Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

GIF , HTR

Prof. Wolfgang Kröger

(http://www.riskcenter.ethz.ch, kroeger@ethz.ch)

Generation IV Initiative – Aims (1/2)

Nuclear energy-systems including fuel cycles of the 4th generation should ...

SR-1 ... be excellent regarding safety and reliability while in operation.

SR-2 ... have very low core damage frequency and little consequences.

SR-3 ... eliminate the need for emergency planning outside of the plant.

EC-1 ... clear lifecycle-cost advantages over other energy sources.

EC-2 ... comparable financial risk to other energy projects.

Generation IV Initiative – Aims (2/2)

Nuclear energy-systems including fuel cycles of the 4th generation should ...

SU-I ... produce sustainable energy, following regulations for air pollution prevention and enhancing the long term availability of the system and efficient usage of fuel.

SU-2 ... minimise the nuclear waste and disposing it, especially they will reduce administration efforts on a long term scale and hence improve the protection of health and environment.

SU-3 ... increase the certainty that they are an undesirable and difficult source to obtain dangerous materials for usage in weapons.

Selected Generation IV Concepts (out of 21)

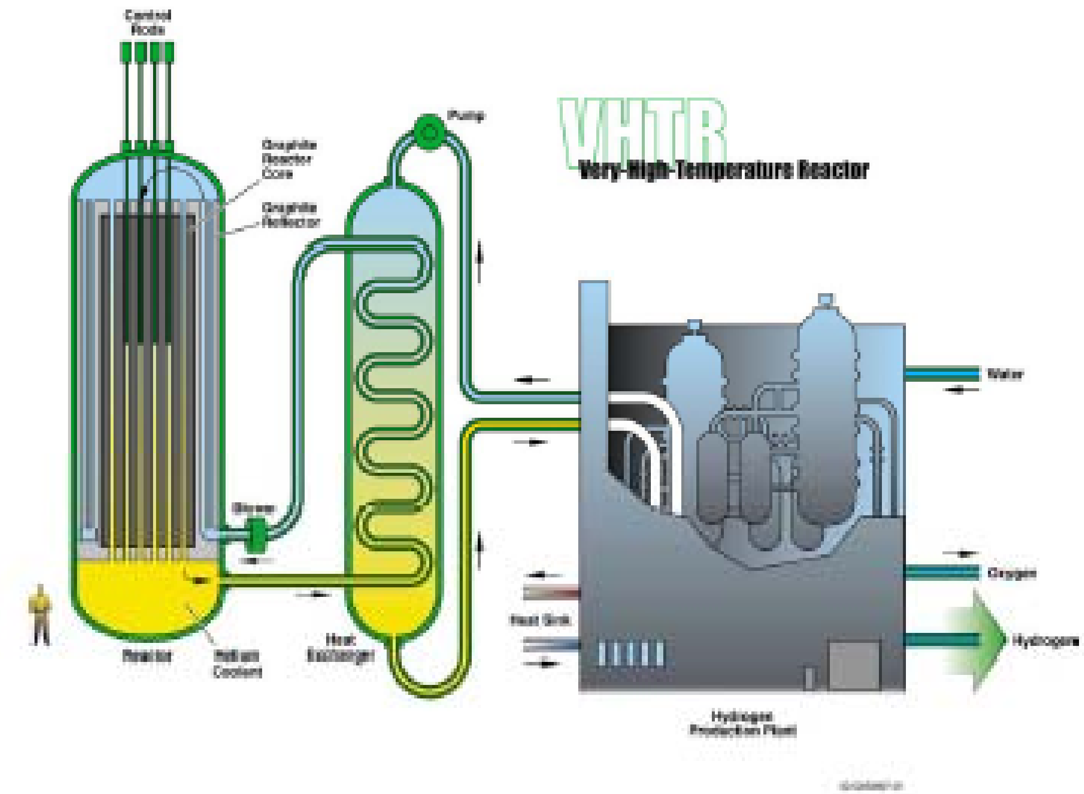
GEN IV Concepts	Acronym	Spectrum	Fuel cycle	Temperature [° C]	Pressure [bar]
Sodium Cooled Fast	SFR	Fast	Closed	530-550	1
Lead Alloy-Cooled	LFR	Fast	Closed	550-800	1
Gas-Cooled Fast	GFR	Fast	Closed	490-850	90
Very High Temperature	VHTR	Thermal	Once-Through	640-1000	70
Supercritical Water Cooled	SCWR	Th.&Fast	Once/Closed	280-510	250
Molten Salt	MSR	Thermal	Closed	565-850	< 5

VHTR - Technology gaps

Process-specific R&D gaps exist to adapt the chemical process and the nuclear heat source Qualification of high-temperature alloys and coatings.

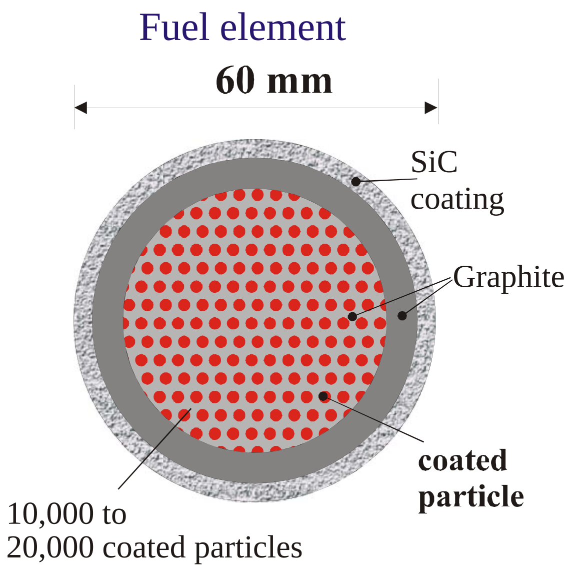
Performance issues include development of a high-performance helium turbine.

