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Gas-Cooled Fast Reactor System

The GFR system features a fast-spectrum helium-cooled reactor.

The high outlet temperature of the helium coolant
makes it possible to deliver electricity, hydrogen,
or process heat with high conversion efficiency.

Through the combination of a fast-neutron spectrum
and full recycle of actinides,
GFRs minimize the production of long-lived radioactive waste isotopes.

The GFR’s fast spectrum also makes it possible
to utilize available fissile and fertile materials
(including depleted uranium from enrichment plants)
two orders of magnitude more efficiently than thermal spectrum
gas reactors with once-through fuel cycles.

Gas-Cooled Fast Reactor System

Why have gas cooled fast reactors ?

- Sodium cooled fast reactors are the shortest route to fast reactors deployment, but the sodium coolant has some undesirable features:
  - Chemical incompatibility with air and water
  - Liquid metal reactors have a strong positive void coefficient of reactivity
  - Avoiding sodium boiling places a restriction on achievable core outlet temperature.

- Gas cooled fast reactors do not suffer from any of the above:
  - chemically inert,
  - very stable nucleus,
  - void coefficient is small (but still positive),
  - single phase coolant eliminates boiling
  - optically transparent.
- But …
  - Gaseous coolants have little thermal inertia
    => rapid heat-up of the core following loss of forced cooling;

- **Motivation is two-fold: enhanced safety and improved performance**

Helium Coolant - Positive features

1. Neutronic quasi-transparency
   Gas coolants generally allow a harder neutron spectrum,
   which increases the breeding potential of the reactor.

2. Simple in-service inspection of the primary system
   and internal vessel components
   because of the translucent nature of the coolant.

3. Helium is chemically inert
   no corrosion products in the primary system are expected.

4. The coolant does not become activated by irradiation.

5. No change in phase of the gas coolant.

6. No decommissioning issues associated with the coolant.

7. Helium coolant can be operated under very high temperatures
   no disassociation of Helium allowing very high system efficiencies.
   (CO_2 disassociates ~ 800 °C)

Helium Coolant - Disadvantages

1. Higher pumping power compared to liquid coolants

2. Need to maintain high pressure in the system,
   typically around 7 MPa for helium systems,

3. Gas coolant properties generally require artificial
   roughening of the cladding to maintain acceptable cladding temperature
   => an increased pressure drop over the core
   => higher requirement on pumping power

4. High coolant flow velocity can lead to significant vibrations of the fuel pins.

5. Decay heat extraction from the high power density core is difficult.

To obtain the highest breeding potential,
the amount of parasitic absorption should be minimized.

=> The core is very tightly packed.
=> The volume fractions of structural materials and coolant are kept to a minimum.

The number of capture reactions producing fissile material per unit time is proportional to the flux level in the reactor.
For reasons of economics and fuel cycle characteristics, it is generally desirable to have the highest possible breeding rate, and thus generally the reactor core is designed to have a very high flux level.

As a result the power density in a fast reactor core is usually very high, typically of the order of 100 MW/m^3.

The choice of coolant is dictated by the desire to introduce the smallest amount of absorption and moderation.

The GFR differs from the thermal gas reactor
in several respects important for safety behavior.

The safety of thermal gas reactor
is assured largely as a result of a very low power density.

The power density in the GFR is greater,
the coolant density coefficient adds reactivity
during depressurization accidents.

These fundamental differences give the reactivity feedbacks
a more prominent role in the safety of the fast reactor
compared to the thermal gas reactor.

An important design objective
is to engineer the fast reactor core
to have sufficient inherent negative reactivity feedback
that core power safely adjusts to the available heat sink.

GFR Safety

For the GFR, the important aspect of the design is the removal of decay heat under depressurized conditions.

A requirement that the reactor be passively safe during a total loss of power at the reactor site necessitates the employment of natural convection.

Studies have shown that natural convection is not effective at atmospheric pressure. Therefore, a guard containment that encloses the primary vessel is used to preserve a backpressure that maintains a high coolant density.

The design goal is to limit the pressure that the guard containment must maintain, since the cost of the guard containment increases with its required pressure capability.

The pressure requirement of the guard containment is determined by the coolant density that permits sufficient natural convection through the reactor core during the prescribed off-normal conditions.

