overpressure:** 14 bar at 180°C
- **Modular structure:** adjustable internals
- **Controlled walls:** three independent heated/cooled mantles over height
- **Controlled area for use of Iodine radiotracer** up to 5 GBq I-123
- **Advanced aerosol generation & instrumentation**
- **Feeding systems for** He, H_2, steam, air

Severe Accident Research

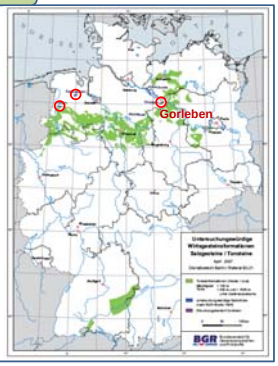
Containment Phenomena: THAI Research Fields



- H_2 recombination during spraying; and O_2 starvation; HTGR graphite dust experiments offered to OECD

Possible Areas for Repository Sites

- Low permeable host rocks such as rock salt and clay are favored in Germany as host rocks for the final disposal of high-level radioactive waste (HLW)



Candidate salt (○) and clay (▬) repository areas (BGR 2007)

Final Disposal Concept

- **Preliminary safety case for the Gorleben site**
  - **Consortium: GRS**, BGR, DBETec, ISTec, RWTH Aachen (NSE), Inst. for Geomechanics, KIT-INE, TU Clausthal
  - **Contents of project:**
    - Compilation of basic information:
      - characteristics of geology and of wastes to be disposed
      - basic safety concept
      - concept for demonstration of safety
    - Development of concepts for emplacement of wastes and for closure of repository
    - Integrated post closure safety analysis
    - Synthesis of results and preliminary evaluation of fitness for purpose
  - **International Peer Review** of results in 2013

Conclusion and Outlook

- In spite of the phase out scenario, German research institutions still cover major fields of nuclear safety: focus on LWR safety
- Key LWR related experimental infrastructures are running but are threatened by phase out
- Need to resolve the final disposal issue will push disposal research
- German research institutions offer advanced computer codes and modern experimental facilities relevant to GEN-IV and P&T: e.g. liquid metal labs at KIT and RC Dresden, HTR related experiments at RC Jülich, RC Dresden, and KIT

THANK YOU !

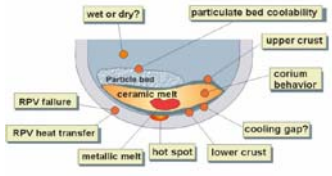
Funding of Nuclear Safety Research

- Safety research for existing LWRs:
  - mainly nationally funded by Federal ministries (BMBF, BMWi, BMU), States, and Industry
  - through base financing of research institutions & universities + dedicated project grants
  - partly embedded into and co-financed by international programs of EU, OECD, etc.
- Safety research on new concepts (GEN-III to GEN-IV, P&T)
  - mainly funded through international projects of EU, OECD, and industry
  - partly co-financed by national funds
- Final disposal research
  - for all formations (salt, clay, granite) mainly relies on national funding
  - complementary funding through EURATOM program

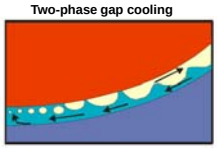
Severe Accident Research

In-vessel Melt Retention

- Relevant phenomena:
  - crust formation
  - heat transfer melt → crust
  - heat transfer melt → covering water on top of melt
  - two-phase gap cooling and heat transfer to RPV
  - heat transfer through RPV
  - heat transfer to external water pool



Two-phase gap cooling

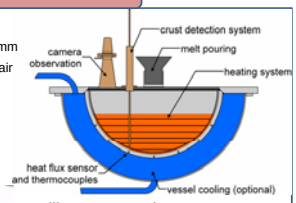


Severe Accident Research

In-vessel Melt Retention: LIVE Test Vessel at KIT

Parameters

- 1:5 scaled RPV, Ø1 m, wall thickness ~30 mm
- cooling vessel to allow cooling by water or air
- heating furnace of ~220 l volume
- volumetric heating system (heater rods in $NaNO_3$-KNO_3)
- maximum temperatures of up to 1100°C
- central and non-central melt release



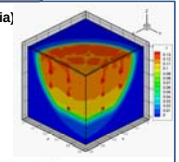
Facility Instrumentation

- thermocouples
- mechanical sensors
- video (optical and IR) cameras
- weighing cells
- recording of the power input
- extraction of melt samples

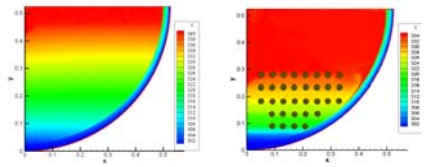
Severe Accident Research

Application of LIVE Testes for SA Codes Validation

- **KIT: 3D thermo hydraulic CFD code CONV (IBRAE Russia)** for the simulation of heat transfer due to conduction and convection in complex geometry, crust formation, etc.
- **GRS: module AIDA within ATHLET-CD**