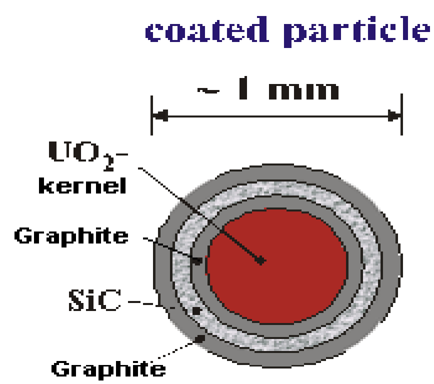
Modularization of the reactor and heat utilization systems is another challenge for commercial deployment of the VHTR.

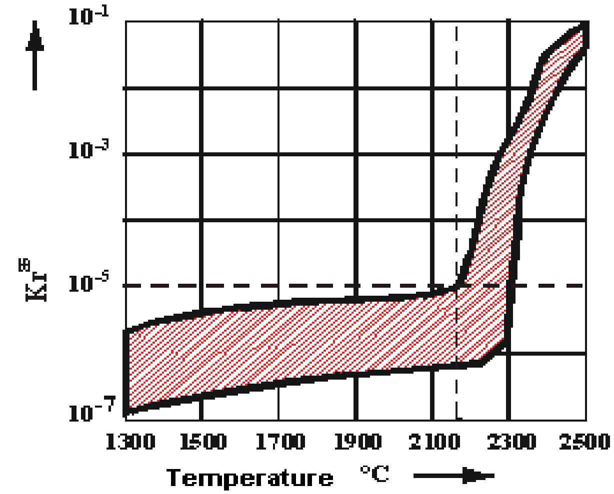


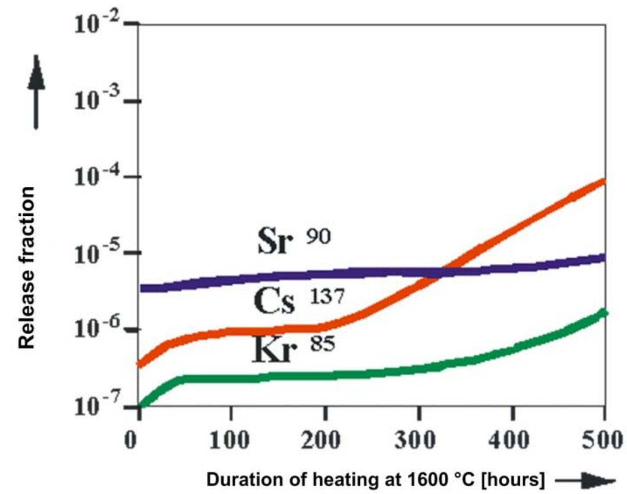
Concept of a modular HTR (1/3)

Fuel element and restraining the fission products up to 1600° C





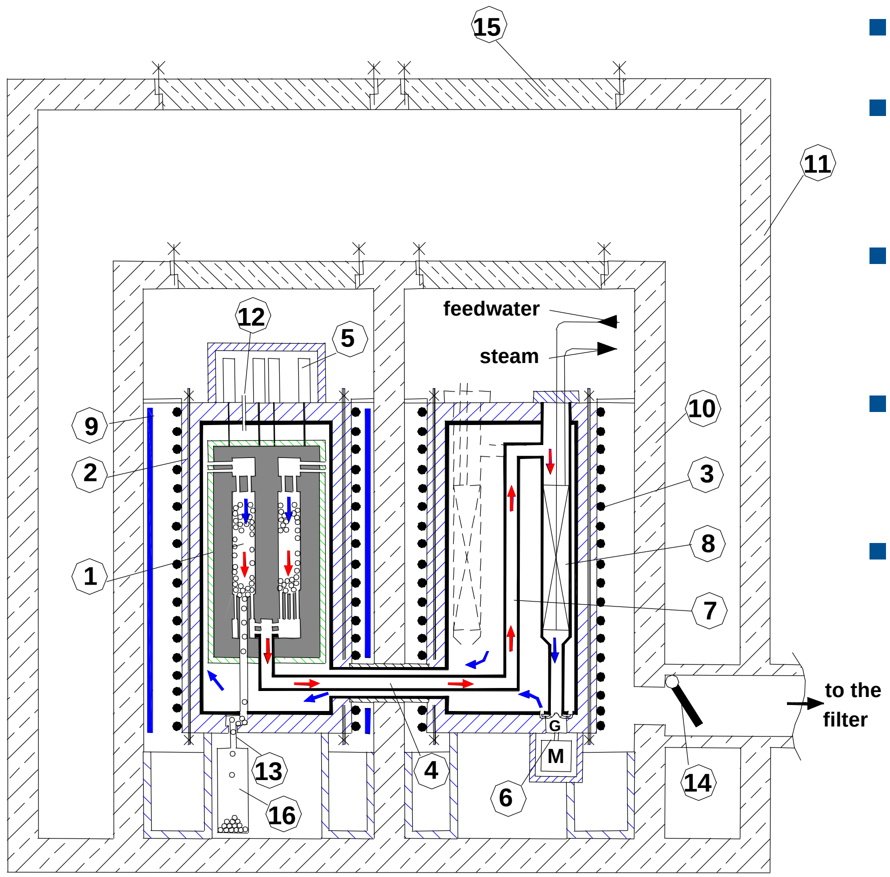




Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Concept of a modular HTR (2/3)