GFR Safety
DHR - main design options

To designate Decay Heat Removal (DHR) system,
the maximum fuel temperature
for accident design basis conditions (DBC) has been set at 1600℃.

A DHR design has been selected
based on depressurization accidents
combined with a total loss of power (blackout).

A fully passive system has been designed:
it consists of three loops (3x100% redundancy)
in extension of the pressure vessel,
equipped with heat exchangers located
at a certain elevation above the core,
so that the driving height enables the flow circulation.

GFR Safety
DHR - main design options

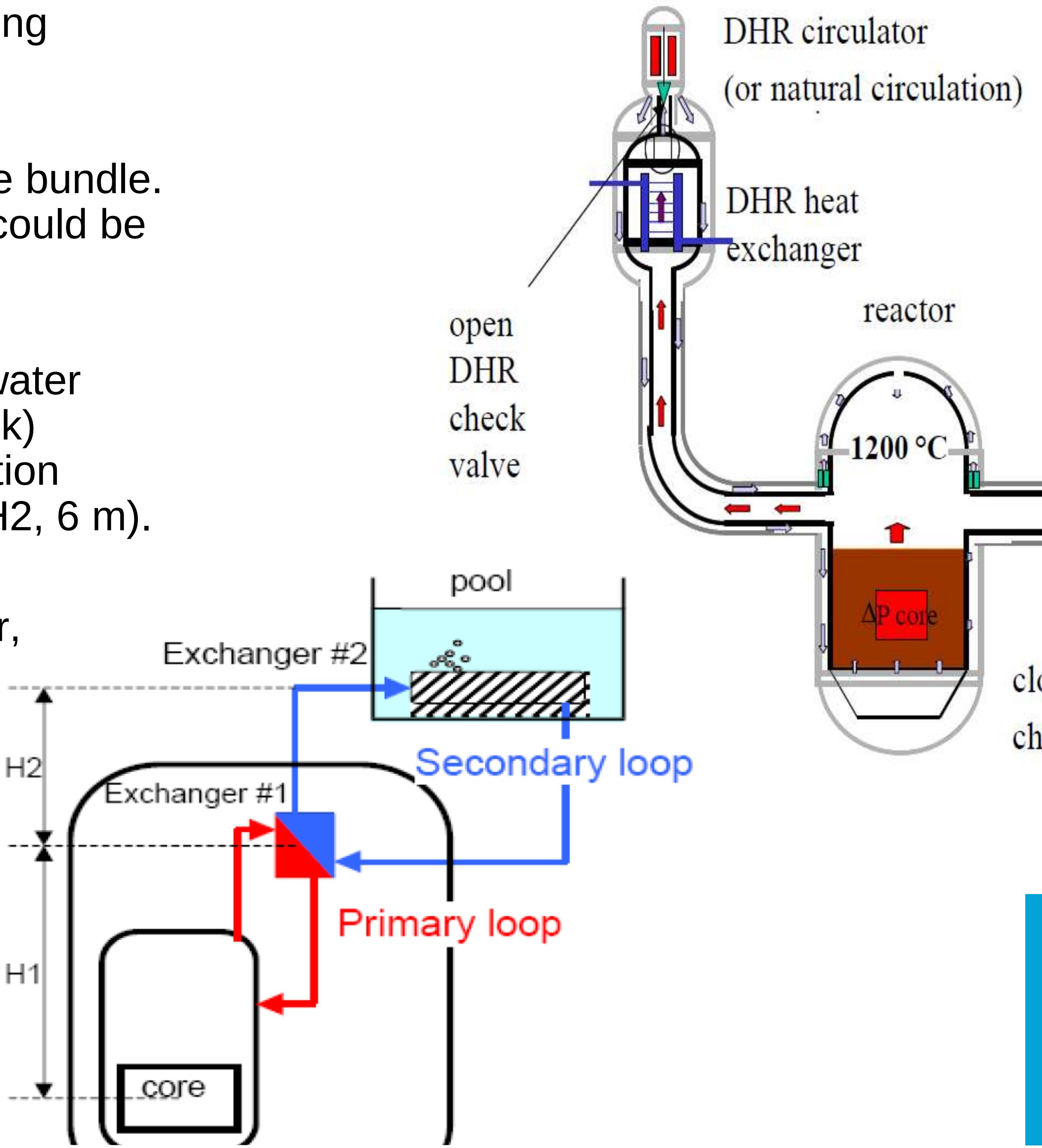
The DHR system consists of a cross-duct piping connected to the reactor vessel.