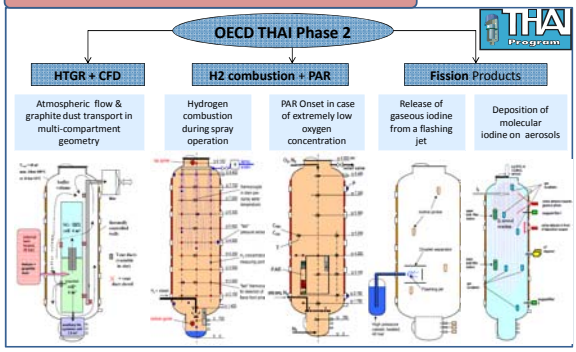
CONV calculation: comparison of volumetric heating versus heating by LIVE spiral



Temperature distribution in the transient heat-up phase

Severe Accident Research

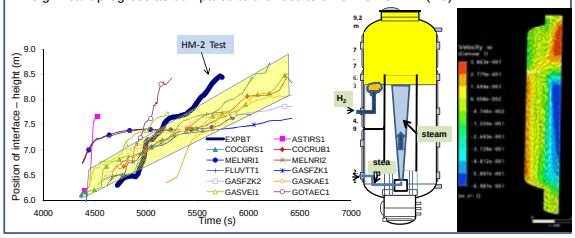
Containment Phenomena: OECD THAI Phase 2



Severe Accident Research

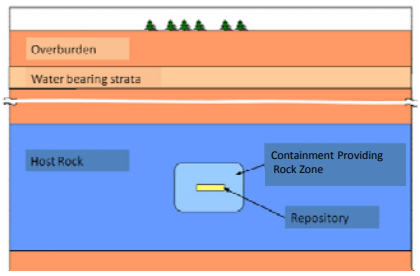
Containment Phenomena: THAI Hydrogen Distribution

- Lower edge of H_2 cloud eroded by the steam plume – stratification interface moves up gradually
- Most of the blind simulations under-predicted the erosion speed in a conservative way
- Significant progress as compared to the results of former ISP-47 (**He**)



Final Disposal Concept

- According to the new safety criteria published by BMU in 9/2010 the containment of HLW in a **Containment Providing Rock Zone** is to be proven for 1 million years



Final Disposal Concept

Current main topics

- Barrier properties of host rock and (geo)technical barriers
- Investigation and modeling of thermal-hydraulic-mechanical-chemical coupled processes
- Development of a quality assured and consolidated thermodynamic data base for (geo)chemical modeling
- System evolution (scenarios, features/events/processes (FEP) catalogue)
- Improvement of computer codes and 3D-visualization of modeling results
- Participation in European Underground Research Laboratories (URL) (Mt. Terri Project/Switzerland, URL Bure/France)

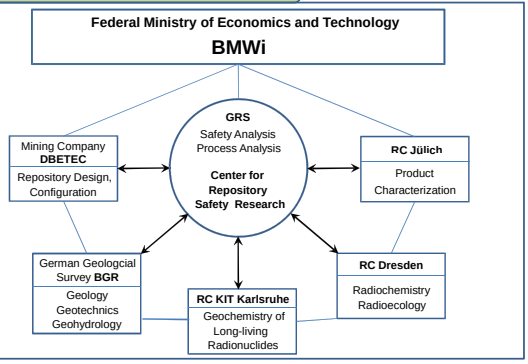
Institutions and their Roles

- In Germany, the state (federal government) is responsible for the final disposal of radioactive waste
- The Federal Office for Radiation Protection (BfS) is responsible for the operation of the repository, supervised by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

  The mining company "Deutsche Gesellschaft für den Bau und Betrieb von Endlagern für Abfallstoffe (DBE)" operates the repository mine in charge of BfS

- Final Repository Research is managed and financed by the Federal Ministry of Research and Technology (BMWi)

Major Involved Research Organizations



Severe Accident Research

Containment Phenomena

- Relevant phenomena:
  - aerosol & iodine
  - H_2-distribution/-combustion/-recombination
  - RPV failure & DCH
  - MCCI
- Main running experimental programs:
  - THAI (different phenomena)
  - DISCO (DCH)
- International collaboration
  - EURATOM: SARNET-2
  - Several OECD-projects
- Modell development & code validation for PWR & BWR
  - COCOSYS – detailed German lumped parameter containment code
  - ASTEC – European integral code developed by IRSN & GRS
  - CFX – validation for containment application using THAI, PANDA, BMC experiments