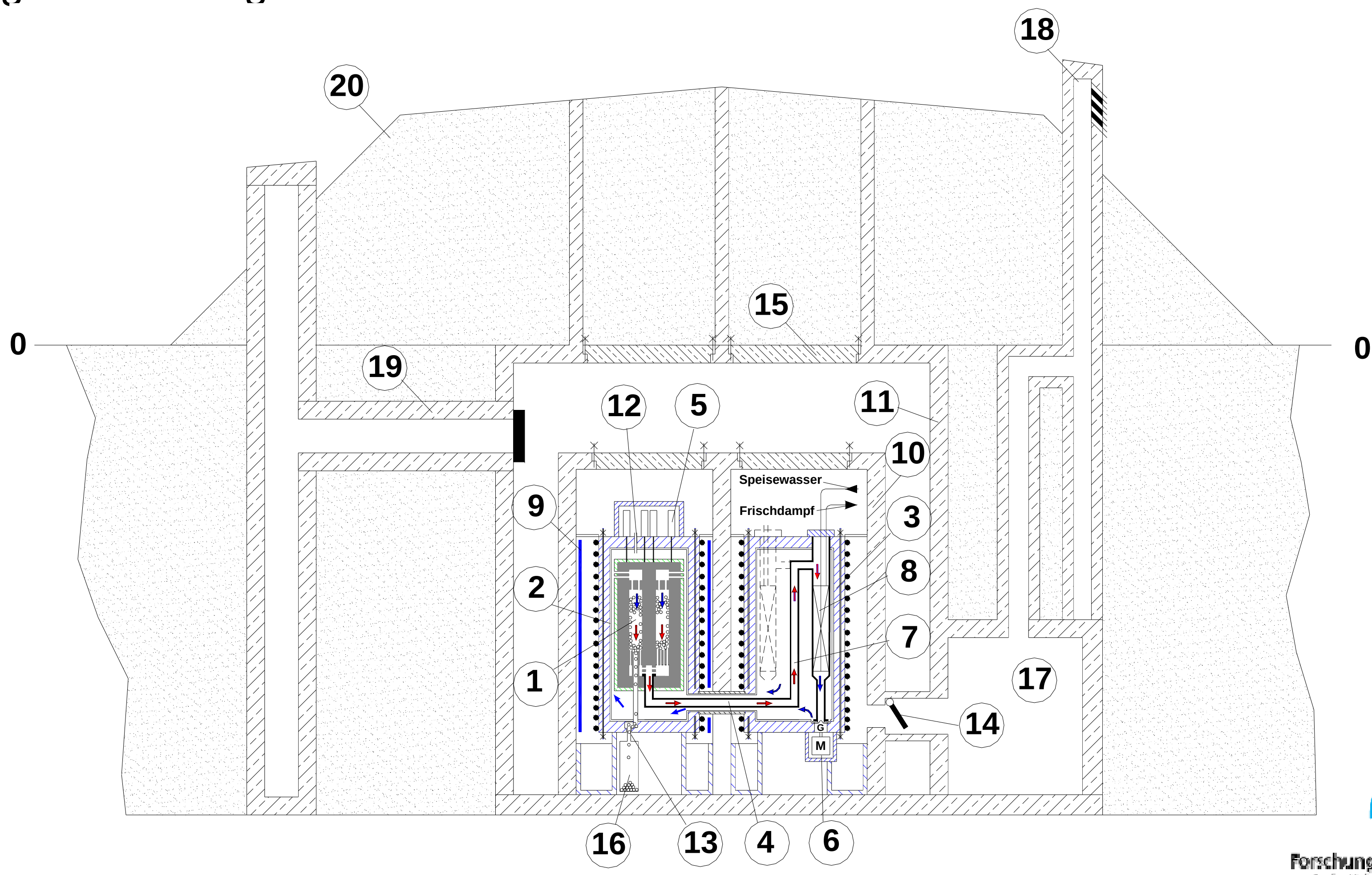


- Thermal power 300MW
- Circular core
- Pre-stressed primary loop as an burst prove inclusion
- Interior concrete cell with a limitation on air amount
- Underground arrangement of the reactor building
- Use of the primary loop to steam production, gas turbines and process heat applications (with in-between heat exchanger)

Forschungszentrum Jülich

Concept of a modular HTR (3/3)

Underground arrangement of the reactor



Accident behaviour of a modular HTR (1/10)
Accident assumptions

internal Causes

- Full loss of coolant
- Full loss of the active residual heat removal
- Massive water ingress into the primary system
- Massive air ingress into the primary system
- Extreme reactivity disturbances
- Massive damage of reactor components