The primary helium circulates outside the tube bundle. It has been assumed that the exchanger could be located at a maximum of 15 meters (H1).

The secondary circuit based on pressurized water is connected to the pool (ultimate heat sink) and can also be based on natural convection (considering a secondary driving height, H2, 6 m).

Both circuits can also operate with a circulator, generating forced convection in addition to the natural convection.

The pool heat exchanger is made of straight horizontal tubes, with the water circulating inside the tubes.



ALLEGRO concept by CEA
Decay Heat Removal (DHR) loops

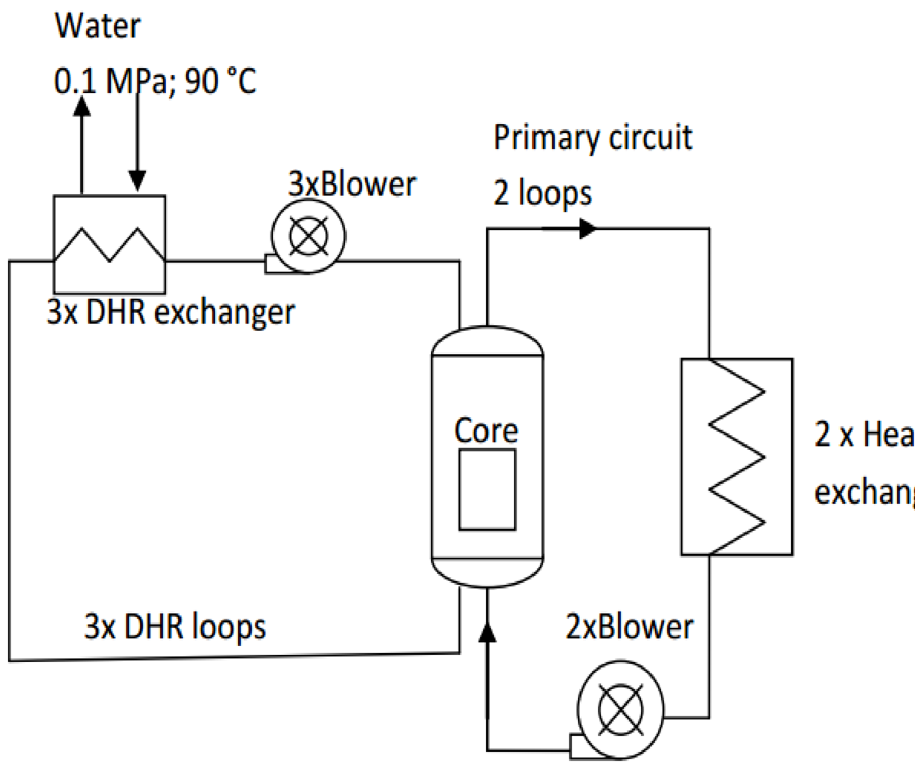
The safety function of the decay heat removal system
shall be to transfer
fission product decay heat
and other residual heat from the reactor core.

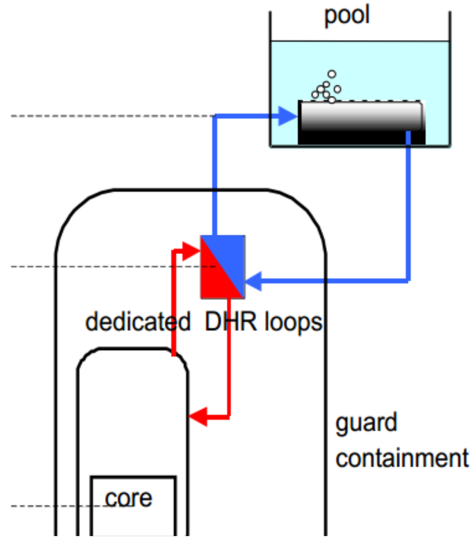
The 3 x 100% DHR loop systems
are designed to remove 3% of the nominal power.
(helium / water heat exchanger)

DHR is located above the core
to allow also natural Helium circulation.

DHR with natural circulation
is proposed for the pressurised case
of loss of flow combined
with a blackout,
where the DHR blowers would not be available.

Forced convection is recommended for the depressurised case.
DHR blowers could be fed by batteries if needed during the short term and then by the diesel generator sets.





Modification of secondary circuit

Severe accidents related features

severe accidents should be considered as part of the design process

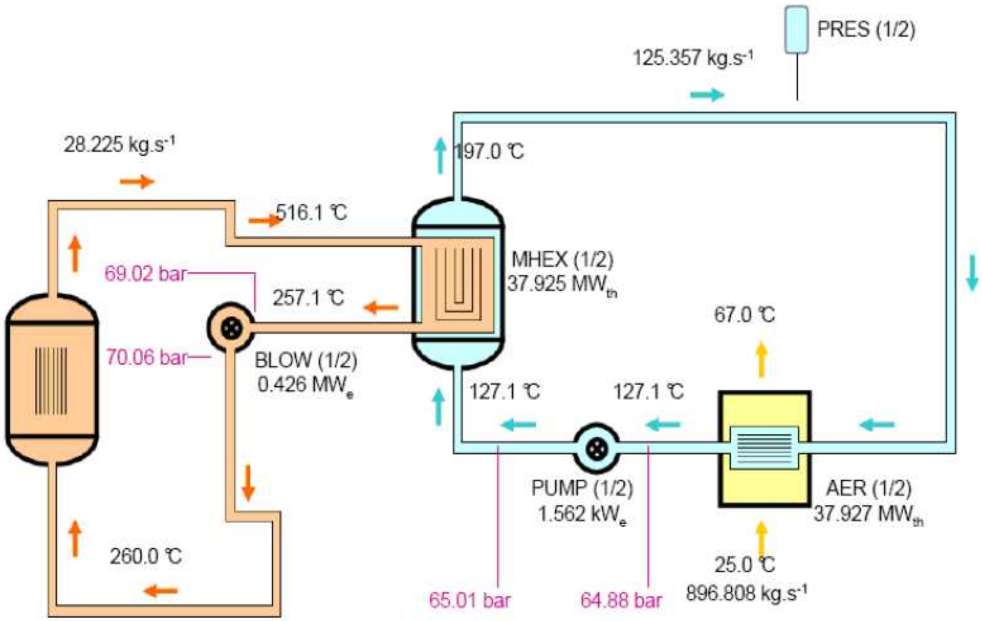
Safety important systems

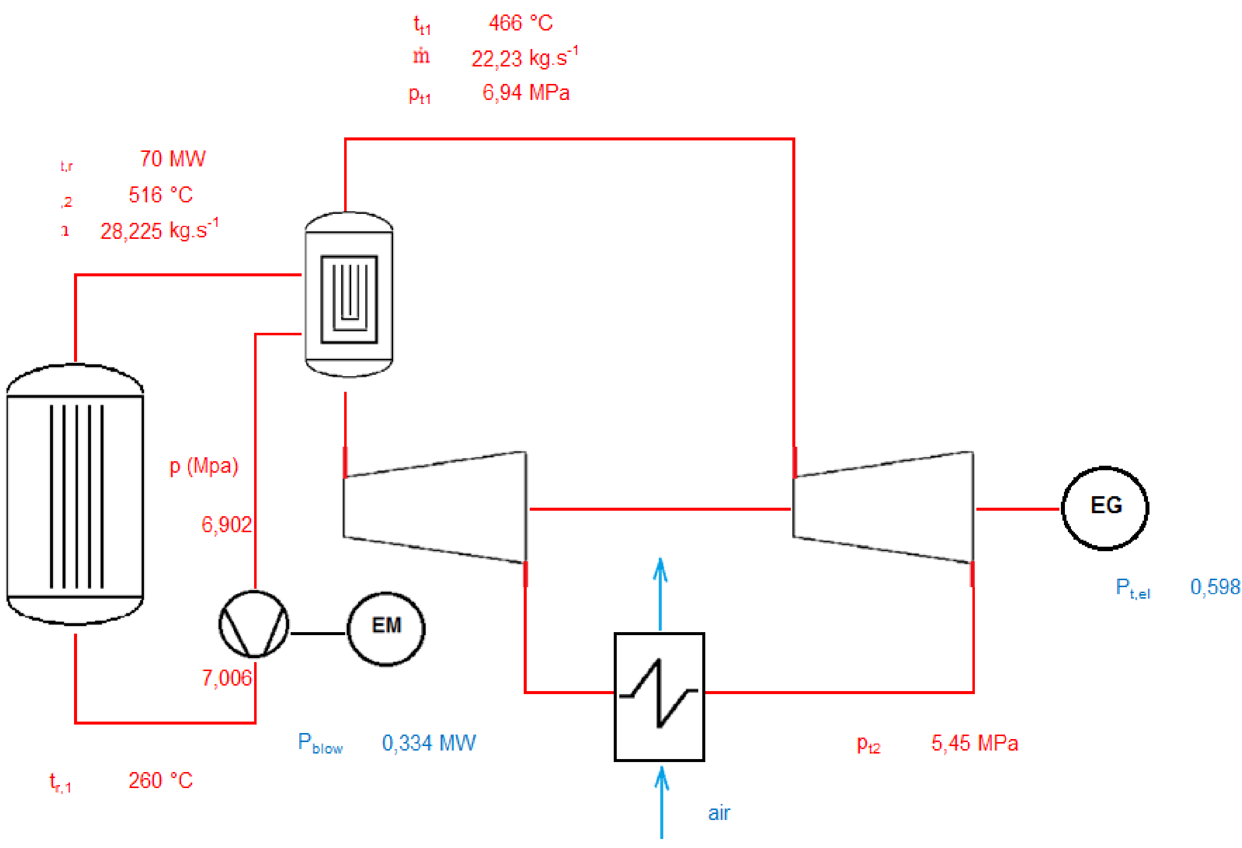
- Cooling system of the containment guard vessel for normal operation conditions
- Passive valves on DRH system and main loops
- Additional passive reactivity control system based on lithium
- Essential water service system for cooling of spent fuel pool, HVAC, water pools of DHR systems, etc . .