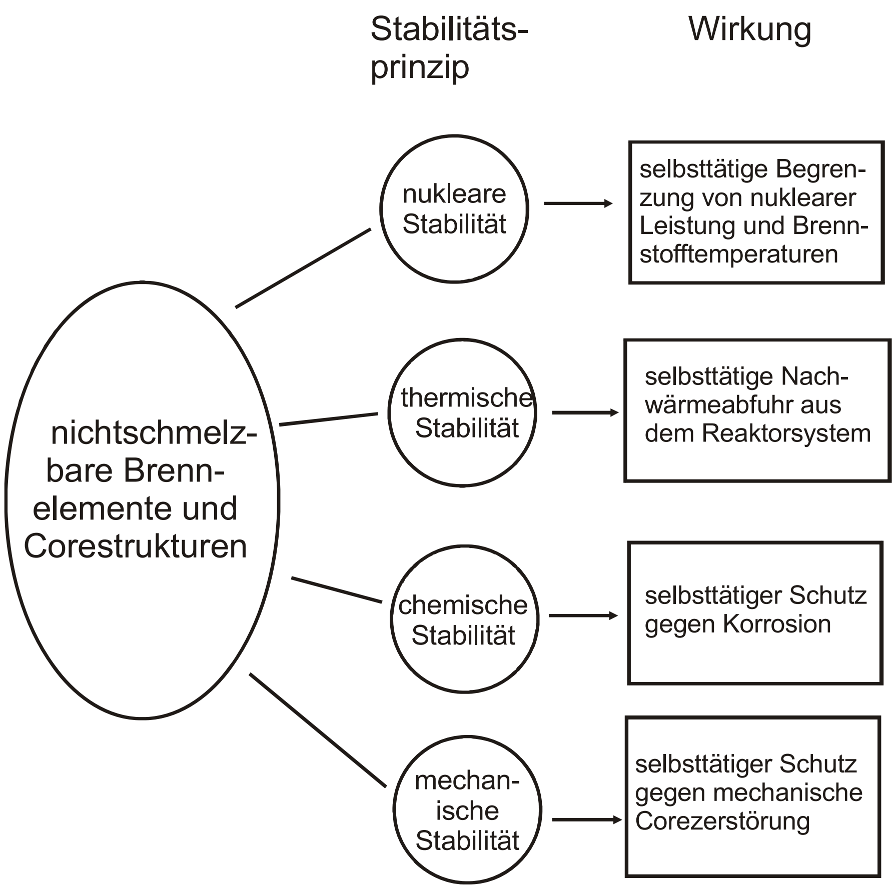
external Causes

- Crash of a plane (Phantom)
- Gas cloud explosion
- Earthquake (b < 0,3 g)
- Fire
- Tornados, hurricanes and floods

external causes (beyond licensing)

- Terrorist attacks with planes (Boeing 747)
- Sabotage
- Impacts of war (missiles)
- Extreme earthquakes (b > 0,3 g)
- Meteorites

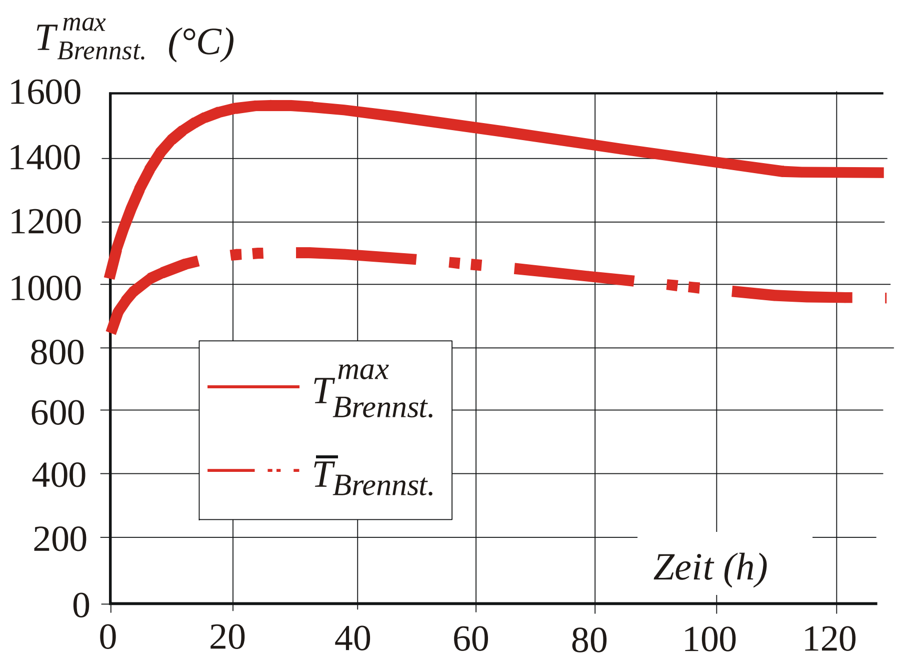
Accident behaviour of a modular HTR (2/10)



Requirements for a non melting inherent safe modular HTR

- Fulfilment of the principles for all accidents due to internal and foreseeable external cause (requirements from licensing)
- Fulfilment of the principles for all accidents including unforeseeable occurrences such as terrorist attacks or extreme earthquakes

Accident behaviour of a modular HTR (3/10)



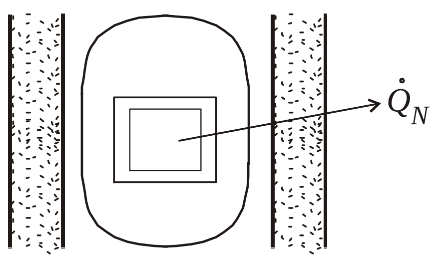
Automatic removal of the residual heat in the case of failing of all active heat removal (for example: PBMR, additionally the total failure of the first shut down system was assumed)

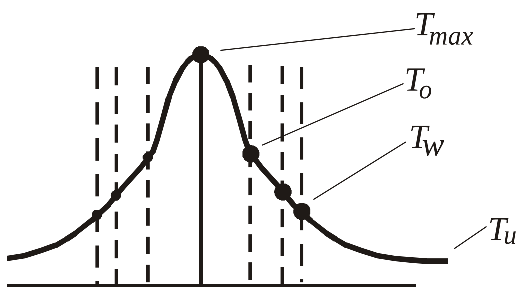
- Fuel elements can never melt
- Maximum fuel temperature remains below 1600° C
- Most fuel elements stay far below this temperature
- Total fission product release stays below 10^{-5} of the inventory

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Accident behaviour of a modular HTR (4/10)

Biological analogue for the automatic residual heat removal and limitation of accident temperature





$T_{max} < 1600\ °C$

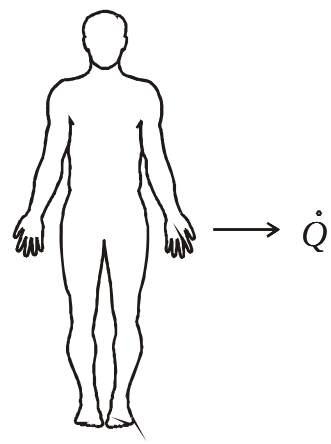
$T_W < 400\ °C$

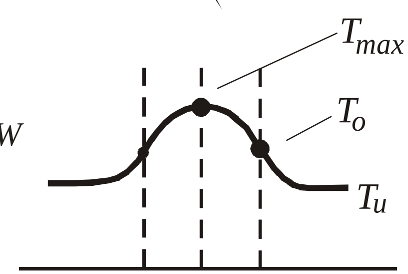
$\dot{Q}_N \approx \alpha_a \cdot A\,(T_w - T_u)$

$T_{max} - T_o \approx \dfrac{\dot{Q}_N/H}{4\pi\lambda_c}$

$\dot{Q}_N \approx 600\ kW$

(entspricht der Nachwärme eines Cores mit $P_{th} = 300\ MW$ nach etwa $30\,h$)





$T_{max} < 38\ °C$

$T_o < 37\ °C$

$\dot{Q} \approx \alpha_a \cdot A\,(T_o - T_u)$

$T_{max} - T_o \approx \dfrac{\dot{Q}/H}{4\pi\lambda_i}$

$\dot{Q} \approx 60\ W$

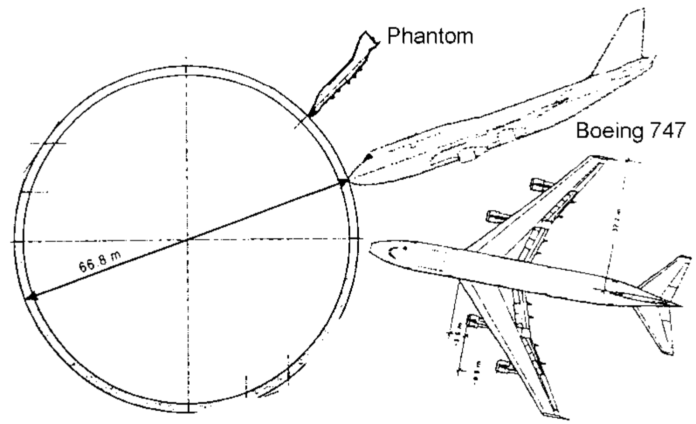
(entspricht der Wärmeabgabe eines Menschen unter "normalen" Bedingungen)

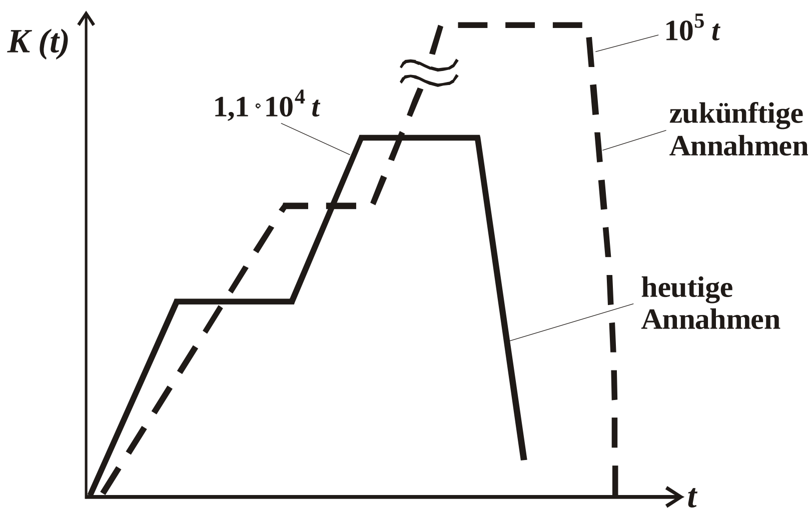
Forschungszentrum Jülich

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

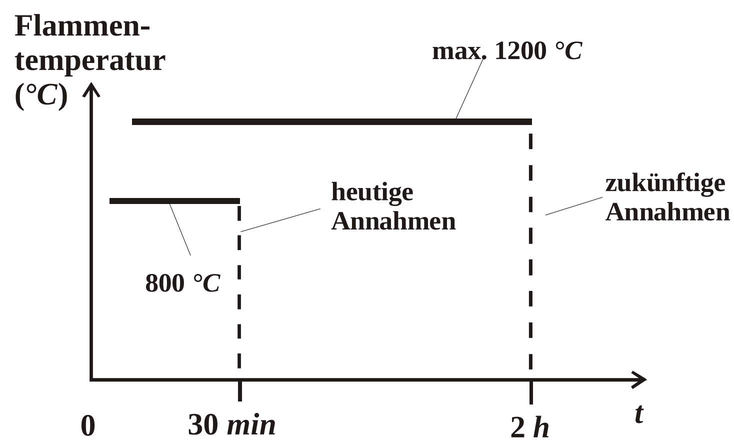
Accident behaviour of a modular HTR (5/10)