ALLEGRO Design Modification

Modification of secondary circuit

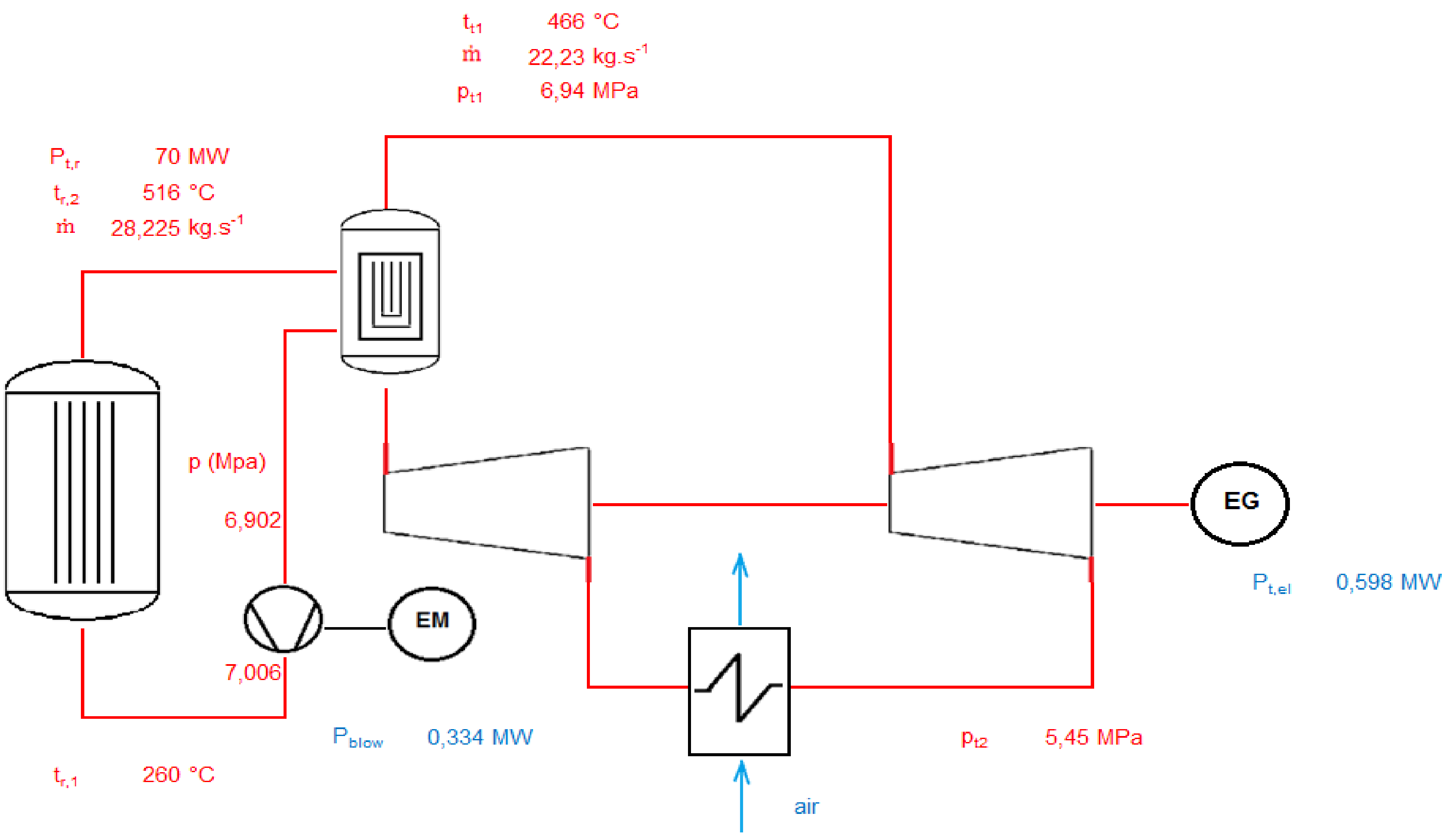
It was agreed that the original CEA concept of ALLEGRO shall be modified.
Objectives:
Take into account the future safety reference frame which should result from the Fukushima accident





ALLEGRO modification of secondary circuit

Design study of the possibility to use turbo machine for decay heat removal from the reactor will be evaluated (availability for low pressure conditions).



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Main safety issues for the GFR technology

Core coolability and a lack of thermal inertia related to the helium coolant:
in the case of depressurisation of the primary circuit it is essential that either forced circulation is maintained within the primary circuit or a minimum pressure adequate for sufficient natural circulation is maintained.

Relative small negative reactivity feedback at power rise
(and small, but positive void effect)
that causes problem during unprotected scenarios.

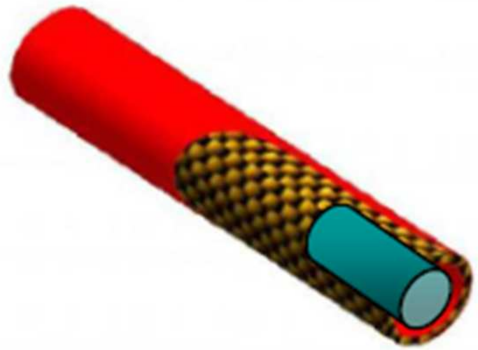
Due to the high outlet temperatures
the difference between clad melting and peak operational temperature is small.

Material problems due to helium
(lack of oxygen can remove the natural oxide layer from structural materials)

Main safety issues for the GFR technology

Two major issues for GFR

The design of a high temperature fuel element,
able to retain integrity in case of loss of forced cooling accident,
to withstand high fast neutron fluxes,
and offering good neutronic performances.



Safety and decay heat removal
in case of loss of helium pressure.

GFR - Conclusions

The GFR concept is attractive as it avoids the coolant handling issues associated with liquid metal-cooled fast reactors:

Chemical inertness of helium

Excellent nuclear stability avoids activation of the coolant

Transparent coolant permits simple inspection and repair

GFR offers a high temperature heat source for high efficiency electricity generation and high-quality process heat.