New safety requirements for nuclear technology





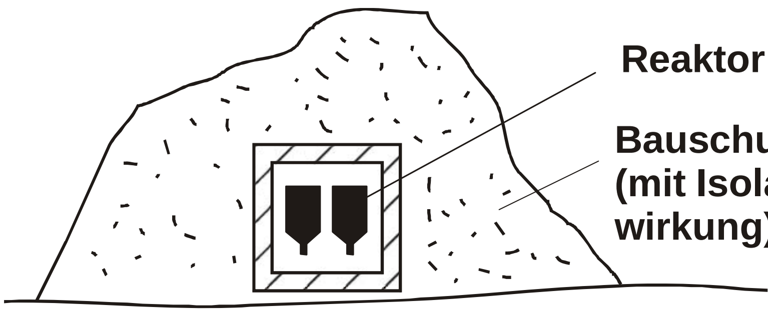
Schutz der Gebäude gegen Penetration und Zerstörung



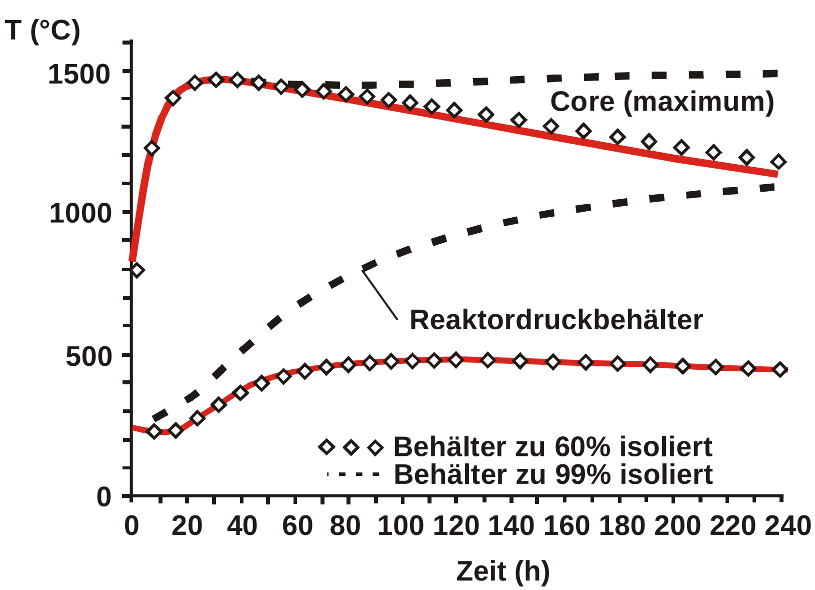
Schutz gegen langandauernde Flammeneinwirkungen mit hohen Temperaturen bei Kerosinbrand

Forschungszentrum Jülich

Accident behaviour of a modular HTR (6/10)



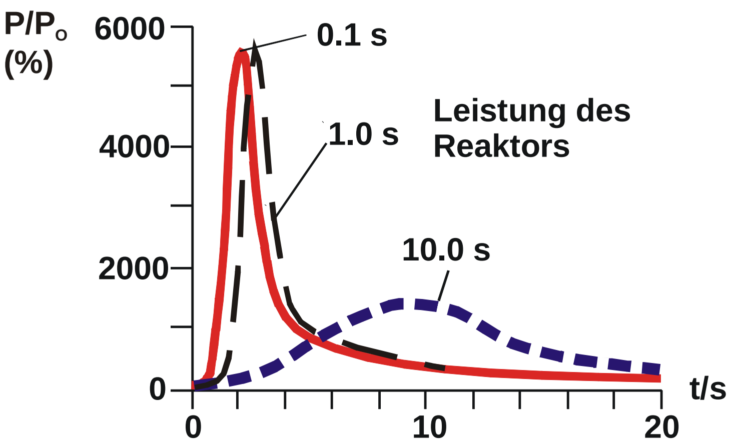
Automatic removal of the residual heat after the destruction of the reactor building (for example caused by an extreme earthquake or a plane crash caused by terrorists)

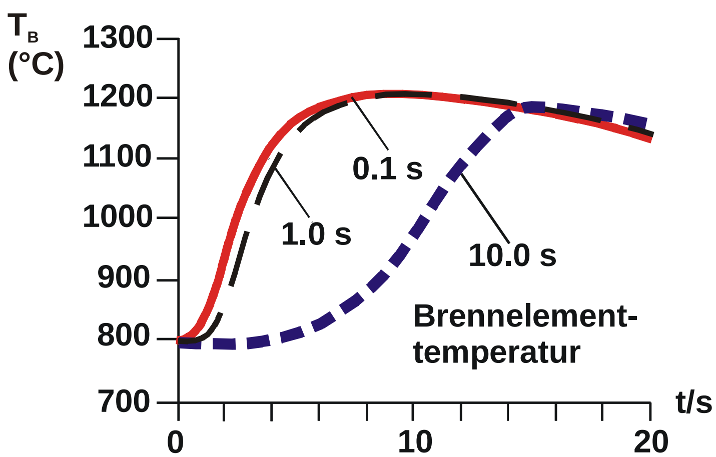


- Reactor totally covered with rumble
- Residual heat is still removed automatically, but slowed down
- Maximum fuel temperature stays below 1600° C
- Total fission product release stays below 10^{-5} of the inventory