The main technical challenges lie in the development of a high-temperature, high-power density fuel and in the development of robust decay heat removal systems.

An indirect combined gas/steam cycle has been chose to be the reference power conversion system as this returns good efficiency with low technological risk and good economics.

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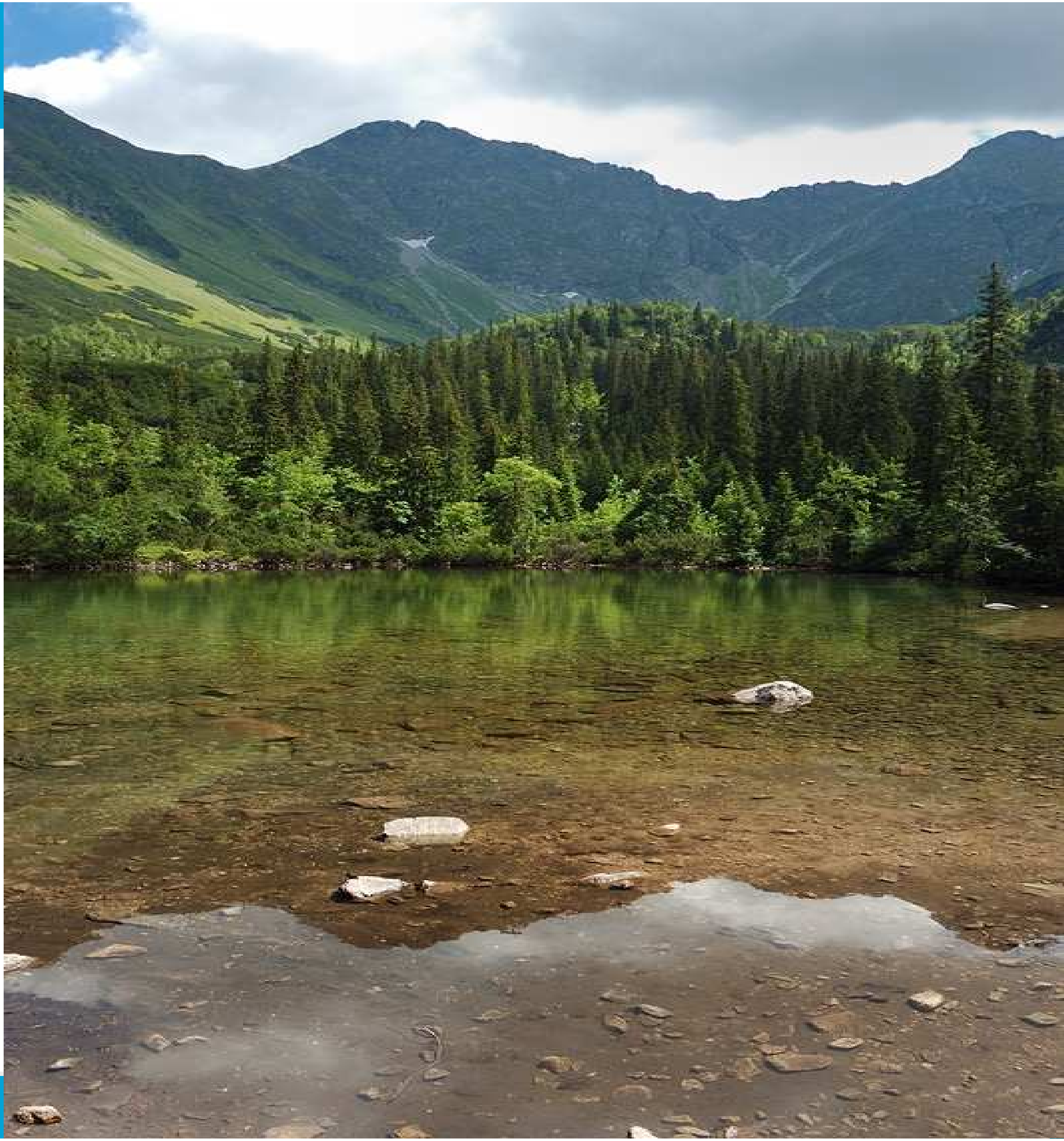
Thank you for your attention



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