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Accident behaviour of a modular HTR (7/10)

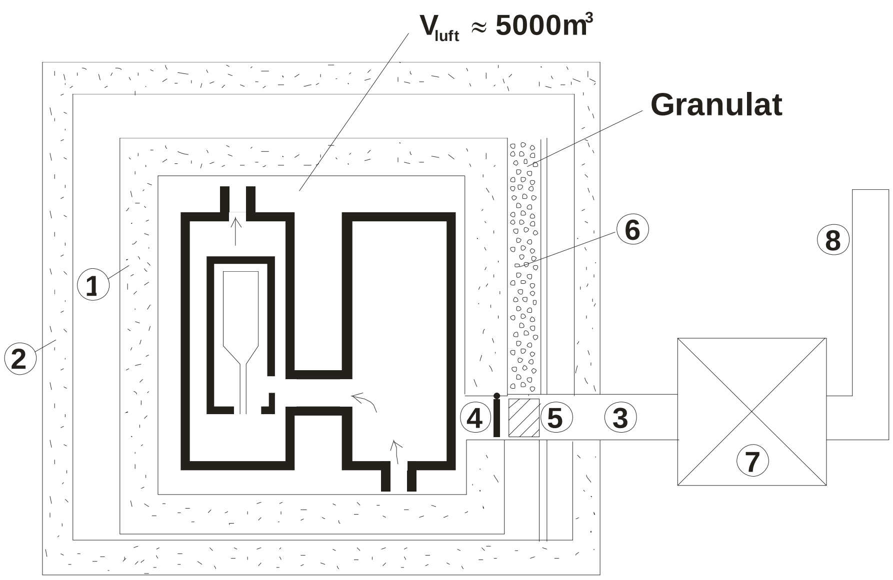




Automatic limitation of nuclear power and fuel temperature when faced with extreme reactivity transient (total loss of the first shut down system: ρ = 1,2 % in a short period of time)

- Strongly negative temperature coefficient ends the excursion
- Transient heat is quickly and for the most part stored in the fuel element graphite
- Maximum fuel temperature stays below 1600° C

Accident behaviour of a modular HTR (8/10)



1) Internal concrete cell (sealed against outside air)
2) Reactor building
3) Draining channel
4) Sealing flaps (gravity)
5) Sealing plug
6) Granulate silo
7) Filter
8) Flue

Concepts for minimising the consequences of an air ingress accident:

- Draining the primary Helium through pipes over a filter
- Automatic limitation on the amount of air within the concrete cell (V < 5000 m^3) by automatic closing mechanisms (flaps and pouring granulate)
- Limitation of possible graphite corrosion to < 500 kg C and therefore no radiological consequences
- Limitation of possible graphite corrosion to < 100 kg by simple intervention methods (protection of investment)

Accident behaviour of a modular HTR (9/10)

Begrenzung der Menge an Luft

↓

- Volumen der inneren Betonzelle ist begrenzt (<5000m³)
- nach erfolgter Druckentlastung schließt eine Klappe oder ein Granulatvorrat den Kanal ab
- innere Betonzelle wird mit Inertgas gefüllt

Begrenzung der Mengenrate an Luft

↓

- Vorgespannter Reaktordruckbehälter mit kleinen Öffnungen
- Berst-Schutz für die Behälter
- Intervention in innerer Betonzelle

Verhinderung der Korrosion von Brennelementen

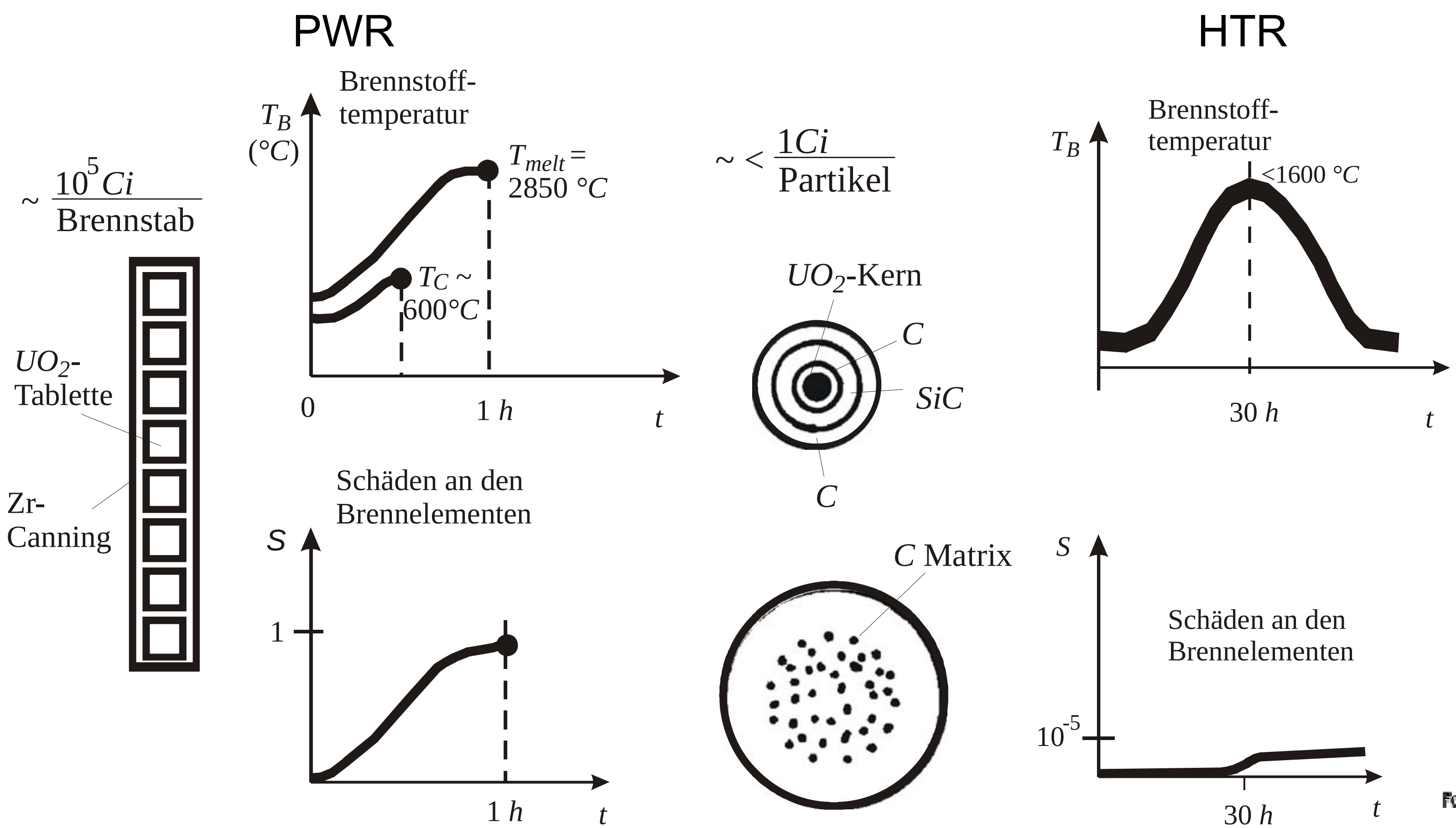
↓

- Korrosionsbeständige SiC-beschichtete Brennelemente
- innere Betonzelle ist mit Inergas gefüllt

Forschungszentrum Jülich
in der Helmholtz-Gemeinschaft

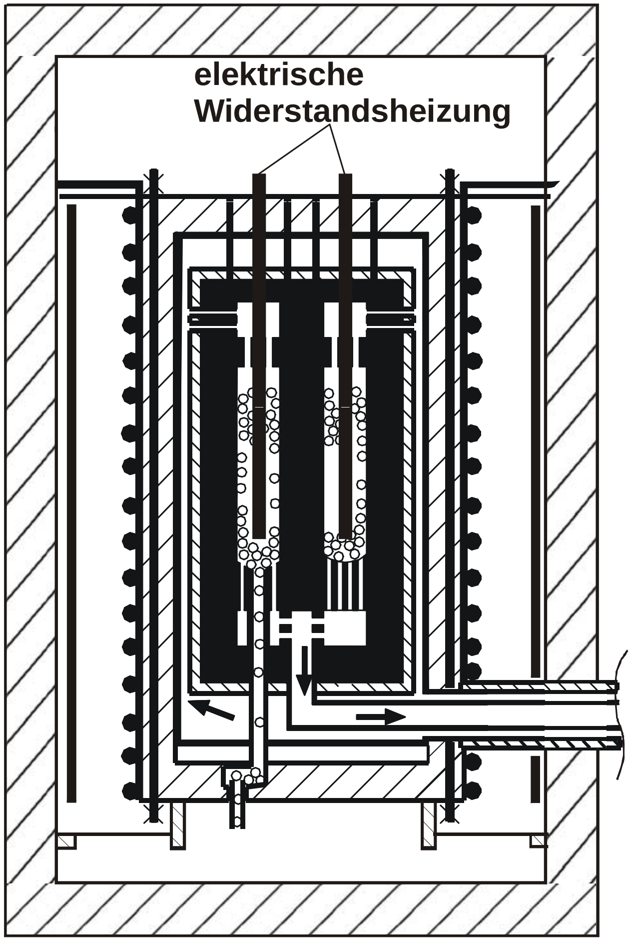
Accident behaviour of a modular HTR (10/10)

Comparison of the fuel behaviour after loss of the active residual heat removal.



Total Assessment of Safety (1/2)

Integral proof of safety behaviour



- Simulation of the residual heat in a graphite-sphere-pile by electrical resistance heating. (~ 2 MW for a 300 MW_{th} - Core)
- Analysis of all assumable accidents (total loss of coolant, air ingress, water ingress, pressure discharge, mechanical impacts on the elements of the shut down system, component damage when pressure relief)
- Validation of all calculating programs for extreme accidents (heat transfer throughout all structures, flow phenomena, acts of pressure discharge).

Forschungszentrum Jülich

Total Assessment of Safety (2/2)

- Fuel elements can never melt; there is no heating up of the fuel elements to a temperature above 1600° C
- The principal of automatic residual heat removal can never fail, even after the destruction of the reactor building it stays intact.
- The reactor would even stay resistant against extreme reactivity transient. There is no temperature raise of the fuel elements to above 1600° C
- The pre-stressed reactor containment can not burst; It is impossible that an unacceptable amount of air enters the primary loop, graphite corrosion is minimal.
- The ingress of larger amounts of water into the primary loop will not lead to unacceptable states of the reactor; in the case of gas turbines operating this accident is not applicable.
- Against extreme, in future even more severe external impacts, the underground way of building with covering mound, and fast removal of spherical fuel elements as protection
- There is no accident in which case a significant amount of radiation is released

Forschungszentrum Jülich